Mikko Koho

Production System Assessment and Improvement
A Tool for Make-to-Order and Assemble-to-Order Companies

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A Tool for Make-to-Order and Assemble-to-Order Companies

Thesis for the degree of Doctor of Technology to be presented with due permission for public examination and criticism in Festia Building, Auditorium Pieni Sali 1, at Tampere University of Technology, on the 28th of May 2010, at 12 noon.
ABSTRACT

This study focused on assessing and improving production systems of Finnish mechanical engineering companies producing order-specific products and using make-to-order (MTO) or assemble-to-order (ATO) approach. These companies play an important role in Finnish industry and the national economy, for example in terms of turnover, exports, and employment, and their production systems, processes and performance have a significant effect on their competitiveness. To assist these companies in improving their production systems, production performance and competitiveness, the study aimed to develop a tool for assessing the current state of production systems and identifying the potential and means for improvement. A review of currently available assessment and improvement tools highlighted the need to develop a more useful and applicable tool for the type of companies considered in this study. The study was limited to the initial phases of an improvement process, and its results are specifically applicable and most beneficial to companies operating within the target industrial sector of the study.

Design science and constructive research approaches were used in developing the production system assessment tool, named TUTKA, which consists of a set of key characteristics of a well-performing production system, an assessment scale and methods of assessment. The set of key characteristics that provide the basis for the assessment tool and process were developed iteratively using information from literature reviews, theme interviews, and observations of production systems. The literature reviews covered production strategy, production paradigms, and tools and approaches for assessing and improving production, whereas the theme interviews and observations provided a practical perspective and information on the development process and enabled evaluation and improvement of the applicability and usefulness of the set of key characteristics in the target companies of the study. Subsequently, an assessment scale and assessment methods were developed and integrated into the assessment tool based on the results of the previous phase of the study and a review of available tools and models of production assessment and improvement. Finally, to demonstrate the applicability of the TUTKA tool and to collect information to evaluate the results of the study, the assessment tool was tested in six companies and presented to three consultants.

The main result and contribution of this study is the TUTKA tool, which enables assessment of the current state of a production system and identification of its strengths and potential and means for improvement. The six pilot cases and the feedback received demonstrated the tool’s applicability and usefulness in assessing and improving production systems. Additionally, a set of key characteristics of a well-performing production system were developed in the study. The observations made and the feedback received during the study indicated the relevance of the key characteristics to the target companies of this study and their usefulness for designing and improving production systems. The study thus provided tools and guidelines for improving production systems, production performance, and competitiveness. The results of the study can be used by the target companies, by companies aiming to change their production approach to make-to-order or assemble-to-order, and by consultants and researchers in the field of production and production systems. Directions for further research were also identified and these included broadening the scope of assessment to cover production network and adding new aspects, such as sustainability of production, to the TUTKA tool.
ACKNOWLEDGEMENTS

Completing this Doctorate is the realisation of a relatively long-standing aspiration, and crossing the finish line of this demanding yet rewarding journey is both satisfying and exhilarating. Getting this far has required assistance from various directions, and I wish to thank each and every one who has supported and encouraged me along the way.

I am grateful to the Tampere University of Technology (TUT) Graduate School and Department of Production Engineering for the great opportunity to focus on this study, pursue the degree, and prepare the dissertation. Without the financing and other resources provided, starting, let alone completing, this work would have been impossible. I would also like to thank the Industrial Research Fund of the Tampere University of Technology and the Emil Aaltonen Foundation for the scholarships I have received.

Although at times the work has been very much a one-man endeavour, I have been fortunate to receive help and support from a number of quarters. I am indebted to Professor Seppo Torvinen, my supervisor, for the guidance he has provided. Moreover, his contacts in both industry and academia have been invaluable during the different phases of this study. I also wish to express my gratitude to Professor Graeme Britton and Dr. Jouni Juuti for evaluating and commenting on the progress of the study and the development of the production system assessment tool; to Professor Johanna Kujala for helping to prepare the interviews; and to Johanna Naukkarinen for enlightening me on the mysteries of research approaches. Furthermore, the workshops, seminars and courses of the Department of Industrial Engineering (TUT), Department of Production Engineering (TUT), and Allianssi-IHME (University Alliance Finland) have provided useful guidance and comments, for which I thank both the organisers and participants. I also extend my thanks to pre-examiners Dr. Timo Määttä and Professor Mikko Ruohonen for their invaluable input and feedback on the manuscript. For proofreading and editing, my thanks to Timo Lepistö and Semantix Lingua Nordica Oy.

Lastly, I would like to express my deep gratitude to my nearest and dearest. The care and support of my parents, Piio and Hessu, have been essential both to me and to this study, and I am unable to find words to thank them enough. My parents-in-law, Hanna and Seppo, also deserve a word of thanks. During this journey, I have come to notice that progress can be made in surprising places and situations, and hence I would like to thank Onni for our fun and useful walks. While he focused on his studies and explorations, I was able to find much needed inspiration and to clarify many issues related to my research work. Finally, heartfelt thanks to my beloved Jenni for putting up with me during the stressful and difficult times of the work, and for bringing and sharing the many high moments and enjoyable experiences.

Tampere, 7th of May 2010

Mikko Koho
KEY TERMS

Assemble-to-order production approach
Approach in which assembly and subsequent operations or processes are customised and carried out on the basis of a customer order, while operations upstream from assembly are independent of and can be conducted prior to an order. In the assemble-to-order approach, products are designed before the order, but are customised and assembled based on an order.

Assessment
Act of assessing or evaluating something. Provides the basis for improvement. The assessment tool developed in this study is intended to assess the current state of a production system.

Best practice
Best available way of performing an action, activity, procedure or process.

Decision areas
Areas or subsystems to which production-related decisions, changes and improvements can be made and categorised. In this study, six decision areas are used: product architecture; production system structure; production processes and management; production equipment; information and communication; and human resources.

Improvement
Act or instance of improving or being improved by changing or enhancing. Improvements can be categorised, e.g., based on their focus and impact. In this study, the focus is on production, production processes, the production system, and production performance, and on larger rather than small, continuous improvements.

Improvement means
Changes or actions that can be made to improve something, e.g. a production system, its subsystem or characteristics. The assessment tool developed in this study and the related assessment process aim to identify and suggest means for improving the assessed production system.

Improvement potential, improvement potential of a production system
Opportunity or possibility to change or improve a production system, its subsystem or characteristics in order to improve the system and production performance. The assessment tool and process developed in this study aim to identify the improvement potential of a production system by assessing the realisation of the key characteristics of a well-performing production system in the assessed system and the adaptability of the system.

Key characteristics of a well-performing production system
Characteristics of a production system that are intended to enable cost-efficient, rapid, and reliable production of the product variety offered to customers. The key characteristics provide the basis for the TUTKA production system assessment tool and assessment process.

Make-to-order production approach
Approach in which part production and subsequent operations or processes are customised and carried out on the basis of a customer order, while operations
upstream from part production are independent of and can be conducted prior to an order. In the make-to-order approach, products are designed before the order, but are customised and produced based on an order.

Production

Refers to the production function of a company, or to the process of producing or making a product from raw materials and parts. In this study the term production covers both part production, i.e., making parts and components from raw materials, and assembly, i.e., joining or fitting parts and components together to create a product or subassembly of a product.

Production network

Consists of production systems of several companies, covers a broader part of the production process or supply chain of a product than a production system.

Production objectives

Dimensions or categories of production performance with which a company and its production operations attempt to satisfy customer requirements and achieve competitive advantage. In this study, the main focus is on six production objectives: quality, lead or delivery time, reliability of lead or delivery time, volume flexibility, product flexibility, and cost.

Production outputs

Outputs such as parts, subassemblies and products produced by a production process or processes.

Production performance

Production performance is determined by and dependent on the production processes and the characteristics of the production outputs. Production performance is also related to production objectives and customer requirements and the ability to fulfil these.

Production processes

The processes required to produce products. Production processes use the resources provided by the production system to produce products.

Production system

Production system consists of production resources needed to produce products, i.e., equipment, tools, human resources and information, and includes also the arrangement and organisation of these resources. A production system provides production resources that enable the production processes to produce the production outputs, e.g., the products offered to customers.

Production system and process themes

The key characteristics of a well-performing production system identified in this study are interconnected. Combinations of key characteristics contribute towards creating certain features of a production system and its production processes. These features are called production system and process themes. They are used in summarising and clarifying the results of an assessment.

Production unit

A production system consists of and can be divided into production units.
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<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>ATO</td>
<td>Assemble-to-order</td>
</tr>
<tr>
<td>BOM</td>
<td>Bill of materials</td>
</tr>
<tr>
<td>C</td>
<td>Cost (one of six production objectives considered in the study)</td>
</tr>
<tr>
<td>$C_p$</td>
<td>Potential process capability index</td>
</tr>
<tr>
<td>$C_{pk}$</td>
<td>Process capability index</td>
</tr>
<tr>
<td>CMM</td>
<td>Capability Maturity Model</td>
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<tr>
<td>CMMI</td>
<td>Capability Maturity Model Integration</td>
</tr>
<tr>
<td>CSD Toolset</td>
<td>Collective System Design Toolset</td>
</tr>
<tr>
<td>HR</td>
<td>human resources (decision area)</td>
</tr>
<tr>
<td>IC</td>
<td>information and communication (decision area)</td>
</tr>
<tr>
<td>JIT</td>
<td>Just-in-time</td>
</tr>
<tr>
<td>LESAT</td>
<td>Lean Enterprise Self-Assessment Tool</td>
</tr>
<tr>
<td>MACL</td>
<td>Model for assessing changes towards lean production</td>
</tr>
<tr>
<td>MDT</td>
<td>Mean down time</td>
</tr>
<tr>
<td>MSDD tool</td>
<td>Manufacturing System Design Decomposition tool</td>
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<tr>
<td>MTBF</td>
<td>Mean time between failures</td>
</tr>
<tr>
<td>MTO</td>
<td>Make-to-order</td>
</tr>
<tr>
<td>MTTR</td>
<td>Mean time to repair</td>
</tr>
<tr>
<td>MWT</td>
<td>Mean waiting time</td>
</tr>
<tr>
<td>OEE</td>
<td>Overall Equipment Effectiveness</td>
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<tr>
<td>OPP</td>
<td>Order penetration point</td>
</tr>
<tr>
<td>PA</td>
<td>product architecture (decision area)</td>
</tr>
<tr>
<td>PDCA cycle</td>
<td>Plan Do Check Act cycle</td>
</tr>
<tr>
<td>PE</td>
<td>production equipment (decision area)</td>
</tr>
<tr>
<td>PF</td>
<td>Product flexibility (one of six production objectives considered in the study)</td>
</tr>
<tr>
<td>PP</td>
<td>production processes and management (decision area)</td>
</tr>
<tr>
<td>PPA method</td>
<td>Productivity Potential Assessment method</td>
</tr>
<tr>
<td>PSD framework</td>
<td>Production System Design framework</td>
</tr>
<tr>
<td>PSS</td>
<td>production system structure (decision area)</td>
</tr>
<tr>
<td>PVLF matrix</td>
<td>Product/volume-layout/flow matrix</td>
</tr>
<tr>
<td>Q</td>
<td>Quality (one of six production objectives considered in the study)</td>
</tr>
<tr>
<td>R</td>
<td>Reliability of lead or delivery time (one of six production objectives considered in the study)</td>
</tr>
<tr>
<td>ROI</td>
<td>Return on Investment</td>
</tr>
<tr>
<td>SCMAT</td>
<td>Supply Chain Maturity Assessment Test</td>
</tr>
<tr>
<td>SCOR model</td>
<td>Supply Chain Operations Reference model</td>
</tr>
<tr>
<td>T</td>
<td>Lead or delivery time (one of six production objectives considered in the study)</td>
</tr>
<tr>
<td>TPS</td>
<td>Toyota Production System</td>
</tr>
<tr>
<td>TUTKIRA</td>
<td>Name of the production system assessment tool developed in this study, derived from the Finnish “tuotantojärjestelmän kehittäminen ja arviointi” meaning production system improvement and assessment.</td>
</tr>
<tr>
<td>VF</td>
<td>Volume flexibility (one of six production objectives considered in the study)</td>
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1. Introduction

“He who stops being better stops being good.”

“First of all, nobody can dispute the value of improvement, since it is generic and good in its own right. It is good by definition. Whenever and wherever improvements are made in business, these improvements are eventually going to lead to improvements in such areas as quality and productivity.” –Imai, M. 1986

The above quotations highlight the need for and importance of improvement, which is the underpinning theme of this study. The first quotation, originally from Oliver Cromwell, was spotted on a wall of one of the companies participating in the study. It emphasises that achieving current success and striving to maintain the same level in future is not enough; improvements must be sought and made continuously. In keeping with this is the ubiquitous need of companies to improve their operations and performance to remain competitive. In the latter quotation the words of Masaaki Imai, a well-known figure in lean production and continuous improvement, also provide further rationale and motivation for business and operational improvement and for the topic of this study. The quotation also indicates that improvement can be focussed across a variety of aspects and areas of a business or company.

This study focused on improving production and its performance and, specifically, on production system assessment and improvement. The production system, i.e., the production resources and their arrangement and organisation, has a significant effect on production processes and performance. Production system assessment and improvement aims therefore at enabling and achieving efficient production processes and high production performance. The aspects covered in this study are of key relevance to the Finnish mechanical engineering sector, which is considered to be the main beneficiary of the study and its results. The study was thus motivated by the aim to assist the target companies in this sector in their improvement efforts and by the researcher's interest in the processes, systems, and performance of production.

The study intended to assist its target companies to improve their production systems, processes, and performance by providing them with a tool with which to assess the current state of their production system and identify the potential and means for improvement. The study consequently focused on the initial phases of such improvement process, and did not cover actual changes and improvements made to the production system or production processes. Although various approaches and tools are available for assessing and improving production, such as performance measurement and benchmarking, certain shortcomings related to their usefulness for assessing and improving the production systems of the target companies in this study were identified. Firstly, the majority of the available improvement and assessment tools and models are company- or industry-generic, which according to, for example, Muda and Hendry (2002a, 2002b, 2003) can make it difficult for companies to identify tools that are appropriate for them and can lessen the usefulness of such tools in assessing and improving production. Furthermore, focusing on production performance, processes and practices rather than on the production system reduces the usefulness of many available tools and models in assessing and improving production systems. A need was thus identified to provide a new perspective on and important contribution to the assessment and improvement of production by developing a production system assessment tool designed for the industrial sector and type of production targeted by the study.

The following sections provide a detailed overview of this study. First, the objectives and research questions are presented, then the focus and scope of the study and the industry sector and type of companies considered are defined. After that, the relevance and need for the study are explained, and, finally, the outline of the study and dissertation are presented.
1.1. Objectives and research questions

This study aims to help companies improve their production systems, performance and competitiveness by developing a tool for assessing the current state of a production system and identifying the potential and means for improvement. Based on the author’s observation, the objectives of production and the means to achieve them, for example, production practices and the structure and organisation of a production system, are quite similar in the type of companies considered in this study (Section 1.3.). Therefore, identifying the characteristics of a production system which are useful and relevant for achieving production objectives and high production performance was assumed to be possible. In the study, these characteristics are called key characteristics of a well-performing production system, and they are used as a reference for the assessment of production systems and to identify potential and means for improving the system. The assessment is based on comparing the characteristics of a company’s production system with the identified key characteristics, and potential and means for improvement are identified based on the differences between the characteristics of the assessed production system and the key characteristics of a well-performing production system, i.e., the realisation of the key characteristics in the assessed production system. Modifying the production system to realize the key characteristics is assumed to result in a production system that better enables and supports efficient production processes and the achievement of production objectives and high performance.

Development of the production system assessment tool consisted of identifying the key characteristics of a well-performing production system and creating methods and a scale to enable assessment of the system. The objectives and research questions were formulated as follows:

Primary objective:
   To develop a tool to assess the current state of a production system and to identify potential and means for improvement

Sub-objective 1:
   To identify a set of key characteristics of a well-performing production system, i.e., enablers or prerequisites for achieving production objectives and high production performance.

Research question 1:
   Which characteristics of a production system are central to achieving production objectives and high production performance?

Sub-objective 2:
   To develop methods and a scale that allow assessment of a production system based on the key characteristics and to present the results of the assessment.

Research question 2:
   Which methods enable assessment of a production system based on the key characteristics of a well-performing production system? What kind of scale should be used in the assessment and in presenting the results?

Pursuing and achieving the primary objective required achieving both sub-objectives and answering the two associated research questions. In addition to these objectives, the production system assessment tool was to be easy to use and to enable quick assessment of a production system. Furthermore, the tool and assessment results provided by it were to be applicable and beneficial to the target companies of the study.
1.2. Focus and scope

The focus and scope of the study and the assessment tool developed are defined and clarified by considering the different aspects of improving production. In addition, the focus and scope are defined with regard to different functions of a company and from the perspective of production networks.

This study focused on production and its improvement. The term production is used in this study to cover the entire process from raw materials to the finished product. Hence it covers both part production, i.e., making parts and components from raw materials, and assembly in which parts and components joined or fitted together to create a product or subassembly of a product. The following figure shows four domains that are important in this context (Figure 1). The product architecture is linked with the design and structure of the products that a company markets and produces for its customers. The production system consists of resources, such as equipment, materials, and people, which enable production processes and production of outputs, for example, products offered to customers or parts or subassemblies of a product. The production processes and characteristics related to the production outputs, for example, the functionality and features of a product, affect and determine the production performance.

As the grey area in Figure 1 indicates, the study and the assessment tool developed in it focus mainly on the production system, i.e., production resources and the organisation and arrangement of these resources. Due to the interrelatedness of the product architecture, production system, and production processes, some aspects of product architecture and production processes are considered. With regards production processes, only general guidelines and principles regarding their execution and management are considered, and their detailed assessment and evaluation have been omitted here. Similarly, product architecture is covered only in general terms from the perspective of production and any detailed assessment of products and, for example, producibility (e.g., Lapinleimu 2001, p. 139) have been excluded.

The focus of the study and the definitions presented above can be further clarified by considering available definitions of production or manufacturing system. Cochran and Dobbs (2001, p. 390) define manufacturing system as “the arrangement and operation of machines, tools, material, people, and information to produce a value-added physical, informational, or service product whose success and cost is characterized by measurable parameters.” Furthermore, they define that “Manufacturing system design covers all aspects of the creation and operation of a manufacturing system. Creating the system includes equipment selection, physical arrangement of equipment, work design, and standardization. The result of the creating process is the factory as it looks during a shutdown. Operation includes all aspects that are necessary to run the created factory.” (Cochran & Dobbs 2001, p. 390-391). Hence, the definitions of manufacturing or production system and its design include the production resources, their arrangement, and
operation of the system. These aspects are included also in the definitions by Lapinleimu (2001) and Miltenburg (2005). Lapinleimu (2001, p. 89) states that “production system is the overall system needed for generating the product”, and divides it into planning system or virtual factory and manufacturing system, i.e. the real factory that carries out the actual manufacturing. Miltenburg (2005) describes that a production system is formed by machines and processes, workers and managers, and departments and control systems working together. These examples also show that the use of the terms manufacturing and production varies in literature. All three sources consider the production process from raw materials to finished product, but Cochran and Dobbs refer to manufacturing system, Miltenburg refers to production system, and Lapinleimu includes both in his definition.

Compared to the definitions above, in this study production system and resources are more clearly separated from operating production, i.e. production processes, control and management. Here, production system is defined as including the production resources needed to produce products, i.e., equipment, tools, human resources and information, and the arrangement and organisation of these resources. Production processes, then, cover the use and operation of production resources, and the control and management of production. Thus, the definition of production system used here corresponds to that of Cochran and Dobbs (2001), with the exception that operation and processes of production are not included, but considered separately. Similarly, with regard to the definition of manufacturing system design by Cochran and Dobbs (2001), a production system, as defined in this study, is the result of creating a manufacturing or a production system, but does not include the operation of the system. Compared to Lapinleimu (2001), in this study production system does not include the planning system or production processes, but focuses on the resources and arrangement of the real factory. With regard to production processes, general guidelines and principles of operating, controlling and managing production are covered in this study, but the actual operation and processes of production are omitted. Hence, the definitions used aim to clarify and emphasise that the study and the developed assessment tool focus on the enablers of production processes, i.e. production resources and their arrangement, rather than the processes and operation of production. In other words, the focus covers enablers of and plans related to production processes that enable starting and carrying out production, but not the actual operation of production.

The focus of the study can be justified by considering the effects of a production system on production performance and the links between production system, product architecture, and production processes. The above descriptions show that the production system is an enabler of production processes that create production outputs. Consequently, the production system and its characteristics, for example, the arrangement and organization of production resources affect the production processes, their performance and production outputs. Therefore, the production system is an important enabler of high production performance. The effects of the production system on production performance are emphasised by Miltenburg (2005, p. 64), who identifies seven different production systems and mentions that each provides a unique set of production outputs. Similarly, Wheelwright (1984, p. 84) has devised categories into which production related decisions can be grouped, and claims that the decisions determine the strengths and weaknesses of a production organisation and the performance it can achieve. Hence, focusing on the production system to improve production processes and production performance is essential and beneficial. Furthermore, covering certain aspects of product architecture and production processes can be justified due to their links with the production system. For example, units can be created in the production system on the basis of entities of a product. The product structure also indicates the order in which parts and sub-assemblies of a product can be assembled in the final assembly, and characteristics of products, such as material and tolerances used, are connected to type and accuracy of equipment needed in production. Furthermore, the organisation and arrangement of the production system affect production processes, for example in terms of material flow and production control. The product architecture, production system,
and production processes thus interact and overlap and should therefore be considered collectively. Many authors, for example, Tersine (1985, p. 14), Muhlemann et al. (1992, p. 8-9), Lapinleimu (2001, p. 174-175), Slack et al. (2004, p. 96-97), and Juutti (2005, p. 50), have also identified this interconnection.

In addition, the focus of the study and the assessment tool can be explained with regard to improving production performance. Instead of focusing directly on production processes, on how they are performed and their current performance, the focus could be shifted to what enables them and their performance, namely the production system. The aim is to assess and improve the production system and to ensure efficient and effective production of products offered to customers. In other words, assessing and improving the production system seeks to enable and ensure high production performance.

With regard to production networks comprising the production systems of several companies, this study and the assessment tool focus on one company, the main company or contractor of the production network, and do not cover the entire network. Typically, the main company or contractor coordinates the production network and is responsible for the final assembly of the product and its sale and delivery to the customer under its name or brand. The focus of the study was limited in this way because, due to the differences in business environment and principles, the same guidelines and characteristics of production and production systems are typically not applicable or beneficial to both main contractors and subcontractors. Additionally, the work had to be proportioned to be suitable for a doctoral study and thesis conducted by a single researcher.

Finally, the study focused on the initial phases of the production system improvement process, i.e., assessing the current state and identifying the potential and means for improvement. The further phases of the improvement process, such as detailed planning and execution of improvements and changes, are therefore omitted. The phases of the improvement process and those covered in this study are also discussed in Section 2.3.2.

1.3. Target industry sector and company types

The target companies of this study were defined by industrial sector, production approach, and products. Various authors, for example, Hendry (1998, p. 1086), Schroeder and Flynn (2001, p. 3, 283), and Davies and Kochhar (2002, p. 290, 301), have shown that the practices and characteristics of a production system are context-specific, i.e., their appropriateness and usefulness depend on, for example, the company type, strategy, and business environment. Therefore, to ensure that the production system assessment tool and the key characteristics of a well-performing production system are relevant and applicable, the target companies in this study were carefully defined and limited.

This study focused on Finnish mechanical engineering companies that produce customer-specific capital goods and operate mainly in the business-to-business market. In terms of production approaches, make-to-order or assemble-to-order companies were considered. With regard to products, included were companies that produce customer-specific products designed before orders are received but configured based on customer order. Hence, make-to-order and assemble-to-order approaches refer here to supply chains and production in which operations starting from part production or assembly, respectively, are customised and carried out based on a customer order, and operations upstream from these points can be performed before receiving orders. Figure 2 aims to clarify these definitions. In terms of product life cycle, the focus was on the later part of the growth stage and on the mature stage, where production processes are established and relatively stable. The annual production volume was assumed to be a few hundred or thousand units, i.e., volumes below mass production, yet justifying investments in
improving production and production systems. The relevance of the industrial sector and companies considered in this study are discussed in the following section.

![Diagram of production approaches]

**Figure 2. Production approaches**

Furthermore, the production system assessment tool and the set of key characteristics of a well-performing production system were developed based on certain assumptions related to production and company strategies. These assumptions, which also defined and limited the type of companies considered, are discussed in more detail in Section 2.1.

### 1.4. Relevance of the topic and industrial sector

This section argues for the importance and relevance of focusing on production, production systems, and their improvement. This is demonstrated by the characteristics of the target companies of the study, the results of a survey, and national and international research in the field. Furthermore, the section aims to justify selecting the above-defined industrial sector and companies based on their role and importance in the Finnish economy.

Production plays an important role in mechanical engineering companies that produce capital goods such as machines for the transport, mining, or forest industries. Such products are typically large and complex and the production processes are multi-phased and complex. Furthermore, production lead times are typically long and production costs high, making up a significant share of the product’s total costs. The financial statement statistics of Finnish companies producing machines and equipment support these arguments and provide concrete information on the role and importance of production in these companies. For example, in 2006 the added value of production was EUR 4 billion, representing 27.1% of the companies’ net turnover (Statistics Finland 2008). The average value of the material, work in progress, and finished goods inventory was EUR 1.95 billion or 13.2% of the 2006 net turnover (Statistics Finland 2008). These observations and figures indicate that production is a key determinant of the competitiveness of the companies chosen.

The results of a survey of Finnish companies’ views on improving competitiveness in production of products and services also support the need to focus on and improve production and production systems. The survey (Fountain Park 2007) was part of the Concepts of Operations technology programme funded by the Finnish Funding Agency for Technology and Innovation. The questionnaire was answered by 290 companies, and the sample covered companies from various industrial sectors. Of the respondents, 137 (49.8%) were classified as metal and discrete part production companies, which is similar to the industrial sector and companies chosen in this study. One survey question focused on the area or areas of a company requiring most effort and
improvement. Of the options provided, 30.3% of respondents considered “How to arrange and manage the production of products and services in a competitive way” to be most important. The other options covered defining the business focus, defining or selecting the customer segment, identifying customer needs, and defining the product and service portfolio offered to customers. Another question focused on key areas for improvement in developing and improving concepts of operations. Of the 15 options, “Improving one’s own production” received 10% of all responses representing the third highest response, with only “Improving the productivity and flexibility of production” netting more responses. Interestingly, topics such as outsourcing production, improving subcontracting and its coordination, and the value chain approach were seen as less important than improving one’s own production. These results indicate that improving production and production systems are still on the agenda of Finnish companies. The responses also demonstrate the relevance and usefulness of focusing on assessing and improving production and production systems of individual companies instead of considering the entire production network.

Furthermore, national and European research programmes and platforms demonstrate the relevance of the research topic. At the national level, in 2009 the Finnish Funding Agency for Technology and Innovation funded two research and development programmes, SISU 2010 and Concepts of Operations, that are focussed on improving the production, performance, and competitiveness of Finnish companies. Furthermore, at the European level, the Manufuture platform is an example of an initiative to promote research, technological development, and innovation aimed at ensuring the competitiveness of the production industry. Active research into various aspects and topics of production at both national and European levels supports the relevance of this study.

With regard to the industrial sector and companies considered in this study, the following table shows the importance and role of the mechanical engineering sector in Finnish industry and the Finnish economy (Table 1). The table compares the most important industrial sectors in terms of turnover, added value, exports, and employees in 2005, i.e., the beginning of this study, with the latest available figures, i.e. 2008.

Table 1. Sectors of Finnish industry in 2005 and 2008 (Teknologiateollisuus 2007; Statistics Finland 2009a; Tullihallitus 2009)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Year</th>
<th>Turnover in m€</th>
<th>Value added in m€</th>
<th>Goods exports in m€</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical engineering</td>
<td>2005</td>
<td>22440</td>
<td>7198</td>
<td>10696</td>
<td>130800</td>
</tr>
<tr>
<td>Electronics &amp; electrotechnical industry</td>
<td>2005</td>
<td>22499</td>
<td>7528</td>
<td>14679</td>
<td>130800</td>
</tr>
<tr>
<td>Metals industry</td>
<td>2005</td>
<td>8877</td>
<td>1575</td>
<td>5607</td>
<td>130800</td>
</tr>
<tr>
<td>Information technology</td>
<td>2005</td>
<td>18357</td>
<td>4900</td>
<td>10636</td>
<td>130800</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>2005</td>
<td>14833</td>
<td>3714</td>
<td>6945</td>
<td>130800</td>
</tr>
<tr>
<td>Finnish industry total</td>
<td>2005</td>
<td>117536</td>
<td>37480</td>
<td>52395</td>
<td>499400</td>
</tr>
</tbody>
</table>

Table 1 shows that mechanical engineering is among the largest industrial sectors based on the above factors. Combining the table to the national level and the Finnish economy, mechanical engineering employed 5.7% of the workforce and produced 24.5% of exports in 2008 (Statistics Finland 2009a; 2009b). Furthermore, in 2008 industry’s share of Finnish GDP was 24.9% (Statistics Finland 2009c). Thus, mechanical engineering, the focus of this study, is an important sector of Finnish industry with an important role in the Finnish economy.
1.5. Need for a new production system assessment tool

The motivation for this study and the need for developing a new production system assessment tool were based on companies’ need to improve production systems, processes and performance, and on the aim and ability to assist companies in such improvement. A review of available production improvement tools indicated their inability to sufficiently assist companies in assessing and improving production systems, and hence demonstrated the need for developing a new tool and provided the motivation for the study.

The importance of improving production and its performance for the target companies in this study was discussed and demonstrated in the previous section (Section 1.4.). In addition, the definitions presented in Section 1.2. indicate that the production system is an important enabler of production processes and high production performance. The effect of the production system and related decisions on production processes and performance has been recognised also, for example, by Miltenburg (2005, p. 64), Wheelwright (1984, p. 84) and Cochran and Dobbs (2001, p. 391). Thus, there is a need to improve production systems and to develop tools that support and assist such improvements. However, the applicability and usefulness of production practices, production system characteristics, and improvement tools based on such practices or characteristics are dependent on factors such as industry sector, company type and business environment (Voss 1995, p. 13; Hendry 1998, p. 1086; Schroeder & Flynn 2001, p. 3, 283; Davies & Kochhar 2002, p. 290, 301; Muda & Hendry 2002b, p. 355). This observation highlights the need for the development of a production system assessment tool for the targeted industrial sector.

The need for this study and for the development of a production system assessment tool for the target sector and companies was also demonstrated by a review of currently available tools and models for production assessment and improvement. The review, which revealed a lack of tools and models able to meet the needs and requirements discussed above, can be summarised by considering four groups of tools and models.

One group of assessment and improvement tools and models focuses on production processes and outputs, and adopts a different assessment approach to this study. Typical examples belonging to this group are performance measures and measurement frameworks, for example, the Balanced Scorecard (Kaplan & Norton 1996) or the Performance Pyramid (Lynch & Cross 1991). Additionally, certain assessment and improvement tools in this group, for example, Activity Based Optimization (Juuti 2005) and Value Stream Mapping (Rother & Shook 2003), are focused almost exclusively on production processes. Focusing on production processes and their output may, however, cause difficulties in linking the assessment results and recognized improvement needs with the production system, i.e. in determining areas and characteristics of the production system to be developed or improved to achieve better production performance. Hence, the models and tools in this group are not considered sufficiently beneficial in assessing and improving production systems.

Another group of assessment and improvement tools and models uses a similar approach to this study and is based on requirements, solutions, best practices or characteristics of a company or production. However, the tools and models of this group adopt a broader perspective to assessment and improvement than this study. For example, the SCOR model (Supply Chain Operations Reference-model, Supply Chain Council 2008) covers the entire supply chain and considers five management processes, plan, source, make, deliver, and return, while the MSDD™ tool (Manufacturing System Design Decomposition, System Design 2008) considers both production system design and production processes. A potential problem with such a broad perspective is that the tool or model becomes too laborious and complicated to use. For example, in a survey on the use of the SCOR model, respondents considered understanding and using the model to be challenging and to require training (Löfgren et al. 2003).
Thirdly, some models and tools consider production and its improvement in very general terms and in a broad perspective. For example, Zhang and Sharifi (2000) and Hormozi (2001) take customer, competitor, and even government actions into consideration, whereas some authors seek to define or describe the characteristics of a well-performing production system or a certain production approach, such as agile manufacturing (e.g., Booth 1996, Gould 1997), at a general level. Additionally, some of the models and tools of this group do not provide adequate measures or methods to assess a production system or to compare it with the definition provided. As an example, Lapinleimu (2001) lays down principles and guidelines for designing and operating a production system, but provides only a couple of operational measures for assessment. Thus, a potential problem related to this group is that the tools and models do not provide sufficiently useful or detailed advice on assessing and improving production and production systems.

Finally, many available assessment and improvement models and tools are meant to be industry- and company-generic, i.e., they do not specify the type of company or industry or the nature of the business considered, but assume that all companies can be treated in the same way. This is observed also by Muda and Hendry (2002a, p. 295). Examples of such models and tools include the SCOR model, the EFQM model, and the Baldrige Criteria. However, as mentioned above, the applicability of production practices and principles to a company depends on the context, for example, company type, production strategy, product variety, and production volume. Thus, if the target group and context are not specified, deciding whether or not the advice and information provided is useful and applicable to a certain company may be difficult. Furthermore, Muda and Hendry (2002a, p. 295) conclude that if the context and target companies are not defined, the resulting definitions and descriptions of well performing production systems or companies and advice on improving performance tend be too universalistic to be useful and applicable to companies.

1.6. Research approach and outline of the study

This section briefly describes various research approaches and provides an outline of the progress and phases of the study (more details in Chapter 4).

This study was based on design science and constructive research approaches. In contrast to describing and understanding reality and the current situation, these approaches aim at developing artefacts or constructions for solving practical and relevant problems, improving a current situation, or capitalizing an opportunity (Kasanen et al. 1993, Järvinen 2008). They therefore suited the objectives of this study well and provided useful guidelines and advice for conducting the study.

This study was divided into five phases:

1. Identifying and defining research problem and objectives
2. Developing a production system assessment tool
3. Testing the production system assessment tool
4. Evaluating the production system assessment tool
5. Evaluating and reporting the study

In the first phases, the topic and objectives were identified and defined, and the focus then shifted to pursuing those objectives, i.e., to developing a new production system assessment tool. Subsequently, the developed tool was tested in pilot cases and evaluated based on the assessments and feedback collected. Finally, the study was evaluated and reported.

The study, its progress, and results have been published in papers and presented in seminars and international conferences. Of the eight international conference papers published and presented, two (Koho 2008a; Koho & Torvinen 2009) describe the production system assessment tool and
its use and six reported on the tool’s parts and development (Koho & Torvinen 2006; Koho 2006; Koho & Torvinen 2007a; Koho & Torvinen 2007b; Koho 2007; Koho & Torvinen 2008). The papers and presentations were intended for researchers to evaluate and comment on the study and its results. Reviewer reports together with comments and questions about the presentations provided useful feedback which assisted in conducting and reporting the study. In addition to the above, the study was presented in a national conference (Koho 2008b), three postgraduate seminars, and a research methodology course. Feedback and comments from these assisted the planning, carrying out and evaluation of the study, and the selection of approach and methods used.

1.7. Outline of the dissertation

Structurally, this dissertation can be divided into the following five main parts (Figure 3):

**Figure 3. Outline and main parts of the dissertation**

The first part of the dissertation, Chapter 1, introduces the study and its topic, its objectives and focus, discusses its need and relevance, and provides an overview of its progress and phases. The second part provides the background and framework for developing the production system assessment tool. Chapter 2 covers the theoretical background in terms of production strategy, production paradigms, and production approaches and discusses the assessment and improvement of production and production systems. Chapter 3 then reviews the state of the art, i.e., available tools and models for assessing and improving production. The third part of the dissertation focuses on developing the production system assessment tool and presents the research approaches, process, and methods. The fourth part reports the results: the developed production system assessment tool, its three parts (Chapter 5), and its use (Chapter 6). The final part evaluates the study and its results (Chapter 7), discusses them, and draws conclusions (Chapters 8 and 9).
2. Theoretical framework

This chapter discusses the perspectives and aspects relevant and useful to the study and to developing the production system assessment tool based on literature. Topics covered include production strategy, production paradigms and approaches, and assessment and improvement of production.

2.1. Production strategy

This section focuses on company strategy, particularly production strategy, and describes the role and impact of production and its improvement within the strategy and in achieving and sustaining competitive advantage. Furthermore, the section introduces the content and process of production strategy and discusses its links with production system design. The discussion helps in developing the production system assessment tool, clarifying the strategic assumptions made in this study, and placing this study in the context of strategy.

2.1.1. Role of production in company strategy

Strategy can be defined as a pattern of decisions that position a company in its environment and help it to achieve a competitive advantage, to be profitable, and to generate value for its shareholders in the long term (Slack et al. 2004, p. 87; Kaplan & Norton 2004, p. 29). Company strategy and strategic decisions can be divided into different interlinked levels that form a hierarchy of strategies. Three levels of strategy are commonly used: corporate, business or business unit, and functional (e.g., Wheelwright 1984, p. 82; Slack et al. 2004, p. 68-69; Miltenburg 2005, p. 220-222). Corporate strategy defines how the corporation or company positions itself in the market or markets where it operates. Corporate strategy also defines the businesses or markets that the company participates in and, in general, how it competes. Business or business unit strategy offers a more detailed definition of goals, products offered to customers, and markets served. It also describes how the business or business unit achieves competitive advantage and high-level goals. Finally, functional strategies describe actions taken by functions, for example, production or marketing, to gain competitive advantage and to realize the goals set in the business or business unit strategy. (Wheelwright 1984, p. 82; Slack et al. 2004, p. 68-69; Miltenburg 2005, p. 220-222) Production strategy then provides guidelines for production and operations management and decisions on design, operation, and improvement of the production processes, production system, and production organisation (Krajewski & Ritzman 1996, p. 46; Slack et al. 2004, p. 95). Thus, in the hierarchy of strategy, production strategy is one of the company’s functional strategies, providing guidelines and objectives for decisions on the production system and production processes, and must accordingly be consistent with the company’s higher-level strategies and objectives.

In addition to the hierarchies of strategy, some authors have identified generic strategies whereby a company can position itself to outperform competitors and create a competitive advantage. Miltenburg (2005) builds on models and classifications by Porter (1985) and Thompson and Strickland (2001) and categorizes different competitive strategies based on two dimensions: competitive advantage and competitive scope. With regard to competitive advantage, Miltenburg (2005, p. 12) adopts the classification of sustainable strategies by Porter (1985), hence the approaches are low cost and differentiation. These two approaches differ in terms of available opportunities to satisfy customers and outperform competitors. The low cost approach aims to create competitive advantage by designing, producing, marketing, and delivering a product for less than competitors. As to production, the emphasis is on continuously improving efficiency and reducing cost without sacrificing quality. In terms of products, the aim is to produce and
provide good quality basic products at a low price. On the other hand, in differentiation, a company aims to create competitive advantage and to satisfy customers by providing a better combination of attributes such as quality, product features, service, delivery time and reliability than competitors. In terms of products and production, the aim is to provide a wide variety of products with features for which customers are willing to pay a premium price. (Thompson & Strickland 2001; Miltenburg 2005) Miltenburg (2005, p. 12) also points out that a successful strategy pays attention to both low cost and differentiation, but emphasizes one. The other dimension, competitive scope, is divided into broad market and narrow or niche market. Based on these two dimensions, five generic competitive strategies with distinct features in terms of competitive advantage, competitive scope, products, production, marketing, and strategy have been identified and defined (Figure 4). (Miltenburg 2005)

<table>
<thead>
<tr>
<th>Competitive Advantage</th>
<th>Low Cost</th>
<th>Differentiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad</td>
<td>Cost leadership</td>
<td>Differentiation</td>
</tr>
<tr>
<td>Narrow</td>
<td>Focused cost</td>
<td>Focused differentiation</td>
</tr>
</tbody>
</table>

**Figure 4. Five generic competitive strategies (Miltenburg 2005)**

This study and its target companies could be located in the above categories and connected to the generic strategies presented by Miltenburg (2005). In terms of competitive scope, the narrower focus was more relevant to this study and its target companies since the companies’ production volumes were assumed to be relatively low, i.e., some hundreds or thousands of products per year (Section 1.3.). The target companies were therefore better positioned to serve a narrow market or market niche than a broad market. With regard to competitive advantage, the two approaches are described so as to indicate that low cost puts more emphasis on production, its efficiency, and improvement. The low cost approach therefore seemed more relevant to the target companies and objectives of this study. However, because of their relatively low production volume, the target companies in this study may find it difficult to achieve cost leadership, for example, by economies of scale. This and the need to consider both the low cost and differentiation emphasized by Miltenburg (2005) indicate that in designing and improving the companies’ production and production systems, a set of objectives broader than cost-efficiency was to be considered and pursued. In focused cost and focused differentiation, the emphasis of production and its improvement should be on cost-efficiency and on producing customized products to meet customer needs in the targeted market segment or niche (Thompson & Strickland 2001, p. 152; Miltenburg 2005). Thus, these approaches and objectives were deemed applicable to the companies considered in this study.

Another framework that clarifies the role of production in the context of company strategy and competitive advantage is the Strategy Map by Kaplan and Norton (2004). The Strategy Map (Figure 5) helps illustrate the links from strategy to processes and assets, is evolved from the Balanced Scorecard, and consists of four perspectives: financial, customer, internal process, and learning and growth (Kaplan & Norton 2004, p. 9, 30).
The hierarchy of the Strategy Map framework extends from the financial to the learning and growth perspective. The financial perspective describes strategy in financial terms and uses measures such as return on investment (ROI), shareholder value, and profitability to evaluate the success of a company strategy and its implementation. The hypothesis is that financial objectives can be achieved only by satisfying customers; therefore, a value proposition that describes how targeted customers are satisfied is defined in the customer perspective. The customer value proposition is presented in terms of objectives and attributes related to products, services, relationship, and image, and it provides the context and objectives for internal processes to create and deliver value for the customer. The customer perspective is thus linked with the internal process perspective, which includes production and operations management, and production processes. Finally, the learning and growth perspective shows the intangible assets that support the internal processes and provide the foundation for the strategy. Kaplan and Norton (2004, p. 30-32) state that aligning objectives and actions in the four perspectives is the key to value creation, to achieving the desired company outcomes and objectives, and to focused and consistent strategy. Thus, as in the hierarchical model of strategies, the Strategy Map framework emphasises that production strategy and decisions on the production system and production processes should be derived from and be consistent with the objectives and decisions formulated at higher levels.

Kaplan and Norton (2004) also present generic strategies and strategy maps, and highlight areas and aspects that should be emphasized in implementing a certain strategy. At the highest level, i.e., in the financial perspective, they give two generic strategies: productivity and growth. The productivity strategy focuses on improving cost structure by reducing cash expenses, eliminating defects, and improving yield. The strategy also emphasises increasing asset utilization, for example, by capacity management. The growth strategy aims to expand revenue opportunities and to enhance customer value. With regard to production, Kaplan and Norton (2004) point out that excellence in operations management, which includes efficiency and effectiveness of production processes, is linked directly to the productivity strategy and indirectly to the growth
strategy. In the customer perspective, once the target market and customers have been defined, company strategy is linked to a value proposition that describes a mix of company objectives such as price, quality, time, function, partnership, and brand offered to the target customers. At this level, Kaplan and Norton give four generic value propositions developed and elaborated from the low cost and differentiation strategies by Porter (1985). The four propositions are best total cost, product leader, complete customer solutions, and system lock-in. Kaplan and Norton (2004, p. 66, 323) mention that in the best total cost strategy, key processes occur in the operations management cluster that includes supply, production, distribution, and risk management. This approach thus places most emphasis on production and the efficiency and improvement of production processes. Though the best total cost strategy emphasises low costs and cost-efficiency, production processes must also be consistent, high-quality, highly responsive, and able to achieve short cycle and lead times (Kaplan & Norton 2004, p. 40-41, 323). Kaplan and Norton (2001) emphasise the need to consider and pursue a broad set of production objectives also in an earlier publication. There, operational excellence, which involves offering and delivering a combination of product and production-related attributes and objectives, for example, price, quality, time, and selection, that competitors cannot match, is presented and discussed (Kaplan & Norton 2001, p. 87-88).

In conclusion, production and production management play an important role in company strategy, and efficiency and the effectiveness of production processes are key enablers especially in the best total cost or operational excellence strategy. Hence, these strategies are relevant to this study and its target companies. However, Kaplan and Norton (2004, p. 40-41; 2001, p. 87-88) emphasise that to remain competitive, the focus should be not only low cost but also high and consistent quality, reliability, and ability to produce and deliver an appropriate selection of products. This is in keeping with the requirements presented by Miltenburg (2005) and was deemed important for this study and for developing the production system assessment tool.

2.1.2. Content and process

Production strategy can be defined as decisions and actions with which production seeks to achieve its objectives and to gain competitive advantage, and it can be divided into process and content (Wheelwright 1984, p. 79; Voss 1995, p. 5; Slack et al. 2004, p. 67; Miltenburg 2005, p. 1). The production strategy process involves identifying decision areas in production, identifying and prioritizing the objectives of production, and linking the decision areas with the objectives (Platts & Gregory 1992, p. 32). The production strategy content consists of a set of production-related decisions intended to contribute to achieving the objectives and performance criteria set for production (Wheelwright 1984, p. 79; Voss 1995, p. 5; Slack et al. 2004, p. 67). The required consistency between the different levels of strategy emphasised in the previous section (2.1.1.) shows that the production strategy and production objectives should be derived from and contribute to realizing higher-level strategies and objectives.

The content and process of a production strategy can be clarified and concretized using three paradigms, which, according to Voss (1995), contain all that is required for an effective production strategy. In the first paradigm, competing through manufacturing, manufacturing or production is seen as a competitive weapon of a company. The paradigm requires that the company focus on the excellence of its production capability and align the capability with its key success factors, corporate and marketing strategies, and the demands of the marketplace. The second paradigm, strategic choices in manufacturing, is founded on the need to achieve internal and external consistency between choices in production strategy. The third paradigm, best practice, is based on the assumption that best or world-class practice will lead to superior performance and capability; therefore, the paradigm focuses on continuous development of best practice in all areas within a company. (Voss 1995, p. 6-10) Voss (1995) also connects the three paradigms in a continuous loop or cycle (Figure 6).
Figure 6. Cycle of production strategy and paradigms (Voss 1995)

The competing through manufacturing paradigm is the starting point of the cycle and must be revisited at regular intervals. The paradigm gives the company a strategic vision and leads to the second paradigm, i.e., strategic choices in production. These choices then require development of world-class performance and best practice in the chosen areas. (Voss 1995, p. 14) Thus, the cycle of paradigms involves making decisions on production and identifying and developing best practices in different areas of production and the production system. Importantly, the decisions and practices should derive from and be consistent with the higher-level strategies and objectives of the company. As a result, the above cycle can be seen as the process of production strategy, and the content of production strategy consists of the production-related decisions and best practices.

The content of the production strategy and the decisions made in developing such a strategy can be illustrated by classifying the decision areas of production. For example, Wheelwright (1984, p. 84) offers the following eight categories of production related decisions:

- Capacity: amount, timing, type
- Facilities: size, location, focus
- Technology: equipment, automation, connectedness
- Vertical integration: direction, extent, balance
- Workforce: skill level, pay, security
- Quality: defect prevention, monitoring, intervention
- Production planning/materials control: computerization, centralization, decision rules
- Organization: structure, reporting levels, support groups

The first four categories represent structural or strategic decisions typically with long-term impacts, difficulty to reverse or undo, and substantial capital investment, whereas the last four are much more tactical (Wheelwright 1984, p. 84). Another categorization comes from Miltenburg (2005, p. 65-66), who divides a production system into six subsystems:

- Human resources: skill level, wages, training, promotion policies, employment security
- Organization structure and controls: relationships between groups of employees, decision-making, culture, performance measurement and incentive systems
- Sourcing: amount of vertical integration, relationships with suppliers, management and control of production network
• Production planning and control: rules and systems for production planning and control, production and support activities
• Process technology: type of production processes and equipment, amount of automation, link between parts of the production process
• Facilities: location, size, focus, and types and timing of changes

In addition to the production strategy, the above categories are linked to the design and operation of a production system. According to both Miltenburg (2005, p. 66) and Wheelwright (1984, p. 84), the decisions made in the categories or subsystems determine the structure and capabilities of the production system and the output and performance of production. Though the categories differ in number and terms used, in content they are quite similar. Miltenburg offers no individual categories of capacity and quality, but the former may be included in the decision areas of facilities and production technology. Furthermore, in Wheelwright’s classification quality refers to processes and procedures that ensure high and consistent quality, rather than to a measurable production objective, and it could be included in the production planning and control subsystem presented by Miltenburg. With regard to this study, the categories or decision areas of sourcing and vertical integration are not within its scope, but the other areas were relevant and useful in developing the production system assessment tool.

The content of a production strategy and the strategic decisions made are also connected to production objectives, i.e. the dimensions or categories of performance with which the company and production attempt to satisfy customer requirements and achieve competitive advantage (Slack & Lewis 2002, p. 36). Various classifications of production objectives are presented in literature. For example, Miltenburg (2005, p. 45) lists the following six production objectives or outputs:

- Cost: the cost of material, labour, overhead and other resources used to produce a product
- Quality: the extent to which materials and operations conform to specifications and customer expectations, and how tight or difficult the specifications and expectations are
- Performance: the product’s features, and the extent to which the features or design permit the product to do things that other products cannot do.
- Delivery time and delivery time reliability: the time between order taking and delivery to the customer. How often are orders late, and if they are late, how late are they?
- Flexibility: the extent to which volumes of existing products can be increased or decreased to respond quickly to the needs of customers.
- Innovativeness: the ability to quickly introduce new products or make design changes to existing products.

Wheelwright (1984, p. 81) includes cost, quality, dependability, and product and volume flexibility in the competitive priorities of a company, whereas Slack and Lewis (2002, p. 37) divide performance objectives into quality, speed, dependability, flexibility, and cost. Quite similar categories of performance and objectives of production or company have been proposed also by Skinner (1992, p. 23), Voss (1995, p. 6), and Kaplan and Norton (2004, p. 31). At least the most typical objectives, i.e., cost, quality, time, reliability, and flexibility, were regarded important to be considered in this study. The definitions of the objectives by Miltenburg (2005) also set a good basis for defining the production objectives covered in this study.

2.1.3. Production strategy and production system design

Decisions related to production strategy and production system design, and a relationship or linkage between these areas can be demonstrated and explained with the help of matrices that include aspects of corporate strategy, production strategy, production system, and production
processes. Hayes and Wheelwright (1979) have presented a product-process matrix that is often referred to in literature on production strategy (Figure 7).

The product-process matrix has two dimensions: product structure and process structure. The former considers product variety and production volume and ranges from low volume and low standardisation to high volume and high standardisation. The dimension of process structure represents different types of production flow from the jumbled flow of job shops to continuous flow. (Hayes & Wheelwright 1979, p. 137) The matrix can be used in various ways. A company can consider the correspondence and match between their product structure and process structure, which indicates how well they can integrate their marketing and production strategy. The matrix can also help to formulate an appropriate production strategy and to design a matching, and hence efficient, process structure based on the product structure and marketing strategy. This involves making decisions related to the structure and organisation of the production system, for example, people, plants, technology, equipment, and control procedures. With the help of the matrix and its dimensions, a company can position itself for competitive advantage. Different combinations of product and process structure can be connected with the competitive emphasis and critical tasks of a company. (Hayes & Wheelwright 1979)

Furthermore, many authors present matrices that explain different production system layouts, their characteristics and applicability on the basis of production volume and product variety. Miltenburg (1995, p. 53) presents three basic layouts, functional, cellular and line layout. These three are identified also by Slack et al. (2004, p. 217) although the terms process, cell and
product layout are used. Slack et al. (2004, p. 207) and Krajewski and Ritzman (1996, p. 403) also present a fourth option, fixed-position layout, in which the product is produced in a fixed place and employees, materials and equipment are moved so that the required tasks and processes can be performed. In a functional or process layout, equipment or processes of a given type are located in a certain area, while in a cellular layout, different types of equipment and processes are located in a department, such that the products of a certain product family can be produced in that department. In a line or product layout, equipment and processes required to produce a certain product or product family are located in a line. (Slack et al. 2004, p. 208-212; Miltenburg 2005, p. 53-54) Slack et al. (2004, p. 214) and Krajewski and Ritzman (1996, p. 403) also point out that often a company or a factory uses a mixed or a hybrid layout in which more than one of the basic layouts are combined. In the following figure, the four layout types have been located on the basis of production volume and product variety suitable for each layout (Figure 8).

![Figure 8. Matrix presentation of different layouts, production volumes and product variety (adapted from Slack et al. 2004, p. 217)](image)

As Figure 8 indicates, of the four options, the fixed position layout typically provides and is suitable for high product variety but low production volume. Product variety reduces and production volume increases when moving to a process or functional layout and further to a cellular layout. The line layout is typically seen to provide highest production volume but lowest product variety of the four basic layouts. The layout decision also has an effect on the material flow and on scheduling and control of production. Production and material flow become more continuous and regular when moving towards a line layout, which typically simplifies the scheduling and control of production. (Krajewski & Ritzman 1996, p. 402; Slack et al. 2005, p. 271; Miltenburg 2005, p. 55) These kinds of classifications and presentations of layouts can be used, for example, to select an applicable and appropriate layout type on the basis of production volume and product variety produced and offered to customers. Hence, they enable the layout types and choices to be aligned with a company’s strategic decisions.

The product-process matrix presented by Hayes and Wheelwright has been modified and developed further by various authors, and a useful extension, the product/volume-layout/flow (PVLF) matrix, has been presented by Miltenburg (2005) (Figure 9).
Figure 9. The product/volume-layout/flow matrix by Miltenburg (2005)

The PVLF matrix includes seven production systems located on the basis of two dimensions. The layout and material flow dimension covers the typical layouts and material flows related to these, while the other axis presents typical combinations of product variety and production volume. Miltenburg (2005, p. 56) states that the matrix makes it possible to identify and select the best production system for a company or factory on the basis of the two dimensions. Furthermore, typical levels of production outputs achieved by the seven production systems have been identified, and the different production systems also have distinctive capabilities with regard to the different subsystems of a production system. These features of the PVLF matrix enable the selection of an appropriate production system on the basis of the objectives and targets of a company as well as analysis of the current production system and its capabilities. (Miltenburg 2005; Miltenburg 1995, p. 105)

The models and descriptions presented could be used to identify appropriate layouts and production system types for the target companies of the study. The study focused on companies producing a relatively high, but predefined product variety at low or medium volume, and the target company definition excluded project-type production of one-of-a-kind products and high volume mass production of standard products (Section 1.3.). Thus, based on the PVLF matrix and the definitions and characteristics of the different layouts discussed above, a cellular layout or line layout were seen to be most suitable for the companies considered. Furthermore, the PVLF matrix indicated the suitability of the JIT production system, which is based on lean production and related techniques, for the target companies in this study. This was supported by the JIT system’s ability to achieve good levels of each of the production outputs considered by Miltenburg (2005, p. 59).
2.2. Production paradigms and approaches

This section discusses current production paradigms, lean production, agile manufacturing, and mass customisation by presenting their background, objectives and typical characteristics. An additional detailed production approach, ideal factory, is also presented. The review of production paradigms enables clarification of the theoretical foundation of this study and its location among the current production paradigms. The paradigms and approaches also play a central role in developing the production system assessment tool.

2.2.1. Lean production

The term lean production was coined at the beginning of 1990’s in the book The Machine that Changed the World (Womack et al. 1990). The roots of lean production are in the Japanese production tradition and, in particular, the Toyota Motor Corporation, but it has also evolved to become one of the most important production paradigms of the Western world (Hines et al. 2004, p. 994-995). The development of lean production began in Japan after World War II. The need for a new production approach was brought about by a scarcity of resources and materials, reduced work force, intense domestic competition and serious financial shortages (Hines et al. 2004, p. 994; Sickler 2004, p. 4). Growing pressure for increased efficiency, effectiveness and competitiveness, coupled with the significant differences in performance between the Japanese and Western companies revealed by Womack et al. (1990) have encouraged Western companies to adopt lean philosophies and practices (Radnor & Boaden 2004, p. 425; Hines et al. 2004, p. 994).

According to Womack et al. (1990), lean production aims to combine the advantages of craft and mass production, while avoiding drawbacks such as the high cost of craft production and the rigidity of the mass production system. Definitions of lean production typically emphasise the ability to produce higher product variety and more output with less resources when compared with traditional mass production. The term lean production has also evolved from describing the production techniques used by the Japanese to provide a more holistic view of the production system or the entire supply chain. As an example, the Lean Enterprise Institute (2008) defines lean production as "a business system for organizing and managing product development, operations, suppliers, and customer relations that requires less human effort, less space, less capital, and less time to make products with fewer defects to precise customer desires, compared with the previous system of mass production." The objectives of lean production can also be summarised as being to create value for the customer while at the same time achieving low cost, high variety, high quality, and very rapid throughput times (Womack 2002; Karlsson & Åhlström 1996, p. 25). Womack et al. (1990) also emphasise that lean producers strive for perfection through continuous improvement. The improvements are aimed at reducing costs, eliminating waste and achieving zero defects and inventories (Karlsson & Åhlström 1996, p. 27-30; Booth 1996, p. 106-107).

Several authors have presented the typical characteristics of lean production systems and frameworks for designing or developing a lean production system. Toyota has been identified as the creator and the most advanced practitioner of lean production and the Toyota Production System (TPS) is consequently often used as a template for lean production. The Toyota Supplier Support Center (cited in Won et al. 2001) has presented the following diagram of the Toyota Production System (Figure 10).
Figure 10. The Toyota Production System framework (Won et al. 2001)

As Figure 10 indicates, the TPS aims to control or reduce costs through the elimination of waste. According to Won et al. (2001), a prerequisite for this is a stable production system, which in the TPS model is achieved through standardised work, levelled and balanced production and kaizen (continuous improvement). Furthermore, the TPS is based on Just-in-Time production and Jidoka, which is the practice of designing machines and processes to deliver perfect quality through rapid recognition and solution of problems.

Karlsson and Åhlström (1996, p. 27-39) focused mainly on the production function of lean production and lean enterprise and identified the following typical or characterising principles:

- **Elimination of waste**, which requires eliminating everything that does not add value to the product and customer in order to reduce costs and use of resources.
- **Continuous improvement** aiming at perfection.
- **Zero defects**, i.e. producing and using fault-free parts and products to attain high productivity.
- **Just-in-time**, i.e. providing each process with one part at a time, exactly when the part is needed
- **Pull instead of push** as a way to schedule material in production. The aim is to increase the number of production phases that produce to customer order rather than based on a forecast.
- **Multifunctional teams** as groups of employees who are able to perform multiple tasks. Teams are typically organized along a cell-based section of the product flow, with each team given responsibility for performing all tasks within this section.
- **Decentralised responsibilities**. Responsibilities such as supervisory tasks are distributed among multifunctional teams.
- **Integrated functions**. Functions and tasks previously performed by indirect departments are integrated into multifunctional teams.
- **Vertical information systems**. The provision of timely information continuously and directly to teams in the production flow. The aim is to ensure that the multifunctional teams can perform according to the goals of the company. (Karlsson & Åhlström 1996, p. 27-39)

As an example of a broader focus covering the entire supply chain or value chain, Womack and Jones (1996) have presented a five step approach to guide managers through lean transformation. They stress the importance of a systemic and strategic view in implementing lean production and state that successful implementation requires that a philosophy or thought process that ties the
techniques of lean production together into a complete system is understood. The five steps are (Womack & Jones 1996, p. 16-26; Lean Enterprise Institute 2009):

1. Specify value: define value from the perspective of the final customer, expressing it in terms of a specific product, which meets the customer's needs at a specific price and at a specific time.
2. Identify the value stream, i.e. the set of all actions required to bring a specific product through the three critical management tasks of any business: the problem-solving task running from concept through design to production launch; the information management task running from order-taking through scheduling and delivery; and the physical transformation task of turning raw materials into finished goods. Create a current-state map of existing value stream and identify waste, i.e. activities that do not add value from the customer's perspective. Then design a leaner future state of the value stream that eliminates the waste.
3. Flow: as wasteful steps are identified and eliminated, make the remaining steps in the value stream flow easily.
4. Pull: let the customer pull products as needed, decreasing reliance on sales forecasts. Pull production means making what the customer wants, when they want it, instead of relying on inaccurate forecasts.
5. Pursue perfection: there is no end to the process of reducing effort, time, space, cost, and mistakes while offering a product which is ever more nearly what the customer actually wants.

To conclude, lean production has its roots in production processes and activities but the term has evolved to cover the entire value chain. The aim is to produce and deliver the required products using the minimum amount of resources, which is enabled by eliminating waste, i.e. activities that do not create value for the customer, by continuous improvement, and by creating standardised, predictable and rapid production processes and a value stream. In terms of the business environment, lean production is considered to require relatively stable and predictable customer demand.

2.2.2. Agile manufacturing

The concept of agile manufacturing was introduced in the early 1990's as a result of a research program conducted by the Iacocca Institute at Lehigh University (Sharifi & Zhang 1999, p. 8; Jin-Hai et al. 2003, p. 172). Many authors (Booth 1996; Gunasekaran 1999; Hormozi 2001) argue that agile manufacturing continues the evolution of production, where the previous phases include concepts such as craftsman, mass production and lean production. The drivers of agile manufacturing, i.e. the reasons for the need to develop a new concept for production, include such characteristics of the business environment as nature of competition, markets and customer requirements. For example, Maskell (2001, p. 6) summarises the axioms and drivers of agile manufacturing as follows:

- Everything is changing very fast and unpredictably
- The market requires low volume, high quality, custom and specific products
- The products have very short life-cycles and very short development and production lead times are required
- Customers want to be treated as individuals

The definitions of agility and agile manufacturing emphasise the need to adapt to changes in the business environment and, generally, agility is defined as the ability to both react to and take advantage of changes and opportunities. For example, Gould (1997, p. 28) summarises that agility is “the ability of an enterprise to thrive in an environment of rapid and unpredictable
Dealing with change and trying to achieve the objectives presented, places a number of requirements on the agile production system and its implementation. Typical requirements include adaptability and flexibility. Lee (1998, p. 1023) proposes that an agile production system should be simple, flexible, reconfigurable, reliable and responsive to market changes, while Hormozi (2001, p. 132) suggests that an agile organisation should be able to reconfigure operations, processes and business relationships efficiently. Achieving agility is seen to require a holistic approach to organisation and operations, and a synthesis of diverse technologies and methods into an integrated system (Yusuf et al. 1999, p. 36; Jin-Hai et al. 2003, p. 173). Hormozi (2001, p. 132) proposes a broad view with regard to required change, stating that successful implementation of agile manufacturing requires changes in government regulation, business cooperation, information technology, reengineering, and employee flexibility. Booth (1996, p. 109) on the other hand, identifies three aspects of change: the organisation, people’s working methods, and information systems. The following model of agile manufacturing (Figure 11), developed by Sharp et al. (1999), serves as an overview of agile manufacturing.

Figure 11. Conceptual model of agile manufacturing (Sharp et al. 1999, p. 161)

The model presents the background of agile manufacturing and its relationship with lean production (foundation), the requirements (continuous change, rapid response etc.) faced by production companies, and the main characteristics of agile manufacturing. In addition, the figure also includes enablers or pillars of agile manufacturing, i.e. principles and practices needed to achieve agility. The enablers or pillars presented are: focus on core competencies,
virtual enterprise, rapid prototyping, concurrent engineering, multi-skilled and flexible people, continuous improvement, team working, change and risk management, information technology, and empowering. (Sharp et al. 1999)

As a summary, the concept of agile manufacturing can be seen as a continuation of the evolution of production paradigms mainly in response to the increasing rate of change in the business environment. Agile manufacturing adopts a broad approach to organisations and operations as well as their improvement, and achieving the objectives of agile manufacturing requires changes in various areas such as organisational structure, product structure, and capabilities of employees. In general, the characteristics and objectives of agile manufacturing presented in literature appear highly demanding, but according to Sharifi and Zhang (2001, p. 774) there is evidence that they can be achieved, or at least approached, by using new production strategies and practices.

2.2.3. Mass customisation

The term mass customisation was coined and popularised in the late 1980’s and early 1990’s by Davis (1987) and Pine (1993). Mass customisation, often contrasted with mass production, aims to provide customers with a wider variety of products that are customised based on their requirements at reasonably low costs that roughly correspond to those of standard mass-produced products (e.g., Pine 1993). The need for developing such a new approach was generated by more demanding and more heterogeneous customers, and it was enabled by flexible technologies and processes (Pine 1993, p. 6-7, 44; Da Silveira et al. 2001, p. 2; Piller & Reichwald 2002, p. 390).

Various definitions for mass customisation exist, and Piller (2004, p. 315) claims that a clear definition and common understanding of the mass customisation concept is still lacking. According to Da Silveira et al. (2001, p. 2), broad definitions of mass customisation emphasise the ability to provide individually designed products and services to every customer through high process agility, flexibility and integration; whereas narrower definitions view mass customisation as a system that uses information technology, flexible processes, and organizational structures to provide a broad variety of products that meet specific needs of customers at a relatively low cost. An example of a detailed definition of the concept is provided by Piller (2004, p. 315): “a customer co-design process of products and services which meet the needs of each individual customer with regard to certain product features. All operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes. As a result, the costs associated with customisation allow for a price level that does not imply a switch in an upper market segment.” Generally, the definitions emphasise the role of customers and meeting their needs with relatively low costs. Furthermore, mass customisation is seen as a broad concept that covers the entire supply chain from sales through design and development to production and delivery. Mass customisation can also be seen as a general level approach that covers and tries to combine both lean and agile manufacturing into one system (e.g., Da Silveira 2001, p. 5). In this study, however, mass customisation is considered in a narrower, production-focused context.

In addition to various definitions, useful classifications of mass customisation and means for implementing the approach are also presented in literature. Gilmore and Pine (1997) identify four approaches to customisation: collaborative, adaptive, cosmetic, and transparent (Figure 12). The classification considers how a product and its representation are changed when a product is customised for a customer. Also, the role and participation of the customer in customising the product is different in the four approaches.
Gilmore and Pine (1997, p. 92) state that the classification allows managers to identify the approach that best serves their customers, and that often a mix of some or all of the approaches is needed. Of the four approaches, collaborative customisation, where both the core product and its presentation is changed and the customer is involved in identifying the offering that fulfils the needs, is most often associated with the term mass customisation (Gilmore & Pine 1997, p. 92).

Many classifications focus on the supply chain and use the point at which customisation is undertaken as a basis for classifying different mass customisation approaches. For example, Alford et al. (2000) divide the supply chain or value chain into three parts, design, production and distribution, and identify three approaches, core, optional and form customisation, based on the stage in the chain at which customisation occurs. Additionally, Lampel and Mintzberg (1996) identify five customisation strategies by dividing the supply chain into different phases and by considering which phases are standard and which are customised (Figure 13).

Figure 12. Four approaches to customisation (Gilmore & Pine 1997)

Figure 13. Five customisation strategies (adapted from Lampel & Mintzberg 1996)

With regard to the supply chain and the point at which customisation occurs, postponement and delayed differentiation are often mentioned as central features of mass customisation (Van Hoek et al. 1999). The aim of these concepts is to delay product differentiation until the latest possible stages of production or the value chain, and to postpone customer-specific activities until after the customer order is received. Furthermore, the aim is to enable the combination of flexible and agile processes with standardised and efficient processes by dividing the value chain or production process into standard and customer-specific parts on the basis of the order penetration point, i.e. the point at which products are differentiated and assigned to a certain customer. (Van
At a more practical level, Pine (1993, p.171) presents five methods for realising mass customisation:

- Customise services around standardised products and services
- Create customisable products and services
- Provide point-of-delivery customisation
- Provide quick response throughout the value chain
- Modularise components to customise end products and services

The methods are not mutually exclusive and can overlap, but they each represent a progressive movement from mass production towards mass customisation. Modular components or modular product architecture are thus seen to be the best method for achieving mass customisation, i.e. minimising costs while maximising individual customisation. (Pine 1993 p. 171, 196) Modular product architecture is also emphasised by other authors (e.g., Da Silveira et al. 2001, p. 4; Blecker & Abdelkafi 2006, p. 919) and is viewed as an enabler of product customisation.

To conclude, compared to mass production, mass customisation emphasises the role of the customer and aims to provide a wider variety of products that are customised based on the needs of the customer. Simultaneously, the aim is to achieve costs and efficiency that are roughly equivalent to those of mass production of standard products. Although a clear and common definition for the concept is lacking, means and methods for achieving and implementing mass customisation presented in literature have been beneficial to this study.

2.2.4. Ideal factory

According to Lapinleimu (2001, p. 11), the research on ideal factory aimed at creating a model of a theoretically ideal production system. The model and theory of the ideal factory were developed by identifying, updating and elaborating known principles of production and factory planning. The results can be used as tools in production system planning and as standards against which actual factories can be compared. (Lapinleimu 2001, p. 1, 11)

The ideal factory model and theory address product ideality, producibility, factory structure and operability, and production efficiency. Lapinleimu’s (2001, p. 138) summary of the principles of the ideal factory includes, for example, the following:

- The production of the ideal factory is continuous, but flexible. Successive products can be different versions or even different end products.
- The production system consists of independent units, each responsible for a defined part of the end product.
- The production units form a network. The structure of the production network corresponds to the structure of the product.
- The operation is based on prerequisites created in advance. The prerequisites enable the immediate implementation of a production schedule or production impulses.
- The entire operation can be summarised as a concept with three levels: system, product and operational. Frameworks and general prerequisites are determined at the system level. The product level generates product-specific prerequisites and the operational process is carried out at the operational level using the prerequisites available.
- The technical prerequisites are developed to a degree where setups have no operational cost significance and production can be mainly controlled on the basis of orders.
The above principles focus mainly on the production system and processes, but product and producibility are also covered by the model. The aspects of product and producibility include modular product structure, easy purchasing of materials, manufacturability of parts, and assemblability and testability of the product (Lapinleimu 2001, p. 140).

The ideal factory model and theory have been used and applied both in research and practice. They have provided the basis for numerous research projects at the Department of Production Engineering of Tampere University of Technology in the late 90’s and early 2000’s (e.g., PlaNet One - Planning and Control of Networked Production Systems 1, PlaNet Two, Process-MSDD and Ramp Up-MSDD). Also, in the Itä-Suomen Ideaalitehdas project, the ideal factory model and theory were applied in small and medium size production enterprises and their production networks (Tekes 2002).

2.3. Assessment and improvement of production

This section provides a brief overview of assessing and improving production and production systems. Firstly, the focus of improvement and the types of changes sought are considered and, secondly, the typical phases of production improvement processes are presented. Finally, the approaches for assessing and improving production are presented. The discussion provides further clarification of the scope and focus of this study and also assisted the development of the production system assessment tool.

2.3.1. Focus and type of improvement

Production improvement processes and approaches can be considered and categorised on the basis of the focus of improvement and the frequency and impact of the improvement. With regard to the focus of improvement, production is often described as a transformation process which converts inputs to outputs with the help of different resources (Figure 14) (Hitomi 1996, p. 5; Lapinleimu 2001, p. 86-87; Slack et al. 2004, p. 12).

![Figure 14. Elements and overview of production](image)

Based on this description and the figure above, the different aspects or objects of improvement, for example, the inputs and outputs, production process, and production resources, can be identified. In keeping with this, Juuti (2005, p. 24, 29) identifies three basic elements of operational business and objects of improvement: products, operations, and resources. The product category includes both input and output products, for example, purchased materials, components, subassemblies, and end products (Juuti 2005, p. 30-31). Resources enable the operations, i.e. processing input products into output products, and include employees, equipment, facilities, and energy (Juuti 2005, p. 48-49). In considering and describing the focus of this study and the assessment tool, a slightly different categorisation comprising product architecture, production processes, production system, and production outputs was used (Section 1.2.). The main focus in the study is on a production system that provides the required resources for production processes and, hence, corresponds to the resource element in the above categorisations and descriptions. Additionally, some characteristics of the product architecture
and production processes are also considered in this study. These correspond to the product and operations elements presented by Juuti (2005), and the processes and outputs in Figure 14.

Improvement approaches and programs can alternatively be categorised on the basis of the frequency, impact and scale of improvement. Typically two categories, continuous improvement and breakthrough improvement are identified, although authors use slightly different terms for them (Figure 15). Continuous improvement consists of small, incremental improvements and changes that occur frequently or continuously (Miltenburg 1995, p. 159; Slack et al. 2004, p. 652). For example, Imai (1986, p. 3), who sees continuous improvement, Kaizen, as one of the keys to Japanese companies’ success and competitiveness, states that it means ongoing improvements that involve everyone in a company and enable the achievement of higher and higher standards and performance. Improvement programs and approaches belonging to the breakthrough category seek for major, dramatic changes in mode of operation and performance of a company. It is also pointed out that these improvements often involve relatively large investments in technology and equipment. (Imai 1986, p. 6; Miltenburg 1995, p. 159; Slack et al. 2004, p. 652) Although these two categories are distinct, they can and should be combined in order to achieve and maintain the highest possible level of performance (Slack et al. 2004, p. 655).

A somewhat similar categorisation to continuous and breakthrough improvement has been presented by Wheelwright (1984) in the area of production strategy (Section 2.1.2.). The decision categories composing a production strategy are divided into two parts, structural or strategic and tactical, based on the impact and investment perspectives. The structural or strategic categories are capacity, facilities, technology and vertical integration, and decisions in these categories typically have long-term impacts and require substantial capital investment. The other four categories, workforce, quality, production planning and organisation, have a more tactical nature due to the large number of on-going and less capital intensive decisions involved. (Wheelwright 1984, p. 84) Thus, based on these descriptions, breakthrough improvements could be connected with strategic or structural decisions in a production strategy, while continuous improvement can be linked with the tactical decision categories.

With regard to frequency, impact and scale of improvement, the production system assessment tool developed in this study seeks for bigger or breakthrough, rather than minor and continuous, improvements. As the main focus of assessment and improvement is on the production system, the suggested improvements are likely to involve significant changes to the organisation and resources of the production system and to the production processes. Furthermore, the assessment tool and assessment process are intended to be used periodically in order to identify and implement improvements rather than to enable continuous monitoring and improvement of production. Also, regarding the categorisation presented by Wheelwright, in this study assessment and improvement mainly consider the strategic and structural categories of production strategy.
2.3.2. Phases of production improvement processes

Although a number of different approaches to production improvement exist, common phases in the improvement process can be identified. One often used example is the PDCA-cycle developed by Walter Shewhart and popularised by Dr. W. Edwards Deming. The cycle is intended to drive improvement and has been widely applied in production. (Tapping 2008) The PDCA-cycle consists of four phases (Miltenburg 2005, p. 254; Tapping 2008):

- Plan: studying the current situation, identifying problems and developing solutions
- Do: implementing the planned changes and improvements
- Check: evaluating how well the changes and solutions are working and whether targets were achieved
- Act: deciding whether the implemented changes and solutions are adopted as new standards or whether additional changes are required

According to Miltenburg (2005, p. 254), the PDCA-cycle provides the basis for the majority of improvement processes. Here, to clarify and put more emphasis on the initial phases of an improvement process, it is divided into five phases:

- Analysing and assessing the current situation
- Identifying or setting the goals for improvement
- Identifying or planning the required and relevant changes and improvements
- Executing the improvement plans, i.e. making the planned changes and improvements
- Stabilising and standardising the improved status and performance

The first phase aims at clarifying the current status and performance of production and the production system. It involves considering the design and operation of the production system and production processes, and the performance of production. The second phase involves identifying or setting the targets for improvement that can be presented, for example in terms of quantitative objectives of production, such as cost, quality and delivery time, or as practices of production and characteristics of the production system that should be implemented. Then, in the third phase, the required changes and improvements are identified and planned on the basis of the difference or gap between the desired state or target performance and the current state and performance. Similar phases to these are presented, for example, by Miltenburg (2005, p. 103), and Mutafelija and Stromberg (2003, p. 13-14). In some improvement models and processes these three phases are combined into a single phase called, for example, diagnosis (Enos 2000, p. 25-27), preparing (Lanning et al. 1999, p. 328-329) or analysis (Swanson 1996, p. 19-20). In contrast, some authors (e.g., Mutafelija & Stromberg 2003, p. 14) present goal and target setting as the first phase of the process, which is followed by current state analysis. The final phases of the improvement process involve executing the improvement plans and stabilising and standardising the changes and the new way of working in order to maintain the achieved performance level. Standardisation also provides the basis for further improvements. (e.g., Imai 1986, p. 74-78; Lanning et al. 1999, p. 328-329).

As mentioned in Section 1.2., this study focuses on the initial phases of an improvement process, and the production system assessment tool is intended to assist in assessing the current state of production systems and in identifying the potential and means for improvement. Although the detailed planning and execution of the improvements are not included in the scope of this study, the assessment tool and the assessment process and its results are intended to provide the basis for these phases.
2.3.3. Approaches of assessment and improvement

A range of approaches can be applied to the production improvement process, particularly with respect to the analysis and assessment of current status and performance. These include performance measurement, process mapping, benchmarking, and self-assessment.

Performance measurement focuses on the outputs and results of production processes or activities and uses quantitative measures of production objectives such as quality, cost, productivity, lead and delivery time, and flexibility. Literature presents performance measures focusing on certain objective (e.g., Hannula 1999), sets of performance measures (e.g., Maskell 1991), and frameworks for developing and organising performance, for example, the Balanced Scorecard (Kaplan & Norton 1996), the Performance Prism (Neely et al. 2002), and the Performance Pyramid (Lynch & Cross 1991). Performance measures and performance measurement systems can be used to identify processes or activities that require improvement. The results of a measurement can also be used as a basis for setting targets for the improvement process.

A process map presents the components of a process, for example, activities and tasks, and the connections between them. Thus, a process map describes how the process is carried out and how products progress through it. An example of a detailed process map is the Value Stream Map (Rother & Shook 2003), which presents the material and information flow through a process that produces and delivers products to customers. Detailed information about the process and its phases, such as processing times, waiting times and batch sizes, can also be included in the Value Stream Map. A process map or a Value Stream Map provides a visualisation of the current process and how it is operated and enables identifying possible improvement needs. Process mapping also assists in setting improvement targets by enabling the creation of a desired state map of the process.

Benchmarking involves comparing a company or a process against others (Coers et al. 2001, p. 1). More specifically, the practices or performance of a company or a process are compared to those presented in literature or those applied and achieved by other companies or other units of the same company. When searching for benchmarking information, competitors as well as companies operating in different markets and industries can be considered. Benchmarking assists in analysing the current status and performance of production as well as in identifying opportunities and targets for improvement. Benchmarking also aims at identifying best practices that can be adopted or adapted to the company and its processes in order to achieve higher performance. Hence, it also provides means for improvement. (Miltenburg 1995, p. 161; Reider 2000; Coers et al. 2001, p. 1-3; Slack et al. 2004, p. 644-646; Wireman 2004)

Self-assessment can be defined as a review or assessment of the practices and performance of a company with the help of a model or framework. The model or framework used in the assessment presents the areas and issues to be considered and evaluated and usually also includes the related positions of excellence or current best practices. Typical examples of frameworks and models that assist in self-assessment are the various quality awards such as the Malcolm Baldrige National Quality Award and the EFQM Excellence model (Kaye & Anderson 1999, p. 486; Van der Wiele et al. 2000, p. 8). The self-assessment process, with its auxiliary models and frameworks and the positions of excellence and best practices presented in them, assists in evaluating current status and performance and in identifying the need and means for improvement.

These production assessment and improvement approaches assisted in and provided a basis for developing the production system assessment tool self-assessment and benchmarking, in particular, provided useful insights in this study. The self-assessment approach suggests that the assessment tool should be based on a framework that identifies key areas for improvement.
Furthermore, the self-assessment and benchmarking approaches both emphasise the need to identify or produce practices or results that enable comparison, assessment and identifying potential and means for improvement. These conclusions and guidelines are similar to those drawn from production strategy (Section 2.1.).

2.4. Summary and implications

This chapter presented and discussed the theoretical background to this study, namely production strategy, production paradigms, and the assessment and improvement of production. This enabled clarification of the study focus and assisted in pursuing its set objectives.

First part of the chapter covered company and production strategy, the role of production in the context of strategy and competitive advantage, and the links between strategy and production system. The hierarchy of strategies and frameworks such as the Strategy Map were presented. These highlighted the need to align objectives and decisions at different strategy levels, and clarified the role of production in pursuing the strategy and objectives of a company. With regard to the importance of production, Porter (1996) states that excellence of operations and production processes is a necessary although not sufficient condition for implementing a successful strategy and achieving competitive advantage. The central role of production in strategy and in achieving competitive advantage also underlines the importance of improving production systems and of the objectives of this study. Of the generic strategic approaches, efficiency and effectiveness of production play a key role, particularly in best total cost strategies and focused low-cost strategies (Thompson & Strickland 2001; Kaplan & Norton 2004; Miltenburg 2005). Hence, companies implementing such strategies are likely to find the study and its results more beneficial than those whose strategy places less emphasis on production and production efficiency.

The definitions of production strategy and its links with production systems and processes provided inspiration and ideas for the development of the new production system assessment tool. Viewing production strategy as decisions made in key areas of production to enable the achievement of company objectives suggested that identifying the key characteristics of a production system and linking these to production objectives could be useful in assessing and improving production systems. The categorisations presented by Miltenburg (2005) and Wheelwright (1984) then suggested areas of production and production systems and production objectives that should be included in the production system assessment tool and considered in assessment and improvement. Finally, the categorisations of layouts and production systems indicated that a JIT production system and a line or cellular layout are applicable to the target companies of this study.

The second part of this chapter focused on production paradigms and approaches and their objectives and characteristics. The review and its implications can be summarised by comparing this study with four production paradigms and the ideal factory model. In the following figure, mass production, lean production, mass customisation, agile manufacturing, and this study are located based on product variety and process flexibility (Figure 16). The figure also indicates the evolution from mass production towards agile manufacturing as discussed, for example, by Gould (1997), Sharp et al. (1999), Hormozi (2001), and Jin-Hai et al. (2003). Mass production produces limited product variety and focuses on cost reduction, while in lean production higher product variety is produced and continuous improvement of both quality and efficiency is emphasised. Agile manufacturing places increasing emphasis on satisfying customer requirements and surviving or prospering in a rapidly changing market environment. Product variety is therefore broader than in lean production. In terms of process flexibility, mass production and lean production aim at stable and predictable production processes, whereas agile
manufacturing requires much more flexible production processes (Naylor et al. 1999, p. 112). Mass customisation aims to use stable yet flexible processes to provide customised products that meet individual customers’ needs (Pine 1993, p. 218; Tseng & Piller 2003, p. 8). Thus, compared to lean production, mass customisation employs stable but slightly more flexible processes, and provides higher product variety. With regard to agile manufacturing, product variety is seen to be nearly as high but the processes are more stable in mass customisation.

Figure 16. Production paradigms and theoretical background of this study

As Figure 16 indicates, this study was based mainly on the lean production paradigm. The objectives and methods related to lean production were seen to be relevant and beneficial to the companies considered and easier to realize and utilise than, for example, the more challenging and demanding objectives and methods of agile manufacturing. Furthermore, the original focus of lean production was on production and, although the paradigm has evolved and adopted a broader perspective, it still places more emphasis on production and the production system than mass customisation or agile manufacturing. Literature on lean production provides an extensive source of well-reasoned production practices and production system characteristics which were beneficial to the development of the production system assessment tool. However, the need for flexibility of processes and a wider variety of customised products was also noticed in the study, and therefore literature on agile manufacturing and mass customisation were also used. Literature on mass customisation presents valuable ideas and concepts related to product structure, for example, modularity, and production processes, for example, postponement and delayed differentiation, while literature on agile manufacturing suggests methods for realising flexible production processes.

In addition to the production paradigms, the model and theory of the ideal factory provided a useful background and starting point for the study. The ideal factory model demonstrated the possibility of identifying principles and characteristics of production and a production system that are useful and applicable in organising and operating the production of a given type of company. This supported the aim and logic of this study, i.e., to identify key characteristics of a well-performing production system and to use them in assessing and improving production systems. The principles and characteristics of the ideal factory presented by Lapinleimu (2001) also provided a starting point for identifying key characteristics of a well-performing production system. However, clear differences between this study and Lapinleimu’s ideal factory work can be identified. The ideal factory model considers production processes and issues related to products and machines, for example, tolerances and accuracy, in more detail than this study. On the other hand, this study also considered human resources and information systems, which were excluded from Lapinleimu’s research (Lapinleimu 2001, p. 15). More importantly, this study emphasised and focused on assessing and improving a production system, which was only briefly touched on by Lapinleimu and was mentioned as an area requiring further research (Lapinleimu 2001, p. 178).
Finally, the third part of the chapter discussed the focus and type of improvements, and presented phases of an improvement process and approaches for assessing and improving production. Production improvement can be focused on inputs, outputs, processes or resources of production, and seek for continuous or breakthrough improvements. In this study, the primary focus was on the production system, i.e., the production resources and their organisation, and larger improvements. The typical phases of the improvement process were then described and the focus of the study on the initial phase of such process was clarified. Finally, different assessment and improvement approaches were presented and benchmarking and self-assessment were identified as potentially applicable and useful to this study and to the development of a new production system assessment tool.
3. Available tools for assessing and improving production and production systems

This chapter presents the available assessment and improvement tools, models and frameworks that were considered relevant and useful with regard to the focus, scope and objective of this study. Tools, models and frameworks that focus on production, production processes or the production system, or cover these aspects in addition to other areas and functions of a company or network, were included in the review. Furthermore, the aim was to identify and include tools, models and frameworks that have been successfully used in practice. For each tool, model or framework, the review covered the development process, purpose of use or objective, for example, the expected result or benefit, the scope and focus, the structure and content, i.e. what provides the basis for the assessment, and the assessment process. The assessment and improvement tools, models and frameworks were reviewed and are presented here for three reasons: the review highlighted the need and grounds for developing a new production system assessment tool, assisted in pursuing the objectives of this study, and provided a basis for evaluating the developed production system assessment tool (Chapter 7.).

3.1. SHEN model

Development and purposes of use

The SHEN model for make-to-order small and medium sized enterprises and the process of developing the model have been presented by Muda and Hendry (2002a; 2002b; 2003). The model is intended to be a comprehensive performance improvement model that helps companies to determine which performance improvements are needed and how to prioritise them. It was developed using make-to-order literature and world class manufacturing models. The model of world class manufacturing presented by Schonberger (1996) was found to be among the most comprehensive performance improvement models in literature and was taken as a starting point in developing the SHEN model. (Muda & Hendry 2003, p. 471)

Scope and focus

With regard to the scope and focus of the tool and improvement, the model is intended to be comprehensive and to bring together many aspects of operations management (Muda & Hendry 2003, p. 470-471). Thus, the model takes a broad perspective on the supply chain and the order-to-delivery process and includes marketing, product design and supplier relationships as well as production.

In terms of the target companies, the model is developed for make-to-order companies, which are defined as producing high variety of products in relatively low volumes. The definition used states that in the make-to-order approach, products are produced on the basis of customer design and specification, and therefore production can be started only after the customer places an order. Furthermore, companies that produce products which have been designed before an order but can be modified according to the order are not included in the make-to-order approach. (Muda & Hendry 2002a, 353-354) With regard to the definitions presented in this study, the companies considered by Muda and Hendry are engineer-to-order companies as each product is designed and produced according to an order. On the other hand, in this study, make-to-order is defined as an approach in which products are designed before the order, but are customised and produced based on an order.
Structure and content of the tool

The SHEN model consists of 12 principles and each principle comprises five levels (Appendix 1). Level one is the first step on the road to improvement, and level five relates to current best practice performance. (Muda & Hendry 2003, p. 471) The principles are categorised into four sections: generate enquiries/sales, operations and capacity, human resources, and general continuous improvement.

Assessment process

The SHEN model is intended to assist companies in the development of appropriate improvement programmes, and to help in assessing their current performance and practice alongside potential future levels of attainment. The focus is on considering whether the company operates according to the principles and related best practices presented in the model. Thus, the principles and the associated five levels provide a benchmark that enables the company to determine whether it is operating best practice make-to-order procedures. The principles for which the company achieves the highest levels are its areas of strength, while the principles ranked lowest identify areas in which improvements could be made. With regard to the assessment results, the aim of the model and the assessment process is to assist in identifying improvement needs and in developing improvement programmes, rather than making a value judgement regarding the current status. The principles and their associated steps assist in generating goals and guidelines for change and improvement based on the assessment results, but the actual assessment score is not intended to carry any further meaning. (Muda & Hendry 2003, p. 484-485; Muda & Hendry 2002a, p 365)

The SHEN model seems to be intended for self-assessment. This is indicated, for example, by the identified need to develop a workbook to support company personnel in carrying out the assessment and in devising improvement programmes (Muda & Hendry 2003, p. 485). However, the assessment process can also be facilitated or carried out by people external to the company. The six assessment cases presented by Muda and Hendry (2002a, p. 365-366) were carried out by the researchers themselves and data was collected using factory observations and semi-structured interviews. The interviews covered 20 major topics and 50 questions and the interviews were carried out at three levels, top level management, shop floor management, and shop floor worker level, and a separate questionnaire was developed for each level. After the data was analysed and the strengths and potential areas of improvement were identified, the results were reported back to the company in a meeting with top level management. (Muda & Hendry 2002a, p. 365-366)

3.2. Supply Chain Maturity Assessment Test

Development and purposes of use

The Supply Chain Maturity Assessment Test (SCMAT) has been presented by Netland and Alfnes (2008) and Netland et al. (2007). The main objective of the SCMAT tool is to rapidly identify improvement areas during the initial stage of a company’s supply chain improvement project (Netland & Alfnes 2008, p. 3). In addition, the tool can be used to map the degree of maturity of a firm’s supply chain activities at the strategic and operational level, and to communicate the degree of maturity in a logical and easy-to-understand style (Netland et al. 2007, p. 2). In developing the tool, 15 requirements related to the characteristics and use of the tool were identified on the basis of a literature review. These include, for example: addresses a company’s supply chain operations, is industry-generic and enables cross-industry comparison, spans several business functions, does not require a large amount of detailed data, does not take a long time to complete, and focuses on business processes (Netland & Alfnes 2008, p. 3). A
literature review on maturity models, maturity tests and self-assessment frameworks was carried out during the building of the SCMAT tool, and the content of the tool is based on a review of best practices in supply chain operations (Netland & Alfnes 2008, p. 3-4).

Scope and focus
The objectives and requirements for the tool indicate that the tool takes a holistic view and approach to improving a supply chain. It considers the entire supply chain from suppliers to customers and covers several business functions, such as product design and development, purchasing, production, distribution and strategic planning. The target companies are not defined and limited. Instead, the tool is intended to be applicable to various types of companies and to be industry-generic.

Structure and content of the tool
The SCMAT tool consists of best practices in supply chain operations and a maturity model. The tool presents 50 best practices that describe the state-of-the-art of how to perform a business (Appendix 2). The best practices are separated into seven categories: strategy, control, processes, resources, materials, information, and organisation. (Netland et al. 2007, p. 3; Netland & Alfnes 2008, p. 4-5) The maturity model then presents five maturity levels related to the extent to which the supply chain uses a given best practice. The levels are 1) never or does not exist, 2) sometimes or to some extent, 3) frequently or partly exist, 4) mostly or often exist, and 5) always or definitely exist. These maturity levels are used for all the best practices that are evaluated, and the highest level corresponds to world best practice. (Netland et al. 2007, p. 4; Netland & Alfnes 2008, p. 4)

Assessment process
In the basic procedure, the maturity assessment is carried out as a self-assessment by a team of company representatives who provide experience-based responses regarding each best practice. The assessment can also be facilitated by researchers, if needed. In the assessment, the extent to which the supply chain uses each best practice included in the tool is evaluated using the five maturity levels. The results can be analysed in various ways, but a quick analysis focusing on the practices that have improvement potential (maturity levels 1-2) or are at a high level of maturity (4-5) is recommended. The assessment process thus enables rapid evaluation of the current maturity level of the supply chain, and can quickly indicate directions for supply chain improvement projects. In addition to this basic procedure, four other test procedures have been identified: gap-analysis (as-is and to-be), counterpart triangulation, third-party triangulation, and maturity benchmark study. The developers of the SCMAT tool state that the tool has been used in a number of Norwegian companies in various industry sectors including food, furniture, sports equipment and automotive industry, and that positive feedback has been received. (Netland & Alfnes 2008, p. 7-9)

3.3. Productivity Potential Assessment Method

Development and purposes of use
The Productivity Potential Assessment (PPA) method, presented by Almström and Kinnander (2007; 2008), has been developed to measure and study the productivity potential of a company based on actual performance on the shop floor. It also provides the possibility of comparing data and results between different companies. The method is intended to enable identification of a
company’s strengths, weaknesses, and improvement potential. The developers aim to establish the method as a de facto standard for assessing productivity potential in the Swedish production industry. (Almström & Kinnander 2007; 2008)

**Scope and focus**
Productivity improvement can be focussed on methods, performance and utilization rate. With regard to these, the PPA method focuses mainly on the utilization of labour and machines and on shop-floor operations, but also includes an overall analysis of the production system and production.

In terms of target companies, the method has been developed for Swedish industry and is intended to be applicable to a large range of production companies, regardless of size, line of business, or product type. An international version of the method is also under development. (Almström & Kinnander 2007; 2008)

**Structure and content of the tool**
The PPA method and assessment process are divided into four levels. At the first level, the focus is on efficiency of manual and machine work. Manual work is measured by means of work sampling within a selected production unit of a factory, while machine efficiency is measured through overall equipment effectiveness (OEE). At the second level, productivity at the corporate level is considered on the basis of inventory turnover, delivery accuracy, scrap rate, and customer reject rate. At level three, the company’s and its management’s ability to run and develop production is considered in two parts. Firstly, the level of production engineering is evaluated using 40 questions grouped into 11 topics: strategy goals, work methods, maintenance, competence, cleanliness and order, material handling, change over, continuous improvements, calculations, planning, and quality. The second part of the third level considers the physical work environment, ergonomics and the psycho-social work environment by means of a questionnaire. At this level, personnel turnover, short-time absence, and total absence due to illness are also considered as a poor working environment is assumed to negatively affect productivity through increased absences and personnel turnover, low motivation, and discontent. Finally, at level four, the methods and related improvement potential are evaluated in an informal manner by the analyst. The PPA method also includes a database of assessment and analysis data which facilitates benchmarking and comparisons between companies. (Almström & Kinnander 2007)

**Assessment process**
The assessment process is standardised and is carried out during a single day by two certified analysts. One analyst is responsible for collecting and assessing the majority of the parameters and getting an overview of the factory and the company. This requires interviews with the factory management, observations during a factory tour, and examining documentation. The other analyst carries out the work sampling study in which 480 samples are taken during 4 hours and the activities are classified into value adding, supporting and not value adding. In addition, the other analyst makes observations of the work place and the work method and performs the work environment study by means of observation and operator interviews. An overall analysis is then conducted and the study is documented using a report template. The results regarding the company’s productivity potential and means to utilize this potential can then be presented to the company management during the same day. (Almström & Kinnander 2007) At least 60 studies have been conducted using the PPA tool since the launch of the method in 2005 (PPA Online 2009).
3.4. Lean Enterprise Self-Assessment Tool

Development and purposes of use

The Lean Enterprise Self-Assessment Tool (LESAT) is a tool for self-assessing the leanness of an enterprise and its readiness to change. The tool has been developed by an industrial, governmental and academic joint team under the auspices of the Lean Aerospace Initiative at Massachusetts Institute of Technology, and is closely connected with two other tools, the Lean Enterprise Model and the Enterprise Transition to Lean Roadmap (Nightingale & Mize 2002, p. 15). The key requirements identified during the tool’s development include (Nightingale & Mize 2002, p.19):

- Must assess degree of leanness for an enterprise and all its core processes
- Must provide feedback for improvement, guidance for next steps
- Must be data-driven, based on documentable evidence
- Should be flexible to allow assessment of varying organizational scope
- Should be understandable and easy to apply
- Should align with business planning process
- Should accommodate various partnership arrangements for an enterprise

Scope and focus

The focus of the tool is at the enterprise level, and it is meant to highlight the key integrative practices at the uppermost level of an enterprise (Nightingale & Mize 2002, p. 21). The tool aims to take a broad overview of an enterprise, covering transformation and leadership and related processes, lifecycle processes that are responsible for the product from conception through to post delivery support, as well as enabling infrastructure (MIT 2001, p. 1). The enterprise assessed can be a business unit, a division, an entire company, an aligned organisation such as a partnership, or a supply chain network. In terms of industry sector, the tool can be adapted and used for a wide variety of industries, although it was initially developed in the aerospace industry environment (Nightingale & Mize 2002, p. 21, 27).

Structure and content of the tool

The LESAT tool includes 54 best practices (Appendix 3) and a maturity model. The best practices are not intended to be all-inclusive, but assessing an enterprise against these practices is argued to provide a good overview of how well the enterprise is progressing along the lean journey (Nightingale & Mize 2002, p. 21). The best practices are organised into three sections. The first section, Lean transformation and leadership, focuses on processes and leadership attributes that nurture the transformation of an enterprise to a lean enterprise and the transformation to lean principles and practices. The second section, Life cycle processes, covers the processes that are responsible for the product from conception through to post delivery support, and that directly determine the value provided to customers. This second section is further divided into six areas: business acquisition and program management, requirements definition, develop product and process, manage supply chain, produce product, and distribute and service product. The third section, Enabling infrastructure, covers the processes that provide and manage the resources enabling enterprise operations.

Capability Maturity Matrices are also included in the tool to enable the assessment. Five levels of maturity are employed, with the first level indicating least capable and level 5 indicating most capable or world-class performance. Five maturity statements have been developed for each of the best practices included in the tool. These make it possible for an enterprise to assess itself on
each performance factor and to determine the means for elevating the organization to the next level of capability. (Nightingale & Mize 2002, p. 23)

Assessment process
The LESAT tool is designed for use in self-assessment by the leadership of an enterprise. The assessment begins with a meeting in which the tool is introduced, usually to the enterprise leader and the management team. The attendees then perform the assessment in collaboration with their personnel by addressing all 54 Lean practices included in the tool. Assessment sheets are used and the current capability and desired capability are determined. The scores of different groups are consolidated and summarised by a LESAT facilitator, and figures such as high, low, average and range of scores are presented. The results clarify the current situation and capability of the enterprise, and indicate the directions for lean transformation. Differences in perception between groups can also be highlighted and discussions regarding the assessment score and differences in perception often prove to be more valuable than the LESAT score itself. (Nightingale & Mize 2002, p. 26-27) The tool was tested in twenty companies in the U.S. and U.K. during its development phase, and the experiences and feedback from these trials have demonstrated the tool’s utility, effectiveness and ease of use (Nightingale & Mize 2002, p. 15, 21).

3.5. Malcolm Baldrige National Quality Award

Development and purposes of use
The Baldrige National Quality Program provides the Baldrige Criteria for Performance Excellence, which is an integrated management framework that can be used by an organisation to assess and improve its performance. More precisely, Performance Excellence refers to an integrated approach to organizational performance management that results in the delivery of ever-improving value to customers and stakeholders, contributes to organizational sustainability, and improves overall organizational effectiveness and capabilities as well as organizational and personal learning. Furthermore, the Baldrige Criteria are intended to help an organisation to improve its ability to think and act strategically, to align its processes and resources, to engage its workforce and customers, and to focus on key results. The criteria are also used in evaluating an organisation for the Baldrige Award. (BNQP 2009)

Scope and focus
The Baldrige Criteria is intended to be inclusive, i.e. to address all factors defining the organization, its operations and its results. The criteria can be used by large and small businesses, by organizations based either in one location or worldwide, and in different sectors of operation. (BNQP 2004, p. 1-2) The criteria thus address an organisation, its operations and improvement from a broad perspective, and aim to be applicable to all types of organisations.

Structure and content of the tool
The Baldrige Criteria consist of approximately 100 questions grouped into seven categories. Categories 1 to 6 focus on key processes and how they work, and cover leadership and strategic planning, marketing and customer relationships, human resource management, design, management and improvement of production, delivery and support processes, and the organisation’s performance management system and its use. Category 7 focuses on the organization’s performance in key areas and on comparing performance with competitors. The
seven categories are further divided into items and areas to address, which contain the questions. (BNQP 2004, p. 4-5; NIST 2009)

Using the Baldrige Criteria

The Baldrige Criteria for Performance Excellence can be used in various ways, for example as a self-assessment that enables identification of an organization’s strengths and opportunities for improvement and the development of an action plan. Alternatively, the criteria can be used to educate the organisation with respect to performance improvement and the principles of performance excellence. (BNQP 2004, p. 6) The recommended procedure for self-assessment involves selecting a “champion” for each of the Baldrige Criteria categories. The champions then lead a team in preparing information and responses to the questions within their criteria category. Based on these responses and using set worksheets, the teams then identify strengths and opportunities, develop action plans and prioritise them. The self-assessment process is expected to take one or two days. (BNQP 2005, p. 10-11) The Baldrige Criteria have been used by a huge number and range of organizations for self-assessment, training, and performance and business process development. Several million copies of the criteria have been distributed since the first edition in 1988, in addition to which heavy reproduction and electronic access has considerably multiplied its distribution. (NIST 2009)

3.6. Production System Design Framework

Development and purposes of use

The Production System Design (PSD) framework, previously called the Collective System Design (CSD) Toolset, has been presented by Torvinen et al. (2004) and Britton et al. (2007). The PSD framework and the tools included in it are based on three separate study lines and concepts: the Manufacturing System Design Decomposition (Cochran 1994), the Ideal Factory concept (Lapinleimu 2001; see also Section 2.2.4.) and the Ideal Process Planning concept (Britton et al. 2001). The PSD framework is a decomposition model. In the development of the model, design requirements have been developed level-by-level, from a company’s high-level requirements down to shop-floor methods and solutions to help achieve the requirements. The development process has involved following steps: stating the functional requirements and the physical solutions to achieve the requirements, defining the relationships and influences between the requirements and solutions so that an uncoupled, path-dependent design is achieved, and finally defining the attributes that describe the degree to which a requirement has been achieved. (Britton et al. 2007, p. 148)

The PSD framework is based on the lean production paradigm and emphasises stable production systems and processes, and reduction of non-value-adding work. A stable production system is defined as a system that meets the following requirements (Cochran 1994; Torvinen et al. 2004, p. 1):

- Produce the customer-consumed quantity every shift (time interval)
- Produce the customer-consumed mix every shift
- Ship perfect-quality products to the customer every shift
- Achieve the above requirements in spite of operation variation
- When a problem occurs, identify the problem condition immediately and respond in a standardized and pre-defined way
- Provide a safe, clean, quiet and ergonomically sound environment
The PSD framework is intended to (Torvinen et al. 2004, p. 15-16):

- Provide a language to effectively communicate a design
- Relate high-level management objectives to low-level, shop floor activities and decisions
- Clearly define relationships between requirements and solutions within the production system
- Support the analysis and explanation of strengths and weaknesses in production systems
- Provide a communication platform (common mental model) for the entire organization
- Assist in justification of systemic costs and improvements

Thus, in addition to assessing a production system, the framework assists in designing a production system and in presenting and communicating the decisions made during the design process.

**Scope and focus**

The PSD framework focuses on production but takes a broad perspective that includes product development, production system design, and shop-floor activities and operations. According to Torvinen et al. (2004, p. 41), the approach starts from product design for producibility and production system design, which include architectural and detailed design of products, process and flow planning, and operations planning. Furthermore, the processes within the production system, the work content of operators, working environment, and finally management of investments are also considered within the framework (Torvinen et al. 2004, p. 41). The PSD framework is intended to be scalable and the context in which the framework is used can be a network, a factory, a cell or a work station (Torvinen et al. 2004, p. 5; Britton et al. 2007, p. 149).

The type of companies for which the framework is developed is not explicitly presented. However, it can be assumed that, similarly to the MSDD tool (Section 3.7.) that has been used as a basis for developing the PSD framework, the framework can be used for designing and developing production systems for discrete-part, repetitive production.

**Structure and content of the tool**

The PSD framework offers a software system and a set of tools for designing, re-designing, analysing and developing stable production systems. It consists of three building blocks: Product Design for Producibility, Manufacturing System Design Decomposition, and 5S. These building blocks should enable consideration of long-term decisions resulting in the basic structure of a production system that provides a stable and predictable output for the customer, as well as short-term decisions concerning continuous process improvement. (Torvinen et al. 2004)

The PSD framework also includes a maturity model that is used in assessing a company’s or network’s capability. The maturity model presents six levels that are defined and described as follows (Torvinen et al. 2004, p. 30):

0. Ad hoc operations, large deviations in all activities, targets achieved with a large amount of effort.
1. Best practice pilots to stop the bleeding exist, deviations locally in control.
2. Best practices documented and standardized.
3. Controllable processes achieved by practicing standardized work.
4. Adjustable operations flexibly manageable, also according to changing requirements.
5. Continuous improvement to achieve process perfection.
The maturity model presents journeys which specify how to move from one maturity level to the next (Torvinen et al. 2004, p. 19). The framework also includes an assessment questionnaire containing a set of questions categorised into levels from 1 to 5 for each pair of functional requirements and physical solutions (Torvinen et al. 2004, p. 30).

Assessment process
Production system assessment based on the PSD framework is carried out using a questionnaire. The assessment results provide a maturity level definition describing the company’s ability to achieve the functional requirements presented in the framework. With regard to improvement, the assessment enables identification of key issues in a company or network, and the journeys describe the best ways to achieve the next level of maturity. (Torvinen et al. 2004, p. 4) Furthermore, Britton et al. (2007, p. 149) point out that changes can be made incrementally by focusing on certain key issues at a time, or radically by changing many features of the company or network at the same time. According to Britton et al. (2007, p. 147), the PSD framework has been used successfully with 17 Finnish companies.

3.7. Manufacturing System Design Decomposition Model

Development and purposes of use
The Manufacturing System Design Decomposition (MSDD) model, developed by the Production System Design Laboratory of the Massachusetts Institute of Technology, is intended mainly to assist in designing or re-designing a production system, or in analysing an existing production system (Cochran et al. 2001; Cochran & Dobbs 2001, p. 390). The concepts and ideas included in the MSDD model are derived from literature on production system design, lean production and the Toyota Production System, and other frameworks focusing on production systems and production strategy (Cochran et al. 2001, p. 375).

The MSDD model serves four major purposes (Cochran et al. 2001, p. 372-373; System Design 2008):

- Clearly separate objectives from the means of achieving them
- Relate low-level activities and decisions to high-level goals and requirements
- Understand the interrelationships among the different elements of a system design
- Effectively communicate this information across the organization

Cochran et al. (2001, p. 372) emphasise that achieving the strategic objectives of a company requires that the production system is designed according to these precepts.

Scope and focus
The MSDD model focuses on the shop floor aspects of production systems and is intended to assist in production system design, which, according to Cochran and Dobbs (2001, p. 390) and Cochran et al. (2001, p. 372), covers all aspects of the creation and operation of a production system. Creating the system includes equipment selection, physical arrangement of equipment, work design, and standardization; while operation includes all aspects that are necessary to run the production system, such as planning, scheduling, and execution of orders (Cochran & Dobbs 2001, p. 390-391; Cochran et al. 2001, p. 327; System Design 2008). On the other hand, aspects such as product design and marketing are not directly within the scope of the MSDD (System Design 2008). With regard to companies and industry sectors, Cochran and Dobbs (2001, p. 390) state that the MSDD decomposition applies to a wide variety of production systems in different
competitive environments, but that it is particularly suitable for medium to high volume repetitive production.

**Structure and content of the tool**

The MSDD model is an axiomatic design-based decomposition that presents a general set of functional requirements for a production system, as well as design parameters that serve as the means of achieving the requirements. The decomposition distinguishes six general functions of production systems, and the MSDD model is divided into six branches: quality, identifying and resolving problems, predictable output, delay reduction, operational costs, and investment. (Cochran et al. 2001, p. 377-378; System Design 2008)

**Using MSDD to assess production systems**

With regard to designing or evaluating a production system, the hypothesis is that a production system design that achieves the functional requirements included in the MSDD model will perform more cost effectively than a production system design that does not achieve the functional requirements (Cochran & Dobbs 2001, p. 391). Thus, the functional requirements are used to evaluate the design and organisation of a production system, while the design parameters provide the ideas and means for improving production system design and production performance. The MSDD model also provides assessment questions and measures related to functional requirements and design parameters.

**3.8. Supply Chain Operations Reference Model**

**Development and purposes of use**

The Supply Chain Operations Reference-model (SCOR) is a process reference model that integrates the well-known concepts of business process reengineering, benchmarking and process measurement into a cross-functional framework. It has been developed and endorsed by the Supply Chain Council as the cross-industry standard diagnostic tool for supply chain management to enable users to address, improve and communicate supply chain management practices within and between all interested parties. (Supply Chain Council 2008, p. 1; Supply Chain Council 2009a) With regard to using the SCOR model, once a management process is captured in a standard process reference model, it can be implemented purposefully to achieve competitive advantage, described unambiguously, communicated, measured, managed and controlled, and tuned and re-tuned to a specific purpose (Supply Chain Council 2008, p. 2).

**Scope and focus**

The SCOR model is a cross-industry model that spans all customer interactions from order entry through to paid invoice, all product transactions including equipment, supplies, spare parts, bulk product and software from supplier’s supplier to customer’s customer, and all market interactions from the understanding of aggregate demand to the fulfilment of each order (Supply Chain Council 2008, p. 3). Thus, the SCOR model is not limited to a certain type of company or to a certain industry, and it takes a broad perspective with respect to the supply chain.
Structure and content of the tool

The SCOR model is based on five distinct management processes and it presents three levels of process detail. The processes are:

- **Plan**: processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements
- **Source**: processes that procure goods and services to meet planned or actual demand
- **Make**: processes that transform product to a finished state to meet planned or actual demand
- **Deliver**: processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management
- **Return**: processes associated with returning or receiving returned products for any reason. These processes extend into post-delivery customer support

The three levels of process detail are top level, configuration level and process element level. In terms of level of detail, the implementation level, i.e. the level at which companies implement supply chain management practices that are unique to their organizations, is not included in the scope of the SCOR model. (Supply Chain Council 2008, p. 7-8) In terms of content, the SCOR model contains standard descriptions of management processes, a framework of relationships among the standard processes, standard metrics to measure process performance, management practices that produce best-in-class performance, and standard alignment to features and functionality (Supply Chain Council 2008, p. 2).

Using the SCOR model

The SCOR model enables supply chain modelling in a variety of ways. Different model types include a business scope diagram that can be used to set the scope for a project or organization, a geographic map that describes material flows in a geographic context, a thread diagram that presents material flow, and workflow or process models that present information, material and work flow at the process element level (Supply Chain Council 2008, p. 16). The SCOR model also includes strategic metrics and performance attributes that can be used in analysing and improving a supply chain. The strategic metrics are presented at three levels and they can be used to measure how successful a company or a supply chain is in achieving their desired positioning within the competitive market space, and to diagnose variations in performance against plan. The metrics are used in conjunction with performance attributes that are characteristics of a supply chain, and enable analysis and evaluation against other supply chains with competing strategies. (Supply Chain Council 2008, p. 14) Furthermore, management practices that produce best-in-class performance are included in the SCOR model, and these assist in identifying objectives and means for improvement. The Supply Chain Council (2009b) states that the SCOR model is the most widely accepted framework for evaluating and comparing supply chain activities and their performance.

3.9. EFQM Excellence Model

Development and purposes of use

The EFQM Excellence Model is a non-prescriptive framework for understanding the connections between what an organisation does and the results it is capable of achieving. The model can be used to assess an organisation and its progress towards excellence. It allows the organisation to identify its strengths and areas in which improvement can be made. On the basis of these,
improvement plans can be launched and progress can be monitored. Furthermore, using the model and the assessment, an organisation can learn what excellence means to the organisation and how it compares with other organisations. (EFQM 2003, p. 9; Hides et al. 2004, p. 195)

Scope and focus
The EFQM model takes a broad perspective on an organisation, considering its strategy, leadership, resources, partnership, processes, and results achieved. The model can be used by large and small organisations in the public or private sector. (EFQM 2003, p. 4-5)

Structure and content of the tool
The key elements of the EFQM model are the nine criteria on which the framework is based, the RADAR logic and the Fundamental Concepts of Excellence. The nine criteria are divided into enablers that consider how the organisation undertakes key activities, and results that are achieved. The enablers include leadership, people, policy and strategy, partnerships and resources, and processes. The results are divided into people, customer, society, and key performance results. The logic of the model is that excellent results are achieved through leadership driving a policy and strategy that is delivered through people, partnerships and resources and processes. Furthermore, it is assumed that improving enablers leads to improved results. (EFQM 2003, p. 5) The RADAR logic defines the learning cycle necessary for effective change management and provides a scoring framework for evaluating an organisation (EFQM 2009). The elements of the RADAR logic are Results, Approach, Deployment, Assessment and Review. The Results element is used when assessing results criteria and the other four elements are used when assessing enabler criteria. (EFQM 2003, p. 5) Finally, the model is underpinned by the Fundamental Concepts of Excellence, which include: results orientation, customer focus, leadership and constancy of purpose, management by processes and facts, people development and involvement, continuous learning, innovation and improvement, partnership development, and corporate social responsibility (EFQM 2003).

Using the EFQM model
The assessment process enabled by the EFQM model can be conducted in different ways, for example, as a self-assessment, external assessment or global assessment (EFQM 2009). Furthermore, self-assessment can follow various approaches and can be carried out, for example, using a questionnaire or a matrix chart or in a workshop (Hides et al. 2004, p. 196). According to EFQM (2009), the EFQM Excellence Model is the most widely used organisational framework in Europe.

3.10. ABO Framework
Development and purposes of use
The study presented by Juuti (2005) aimed at developing a method to identify concrete and sufficiently detailed development actions which optimise the order-delivery process and are derived from higher-level strategic goals of the business activity and the organisation. The key requirement of the method was that it should enable performance analysis based on operational success factors derived from the competitive strategy of the organisation under study. Furthermore, the ability to identify development potential linked to optimisation of the existing mode of operation, as well as factors preventing optimal performance was required. (Juuti 2005, p. 22).
Scope and focus
The method and framework focus on developing operations. Moreover, the focus is on the operational capability of the order-delivery process for physical products, covering all operations from customer order receipt to product creation and delivery to the customer. (Juuti 2005, p. 21, 24) With regard to the development and optimisation of the order-delivery process, the focus is on quality of operations, resource costs, and process speed (Juuti 2005, p. 23). The company types or industry sectors for which the method is intended are not specified in detail, although the focus is stated to be on companies and order-delivery processes that produce physical products.

Content and use of the ABO framework
The framework presents approaches for stabilising the order-delivery process and for optimising its performance with regard to operational success factors. In evaluating and ensuring the stability of a process, a maturity model is used. The Capability Maturity Model developed by the Software Engineering Institute at the Carnegie Mellon University is adopted, and the maturity levels are: initial, repeatable, defined, managed and optimising. In stabilising a process, the aim is to bring the process maturity to level 4, i.e. managed. (Juuti 2005, p. 47, 123) The optimisation approaches and methods also include analyses and measures for identifying development objectives and development actions (Juuti 2005, p. 121). The identification of development objectives is mainly based on quantitative performance measures. The framework can be used in-house or with the help of external experts. At its best, the framework works as an expert’s tool kit, from which it is possible to select appropriate tools to meet the need at hand. (Juuti 2005, p. 23, 225)

3.11. Model for Assessing Changes Towards Lean Production

Development and purposes of use
Karlsson and Åhlström (1996) present an operationalised model that can be used to assess changes towards lean production (Karlsson & Åhlström 1996, p. 24, 41). In developing the model, the important principles contained within lean production were summarised on the basis of the book The Machine that Changed the World (Womack et al. 1990). Determinants capable of reflecting changes in efforts to become lean were then developed for each of the principles with the help of available theory. Finally, these determinants were operationalized into a measurable format. (Karlsson & Åhlström 1996, p. 24, 26)

Scope and focus
The focus of the model is on the production function of a company or, more specifically, on the work organisation within the production part of a company. The model’s target company type and industrial sector are not specified.

Content of the model
The model consists of nine principles of lean production, with measurable determinants identified for each. With regard to improving performance, it is implicitly assumed that performance can be enhanced by introducing lean production. Furthermore, lean production is seen as an intended direction rather than a certain state to be achieved. Thus, the aim is to consider and measure progress made in the effort to become lean, and therefore the focus of assessment is on changes rather than the absolute values of the determinants of lean production. To enable such assessment, the desired direction of movement towards lean production is presented for the measures or indicators of each determinant. In some cases, instead of using quantitative measures and indicators, the determinant is elaborated into breakdown points and
the desired direction of change and improvement are presented. (Karlsson & Åhlström 1996, p. 24, 26, 27) The following list presents the principles included in the tool and briefly explains the determinants of each principle (Karlsson & Åhlström 1996, p. 27-40):

- Elimination of waste: emphasises reduction of work in progress, lot sizes, set-up times, machine down time and transportation
- Continuous improvement: considers suggestions from employees and the organisation of improvement activities
- Zero defects: covers responsibility for identification and adjustment of defective parts, number of people dedicated to quality control department, degree of process control, autonomous defect control and size of adjustment and repair area
- Just-in-time: emphasises reduction of lot sizes, work in progress and order lead time and considers progress with regard to three levels of implementing the just-in-time principle
- Pull instead of push: emphasises increase in backward request in relation to forward scheduling as well as in degree of pull scheduling
- Multifunctional teams: covers team and task structure, job classification, task rotation and training
- Decentralized responsibilities: the determinants are supervisory task performed by the teams, team leadership, organisation hierarchy and areas of responsibility
- Integrated functions: considers support functions and work content in teams
- Vertical information systems: the determinants focus on mode of information provision, strategic and operational content in information and information frequency

Using the model

The model can be used by managers to follow the progress of efforts to introduce lean production or as a checklist for what to aim for when striving to implement lean production (Karlsson & Åhlström 1996, p. 24). The model provides answers to questions such as: Are the actions taken in the direction of lean production? What progress are we making on different variables? (Karlsson & Åhlström 1996, p. 41).

3.12. Summary

The following table (Table 2) provides an overview of the assessment and improvement tools, models and frameworks presented in the previous sections by summarising the following aspects of each tool, model or framework:

- Scope and focus of assessment: the focus of assessment and improvement in terms of processes and functions and the scope of assessment and improvement, e.g., a company or network of companies
- Target companies: the types of companies or industrial sectors for which the tool or model has been developed
- Theoretical background: the approach, philosophy or paradigm on which the tool or model and the objectives of assessment and improvement are based
- Content of the tool or model: what provides the basis for the assessment and improvement, how the tool is structured
- Assessment approach and process: what is the assessment approach, how is the assessment process carried out, and what are the main results or benefits of the assessment
<table>
<thead>
<tr>
<th>Tool or model</th>
<th>Scope and focus</th>
<th>Target companies</th>
<th>Theoretical background</th>
<th>Content of the tool</th>
<th>Assessment methods and approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCMAT test</td>
<td>Supply chain.</td>
<td>Industry-generic.</td>
<td>Literature on supply chain management and improvement, supply chain best practices.</td>
<td>Best practices and five-level maturity model. Highest maturity level corresponds to world best practice.</td>
<td>Self-assessment or facilitated assessment. The extent to which best practices are used is evaluated. Assessment results indicate current maturity level and required directions for improvement.</td>
</tr>
<tr>
<td>PPA method</td>
<td>Main focus on productivity and utilisation of labour and machines. Considers also productivity at corporate level and company’s ability to run and improve production.</td>
<td>Generally applicable to Swedish production industry and companies. International version currently under development.</td>
<td>Productivity and productivity assessment.</td>
<td>Tools and methods for productivity assessment divided into four levels.</td>
<td>Standardised assessment process carried out by two analysts. Results indicate productivity potential and the means to utilise it.</td>
</tr>
<tr>
<td>LESAT tool</td>
<td>Broad overview of an enterprise e.g., company or a supply chain network. Considers transformation, leadership and lifecycle processes as well as enabling infrastructure.</td>
<td>Initially developed for aerospace industry, but applicable to a wide variety of industries.</td>
<td>Lean production.</td>
<td>54 best practices divided into three sections. Capability Maturity Matrices with five levels of maturity, the highest indicates most capable or world-class performance.</td>
<td>Self-assessment by teams. Current and desired capability related to the best practices is determined. Results clarify current situation and directions for improvement and lean transformation.</td>
</tr>
<tr>
<td>Baldrige Award and Criteria</td>
<td>All factors that define an organisation, its operations and results.</td>
<td>Applicable to all industries and all types of companies.</td>
<td>The Criteria are at the leading edge of validated management practices. Theoretical background is not clearly stated.</td>
<td>Approximately 100 questions grouped into seven categories.</td>
<td>Self-assessment or external assessment. Assessment enables identification of strengths and opportunities and development of action plans.</td>
</tr>
<tr>
<td>PSD framework</td>
<td>Broad perspective on production system design from product development to shop floor operations. Scalable from network level to work station level.</td>
<td>Discrete-part, repetitive production systems. Target company type or industry sector not specified.</td>
<td>Lean production, production system design literature.</td>
<td>Three building blocks, Product Design for Productibility, Manufacturing System Design Decomposition, and 5S, that present functional requirements and physical solutions for the design process. A six-level maturity model that also presents journeys from one level to the next.</td>
<td>Self-assessment or facilitated assessment. Questionnaire based assessment. Results are presented using the maturity model and enable identification of potential and the means for improvement.</td>
</tr>
<tr>
<td>Model</td>
<td>Description</td>
<td>Context</td>
<td>Features</td>
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<tr>
<td>MSDD model</td>
<td>Design and organisation of a production system, production processes.</td>
<td>Medium to high volume repetitive production. Applicable also to a wider variety of production systems in different environments.</td>
<td>Lean production, literature on production systems and production strategy. Divided into six branches that present functional requirements and design parameters for a production system. The production system and its design are assessed with a questionnaire and assessment measures and by considering whether or how well functional requirements are achieved.</td>
<td></td>
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<tr>
<td>SCOR model</td>
<td>Supply chain from supplier’s supplier to customer’s customer.</td>
<td>Cross-industry model, not limited to certain company type or industry.</td>
<td>Developed on the basis of and captures the Supply Chain Council’s consensus view of the state-of-the-art in supply chain management systems and practices. Model is based on five distinct management processes and presents three levels of process detail. The model contains descriptions of processes, performance measurement metrics and management practices. The descriptions and models of processes, metrics and management practices enable supply chain modelling, analysis and various means of improvement.</td>
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<tr>
<td>EFQM model</td>
<td>Organisation viewed from a broad perspective.</td>
<td>Applicable to a wide variety of organisations in different sectors.</td>
<td>Theoretical background not specified. Model developed by the EFQM in collaboration with similar national organisations in Europe. Three key elements: nine criteria divided into enablers and results, RADAR logic and the Fundamental Concepts of Excellence. Self-assessment or external assessment. The model and assessment enables identification of strengths and improvement potential as well as development and launching of improvement plans and monitoring of progress.</td>
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<tr>
<td>ABO framework</td>
<td>Order-delivery process.</td>
<td>Companies producing physical products.</td>
<td>Literature on business and process improvement. Framework includes tools for modelling a process, analyses and measures for identifying development objectives and development actions. Framework and method can be used in-house or by external experts. Aims at identifying development objectives and suggests development actions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model for Assessing Changes Towards Lean Production</td>
<td>Production function of a company.</td>
<td>Not specified.</td>
<td>Lean production. Model consists of nine principles and measurable determinants for them. The determinants are measured with quantitative measures or by evaluating practices. Self-assessment that enables following progress towards lean production. Also presents objectives for implementing lean production.</td>
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</tbody>
</table>
The review of available assessment and improvement tools, models and frameworks can be summarised based on the aspects considered. The observations can then be connected to the need for and development of the new production system assessment tool.

In Figure 17, the reviewed tools, models and frameworks are located and grouped based on the focus and scope of assessment and the target group. With regard to the focus and scope of assessment, the majority of the reviewed tools adopt a broad perspective and cover and consider all aspects and functions of a company or entire supply chain consisting of several companies. This group includes the SHEN model, the SCMAT test, the LESAT tool, the SCOR model, the EFQM model and the Baldrige criteria. On the other hand, the MSDD model, the PPA method and the Model for Assessing Changes Towards Lean Production (MACL) adopt a narrow focus and scope by focusing on production. In terms of focus and scope, the PSD framework and the ABO framework are located between these two groups. The PSD framework addresses production and product design and can be applied to production networks consisting of several companies. The ABO framework focuses on the order-delivery process, which in contrast to supply chain, is limited to one company. Thus, these frameworks adopt a broader perspective than the production-oriented tools, but have a more limited focus compared to those covering all aspects of a company or a supply chain. In terms of company or industry type, most of the tools (MACL, EFQM, SCOR, Baldrige, LESAT and SCMAT) are intended to be either company- and industry-generic or the target companies and industries are not defined. Regarding the ABO framework, PPA method, PSD framework and MSDD tool, the target companies or industries are slightly more specified. These are intended either for production companies (ABO and PPA) or more specifically for repetitive discrete-part production (MSDD and PSD). Finally, the only tool for which the target companies are clearly defined is the SHEN model, which focuses on traditional make-to-order companies or, according to the terms and definitions used in this study, on engineer-to-order companies.

Figure 17. Summary of available assessment and improvement tools and models based on focus and scope and target group

The above figure and discussion supports the need to develop a new production system assessment tool, and indicates the differences between the new tool and currently available tools (Section 1.5.). Based on the review, most of the available tools, models and frameworks adopt a relatively broad focus and scope by considering the entire organisation, order-delivery process or supply chain. Furthermore, all but one of the reviewed tools, models and frameworks are
intended to be company- and industry-generic, i.e. the target companies are not clearly defined. Thus, the review and Figure 17 indicated a potential and need to develop a tool that adopts a narrow focus and scope and is targeted towards a specific industry and company type. The review also indicated that this study and new production system assessment tool differ from the available assessment and improvement tools, models and frameworks based on the focus and scope of assessment and improvement, and by clearly defining the target companies and industry.

The review presented can be further summarised by considering the content, assessment methods and approach, and theoretical background of the tools, models and frameworks. Most of the tools, models and frameworks present principles, practices or requirements that are used as a basis for the assessment, and provide guidance and advice for improvement. In these cases, the assessment is based on considering the realisation of practices, principles or requirements, or on evaluating how well they have been implemented or achieved in the assessed production system, process of organisation. Assessment is carried out by means of questions or quantitative measures, and often a maturity model is used to facilitate the assessment and presentation of results. In terms of the assessment process, all but one of the reviewed tools, models and frameworks enable both self-assessment and facilitated assessment. Finally, lean production seems to be the dominant theoretical background of the reviewed tools. These observations provided the background and basis for the structure and development of the new production system assessment tool. The content and assessment approach of the reviewed tools indicated that production system characteristics and principles can be used as the basis of the new production system assessment tool and assessment process. Furthermore, the content of the tools, i.e. the best practices, assessment scales and methods, assisted in developing the new tool and its main parts: the key characteristics of a well-performing production system, the assessment scale, and assessment methods. Finally, the review supported the view (presented in Section 2.4.) that lean production provides a useful starting point and theoretical background for this study.
4. Development of the production system assessment tool

This chapter outlines the process of developing the production system assessment tool, and describes the research approaches and methods used. Firstly, the research approaches used in the study are discussed, and then the development of the tool and its parts is presented. Finally, the approach and methods used in testing and evaluating the tool are presented.

4.1. Research approach

This section begins by discussing the epistemological foundations of the study. The research approaches used in developing the production system assessment tool are then presented and discussed based on three classifications. The research approaches were selected and are reasoned based on the characteristics and objectives of the study.

Examining the study and its characteristics from different methodological perspectives provided an overview of guidelines offered by approaches for conducting, evaluating and presenting research. As a result, a better insight into the present study as a whole was achieved and variety of tools for conducting and evaluating the study and its results were identified.

4.1.1. Epistemological foundations

According to Girod-Seville and Perret (2001, p. 13), all research work is based on certain epistemological presuppositions related to the researcher’s world view and knowledge and the type of results sought. Furthermore, they state that examining the epistemological foundations of a study is important and useful as it helps to evaluate and establish its validity and legitimacy (Girod-Seville & Perret 2001). Epistemological approaches can be defined in different ways. For example, Kasanen et al. (1993) and Koskinen et al. (2005) divide them into two categories, positive and interpretative, while Girod-Seville and Perret (2001) distinguish three approaches: positivism, interpretivism and constructivism. According to Girod-Seville and Perret (2001), positivists search for external reality and mechanisms that condition it, and aim to explain reality by finding or creating laws and causal links between elements. Positivists also emphasise the independence between object and subject, meaning that the researcher is independent of the object he or she observes or studies. On the other hand, for interpretivists and constructivists the object studied is dependent on the observer, which means that the researcher is part of the research setting and object (Girod-Seville & Perret 2001; Koskinen et al. 2005). Furthermore, with regard to generating knowledge, interpretivists and constructivists focus on understanding and describing reality rather than on identifying causal links and laws emphasised by positivists. More specifically, in the interpretive approach the aim is to interpret and understand reality and to deepen understanding of reality and the researched issues, while in the constructive approach more emphasis is put on constructing reality (Girod-Seville & Perret 2001).

Of the epistemological level approaches described, this study followed the constructive approach. This can be clarified by considering the characteristics and objectives of the study. Here, the aim was not to create and test laws or causal links, but to deepen understanding of production systems and production performance, and to develop or construct a tool for assessing and improving production systems. Pursuing the objectives was based on the understanding of reality and the object researched, and the researcher’s thinking and reasoning play an important role in analysing the data and constructing the results. Thus, the researcher actively participated in collecting and analysing the data and there was dependence between the subject and object of the study. Furthermore, the results are contextual and dependent on the researcher’s
understanding of the research object rather than based on observed and tested causal links and laws. Hence, the approach and objectives of this study clearly differ from the positivism approach. With regard to interpretivism and constructivism, the aim was to not only understand reality but to develop a new tool, thus placing the study in the constructivism category.

4.1.2. Design science and innovation building research

The taxonomy presented by Järvinen (2008) (Figure 18) was used to identify and select an appropriate research approach for the study. The taxonomy was initially developed for the field of information systems, but can be applied to other disciplines such as engineering, education or management (Järvinen 2008, p. 39).

![Figure 18. Taxonomy of different studies (Järvinen 2008)](image)

In the taxonomy, approaches focusing on the real world are divided into natural sciences and design sciences. According to March and Smith (1995, p. 253) natural science is concerned with understanding reality and explaining how and why things are. Hence, the aim of natural scientists is to develop concepts, laws and theories that characterise and explain phenomena and reality. On the other hand, design science attempts to create things or artefacts that serve human or business purposes. (March & Smith 1995, p. 253) Similarly, Järvinen (2008, p. 31) summarises that natural science focuses on understanding a situation, whereas design science aims at developing artefacts. The artefact or innovation can be, for example, a construct, model, method or implementation that is intended to improve the current situation, for example, by solving a problem or exploiting an opportunity (March & Smith 1995, p. 253; Järvinen 2007, p. 1389). The distinction between natural and design sciences may also be based on the object of study (use of an artefact vs. construction of a new artefact), on the type of research question (how and why things are vs. devising an artefact), or on the language used (e.g. understand vs. improve) (Järvinen 2008, p. 31). The aim of this study was to develop an assessment tool that assists in assessing and improving production systems. Hence, the aim was to develop a new tool that assists in improving the current situation. Such an objective is typical of design science, and this therefore provided an appropriate research approach for this study.

Design sciences can be further divided into innovation-building and innovation-evaluating studies (Järvinen 2008, p. 31). This division is based on the two basic activities of design science: build and evaluate (March and Smith 1995, p. 254; Järvinen 2008, p. 31). In innovation-building studies, new artefacts are built, whereas in innovation-evaluating studies the focus is on
measuring and evaluating an existing artefact. However, innovation-building typically also includes demonstrating and evaluating the feasibility and utility of the developed artefact. (Järvinen 2008, p. 31-32) Of these options, this study belongs to innovation-building research, since a new assessment tool is developed. Hence, the approach adopted in this study is innovation-building design science research.

In addition to the objectives of the study, the choice of research approach can be considered on the basis of its epistemological foundations. Rather than attempting to understand or explain reality in the manner of interpretivism and positivism, the objectives of design science are founded in a constructive approach aimed at constructing reality. Furthermore, design science and the constructive approach both accept the interdependence between the subject and object of research, and hence the results of a research work and the knowledge generated are contextual and subjective. Finally, both approaches emphasise value, utility and usability in evaluating the research work and its results. (March and Smith 1995, p. 253; Girod-Seville & Perret 2001, p. 13-27; Hevner et al. 2004, p. 76) Hence, using design science as a research approach was consistent with the epistemological foundations of this study.

4.1.3. Constructive research approach

In addition to Järvinen’s (2008) taxonomy, the research approach was considered on the basis of the classification presented by Neilimo and Näsi (1980) and later completed by Kasanen et al. (1993) (Figure 19).

<table>
<thead>
<tr>
<th>Theoretical</th>
<th>Empirical</th>
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<tbody>
<tr>
<td>Descriptive</td>
<td>Conceptual approach</td>
</tr>
<tr>
<td>Normative</td>
<td>Action-oriented approach</td>
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Figure 19. Classification of research approaches (Kasanen et al. 1993)

In the classification, five research approaches have been located according to two axes: descriptive-normative and theoretical-empirical. Descriptive research focuses on describing or explaining the object of research and answers to questions such as “how things are” or “why things are as they are” (Lukka 1991, p. 167), while normative research aims at supporting decision-making and answering questions such as “how things should be” or “what should be done” (Lukka 1991, p. 167). The theoretical-empirical axis is connected with issues such as the type of data used, how the data is collected, and how and where the results of the research are tested and applied. For example, Lukka (1991, p. 167-168) states that in empirical approaches empirical data collected from the field or laboratory has an important role. Empirical approaches typically involve implementing the results into practical use or demonstrating their usability in practice (Lukka 1991, p. 169; Kasanen et al. 1993, p. 256-257). On the other hand, in theoretical research and approaches, empirical data is derived from previous research and has a less significant role than in the empirical approach (Näsi 1980, p. 30; Lukka 1991, p. 167-168).

Of the five research approaches included in this classification, the constructive research approach was best suited and applicable to this study. Kasanen et al. (1993, p. 244-245) state that the constructive research approach aims at constructing or developing entities, for example, models or plans, that provide solutions to explicit and practically relevant problems. Furthermore, the developed entity or construction should be theoretically justifiable and its usefulness and usability should be demonstrated through practical implementation (Kasanen et al. 1993, p. 246, 259). The primary aim of this study was to develop an assessment tool for assessing production
systems and for identifying the potential and means for improvement. This is consistent with the objectives of the constructive research approach, as the aim was to develop a construction that provides solutions to or assists in solving a practically relevant problem. Furthermore, in identifying an appropriate research approach, the study was located using the classification presented by Neilimo and Näsi (1980) and Kasanen et al. (1993). With regard to the descriptive-normative axis, the study has normative features, since the production system assessment tool is intended to provide ideas and guidelines on how to improve a production system. In terms of the theoretical-empirical axis, the study and its results are located on the empirical side. In developing the assessment tool, information collected in interviews and plant tours was used, and the resulting tool was tested in pilot cases. Furthermore, the aim was to develop a practical assessment tool that can be used in assessing and improving production systems rather than developing theories of production and production system. Thus, locating this study based on the two axis presented in Figure 19 indicated the applicability of the constructive research approach to this study.

With regard to the Järvinen classification discussed above, the characteristics and definitions of design science and the constructive approach are quite similar (see e.g., Kasanen et al. 1993; March & Smith 1995; Hevner et al. 2004; Järvinen 2008). In terms of research objectives, both emphasise developing an innovation or artefact that improves, or can be used to improve, the current situation. Furthermore, the utility and usefulness of a study and its results are emphasised, and therefore the developed artefact should be tested and evaluated in practice. These research approaches were hence seen to be complementary and able to provide an applicable approach and framework for this study and for pursuing its objectives.

4.1.4. Qualitative research

The research approach for this study was also considered in terms of quantitative and qualitative research, although the distinction is somewhat ambiguous. Qualitative and quantitative research are found to differ, for example in terms of epistemological foundation, research orientation, type of data used, and methods of data collection and analysis (Baumard & Ibert 2001, p. 77-80; Bryman & Bell 2003; Saaranen-Kauppinen & Puusniekka 2006).

Based on the descriptions presented in literature, this study corresponds with the characteristics of qualitative research. Data collection, for example, involved interviews, observations and case studies carried out in companies, and the data collected was qualitative in nature, i.e. the aim was not to collect quantitative or quantifiable data. Furthermore, the samples were relatively small and not selected based on probability sampling. The analysis of the collected data and generation of results were based on analysis and reasoning by the researcher, which is in contrast with quantitative research where statistical tools and measures play a key role. Also, as is typical to qualitative research, the aim of analysis was not to test and prove preset hypotheses. Finally, the epistemological foundations of this study were consistent with qualitative research.

4.2. Phases of the study and the development project

This section presents an overview of the phases and progress of the study, and demonstrates their correlation with the typical phases and progress of design science and constructive research projects. The phases of the study and the development of the production system assessment tool are described in more detail in the following sections.
The progress and structure of the study can be divided into five phases:

1. Identifying and defining the research problem and objectives
2. Developing the production system assessment tool
   - Key characteristics of a well-performing production system
   - Assessment scale
   - Assessment methods
3. Testing the production system assessment tool
4. Evaluating the production system assessment tool
5. Evaluating and reporting the study

In the first phase, the topic, focus and objectives of the study (see Chapter 1) were determined and defined based on literature, observations made in industry, and the researcher’s own experience and interests. The production system assessment tool was developed in the second phase, which consisted of three parts or subprojects: development of a set of key characteristics of a well-performing production system to provide the basis for the assessment tool, development of an assessment scale, and development of assessment methods (see Chapters 4 and 5). Each phase progressed in a similar manner to the study as a whole, i.e. first obtaining knowledge and understanding, and then developing and evaluating the artefact. The developed production system assessment tool was then tested and used in six pilot cases in order to demonstrate and evaluate its applicability and usefulness in practice (Chapter 6). The assessment tool, assessment process and assessment results were presented to consultants and feedback was collected from both the participants in the assessment cases and the consultants. Based on the tests and feedback, the production system assessment tool was evaluated in the fourth phase of the study (Chapter 7). Finally, the entire study was evaluated and reflected on (Section 7.8. and Chapters 8 and 9) and reported.

At the general level, a design science research project consists of two basic activities: building and evaluation. The former involves constructing an artefact or innovation, while the latter activity focuses on determining how well the artefact or innovation performs. Typically, these two activities are iterated and repeated during the research process. (March & Smith 1995, p. 254, 258; Hevner et al. 2004, p. 78; Järvinen 2008, p. 31) Takeda et al. (1990) and Vaishnavi and Kuechler (2004) present a more detailed model of a design research project and its progression (Figure 20).

![Figure 20. Phases of a design research project](attachment:image.png)

The design research project model consists of five phases and illustrates how such projects can, and often do, progress in an iterative manner. The first phase includes clarifying and determining...
the problem and objective of a research project and results in a formal or informal proposal for a new research effort. Then, in the second phase, a suggestion or suggestions for solving the identified problem and achieving the objectives are generated based on existing knowledge and theory. The subsequent phases include developing and implementing an artefact or artefacts, and evaluating it or them based on relevant criteria. The conclusion phase is the finale of the research effort. In the case of developing a single artefact, the conclusion phase is reached once the artefact and the results of its evaluation reach a satisfactory or “good enough” level, while in the case of developing and evaluating multiple candidates, the conclusion phase involves deciding which candidate to adopt. (Takeda et al. 1990, p. 43; Vaishnavi & Kuehler 2004) Similarly to more general presentations of a design science project, this detailed model clearly includes the build and evaluate phases.

With regard to the constructive research approach, Kasanen et al. (1993, p. 246) and Lukka (2001) divide the research project to six phases:

1. Find a practically relevant problem which also has research potential
2. Obtain a general and comprehensive understanding of the topic
3. Innovate, i.e., construct a solution idea
4. Demonstrate that the solution works
5. Show the theoretical connections and the research contribution of the solution concept
6. Examine the scope of applicability of the solution

In the structure and progress presented by Kasanen et al. (1993 and Lukka 2001), the first phase focuses on identifying the research topic, problem and objectives that are relevant from both a practical and theoretical perspective. Then, in the second phase, the researcher obtains and develops a thorough understanding of the research topic and existing theories and research results. This supports the research work itself, i.e. the construction of a solution, as well as the identification and presentation of the research contribution. In the third phase, the solution to the research problem is constructed. This phase typically involves creativity and is heuristic by nature. Subsequently, testing and demonstrating the applicability and usefulness of the solution in practice is required. The final two phases focus on evaluating the research project and its results, with the focus on the contribution and applicability of the results in different contexts. (Kasanen et al. 1993, p. 246-247; Lukka 2001, p. 3-6)

Constructive research projects and design science research projects are structurally similar. The first three phases of a constructive research project correspond to the building or awareness of problem phase, the suggestion phase, and the development phase in a design science research project. The remaining three phases presented by Kasanen et al. (1993) and Lukka (2001) correspond to the evaluation and conclusion phases suggested by Takeda et al. (1990) and Vaishnavi and Kuehler (2004), and also provide guidelines for evaluating and reporting the research project. Furthermore, the approaches and models indicate that the research or development project is often iterative, i.e. the phases of building, developing or innovating, and evaluating or testing are repeated and iterated during the project.

The following figure illustrates the correlation between the phases and progress of this study with the models and phases of design science research and constructive research (Figure 21). In the first phase, the focus, problem and objectives of the study were defined. The phase is thus clearly connected and similar to the first phases of constructive research and design science research projects. In this phase, the assessment approach, i.e. focusing on production system and its design, and the general structure of the assessment tool were determined, hence the suggestion phase of the design science research project was also covered and completed. Additionally, a general overview of available assessment tools and understanding of the research topic were obtained. Hence, the first phase of this study is also connected to the second phase of
a constructive research project, i.e. obtaining understanding of the topic. The second phase of the study, development of the production system assessment tool, corresponds to the development and construction phases of both models. The development phase included literature reviews which provided a thorough understanding and knowledge of production strategy, production paradigms, and design, operation and improvement of production systems. Therefore, the development phase is also connected to the second phase of a constructive research project. The third phase of this study in which the developed TUTKA production system assessment tool was tested and used in practice corresponds to the phases of evaluation in design science research and to demonstrating that the solution works in constructive research. The final two phases in which the study and its results were evaluated are similar to the last phases of design science and constructive research projects.

To conclude, the 5-phase study exhibits a similar structure and progress to that suggested in literature on the selected research approaches, constructive and design science. In a similar manner to the design science and constructive research projects, this study can be divided into building and evaluating an artefact, i.e., the new production system assessment tool. Furthermore, in particular, the development of the key characteristics of a well-performing production system (Section 4.3.) involved iteration between building or developing and evaluation, which is typical to both constructive and design science research projects.

**Figure 21. Correlation between the progress and phases of the study and design science research and constructive research**

To conclude, the 5-phase study exhibits a similar structure and progress to that suggested in literature on the selected research approaches, constructive and design science. In a similar manner to the design science and constructive research projects, this study can be divided into building and evaluating an artefact, i.e., the new production system assessment tool. Furthermore, in particular, the development of the key characteristics of a well-performing production system (Section 4.3.) involved iteration between building or developing and evaluation, which is typical to both constructive and design science research projects.
4.3. Key characteristics of a well-performing production system

This section focuses on the process of identifying and developing the set of key characteristics of a well-performing production system which provides the basis for the production system assessment tool. The research approach and phases of the development process, the research methods used, and the different versions of the set of key characteristics developed during the process are presented. The key characteristics are grouped into decision areas, i.e. areas to which production-related decisions and changes can be made, and linked with production objectives. Therefore this phase of the study also involved identifying the production objectives and decision areas included in the production system assessment tool.

The term key characteristics of a well-performing production system refers to the characteristics of a production system that are intended to enable cost-efficient, rapid, and reliable production of the product variety offered to customers. Hence, they support and contribute towards competitiveness and high performance of production. Furthermore, the key characteristics are required to be applicable and useful to the target companies in this study. In the early phases of this study the characteristics were referred to as best practices. The term key characteristics was, however, considered to be more appropriate, since best practices refer to actions, activities or procedures, whereas the principles or guidelines identified in this study define and describe the status and state of a well-performing and well-organized production system.

4.3.1. Research approach and role of theory

In addition to the design science and constructive research approaches, the conceptual approach was also used in pursuing the objectives of this phase of the study. According to Näsi (1980, p. 10), the conceptual approach aims to develop or create concepts or concept systems, and was therefore well suited to developing the set of key characteristics of a well-performing production system. The applicability of the conceptual research approach was also considered using the classification presented by Näsi (1980) and Kasanen et al. (1993) (Figure 19, Section 4.1.3.). With regard to the descriptive-normative axis of the classification, this phase was categorised as descriptive. The focus was on understanding, explaining, and describing a production system that is able to achieve high levels of production performance. In other words, the aim was to identify and describe a set of characteristics of a production system that have an important role in the design and implementation of a production system that is able to achieve high production performance. On the other axis, this phase of the study was categorised as theoretical, because literature and previous research on production systems and production approaches had an important role in the development process. Furthermore, the literature review and the set of key characteristics provided the theoretical background and basis for the production system assessment tool and its development. As a result, this phase of the study was located in the descriptive and theoretical category of the classification, which indicated the applicability of the conceptual approach. The conceptual approach was hence used as an auxiliary research approach, and was combined with the constructive research and design science approaches in pursuing one of the sub-objectives of the study. According to Näsi (1980) and Lukka (1991, p. 167), the conceptual approach is often used as part of or to support other research approaches.

The approach used in developing the set of key characteristics of a well-performing production system can also be described by considering the role of theory and the relationship between theory and empirical information in the development process. Approaches related to these can be categorised as theory-based, theory-bounded or data-based, or as testing, hybrid exploration and empirical exploration, and connected to deductive, abductive and inductive reasoning (Charriere & Durieux 2001, p. 59-64; Saaranen-Kauppinen & Puusniekka 2006). In the testing or theory-based approach, collection and analysis of data are based on or guided by available theories, models or frameworks, and the aim is to test existing theories, models or frameworks (Charriere & Durieux 2001, p. 62; Saaranen-Kauppinen & Puusniekka 2006). On the other hand, in the
empirical exploration or data-based approach, collection and analysis of data are not guided or bounded by preconceived ideas, models or theories, and the aim is to generate theories or laws from the collected data through analysis, in which tools such as coding and categorisation can be used. Such an approach is especially applicable and useful for research projects that focus on a little-known phenomenon or a topic for which no relevant or useful literature or theory is available. Then, the hybrid exploration or theory-bounded approach can be located between these. The collection and analysis of data are connected to, but not strictly limited by, theory, and the aim is, for example, to theoretically explain observations and empirical data, or to produce constructs based on observations, data and theory. (Charriere & Duireux 2001, p. 59-64; Bryman & Bell 2003; Saaranen-Kauppinen & Puusniekka 2006)

Of the approaches related to the role of theory and empirical information, the theory-bounded approach or hybrid exploration was regarded to be appropriate and useful for developing the set of key characteristics of a well-performing production system. First, the aim was to understand and describe a well-performing production system, and to identify or develop a set of key characteristics of such a system. Hence, a theory-based approach that focuses on testing existing theories, models or frameworks using deductive reasoning was not applicable. Due to the ready availability of literature and research results related to production, production systems and their improvement, and since the utilisation of available theories and frameworks was seen to simplify and support the study by providing a structure and basis for collecting and analysing information, the theory-bounded or hybrid exploration approach was used. With regard to this, an explorative or data-based approach could have provided more versatile data for developing a new construction. However, using available theories and frameworks to provide the basic structure and guideline for collecting and analysing information, rather than strictly limiting these phases, was seen as a means of ensuring the collection of versatile and varied data within the chosen research approach.

### 4.3.2. Overview and phases of the development process

The set of key characteristics of a well-performing production system were developed in an iterative process. The phases and results of the development process are summarised in Figure 22.
As Figure 22 shows, firstly, an initial version of the set of key characteristics was developed on the basis of a literature review. Subsequently, two rounds of interviews and observations of production systems in factory tours were conducted. These aimed at evaluating and improving the applicability and appropriateness of the set of key characteristics to the target companies in this study. The interviews were used to collect practitioners’ views and opinions on the set of key characteristics and on the modification needs related to them. Thus, the interviews and factory tours provided a practical perspective and information to the process of developing the set of key characteristics. As Figure 22 indicates, after each round of interviews and factory tours, the set of key characteristics was modified and improved using information collected from the interviews, observations and literature. The progress and results of the process and its phases were also reported and presented in international conferences. These aimed to provide an academic perspective on the process and to enable assessment of the study and its results. As a result, the process of developing the set of key characteristics combined three perspectives: theoretical, practical and academic (Figure 23).

The iterative development process, and combining the theoretical and practical perspectives were intended to ensure the relevancy, applicability and usefulness of the developed set of key characteristics.
characteristics to the target companies in this study, which was one of the main objectives and requirements of this phase. Furthermore, regarding the academic perspective, the author’s articles and presentations in international conferences enabled academic evaluation of and provided feedback on the research process and its results. In addition, participation in conferences provided both practical and theoretical information that could be used in developing the set of key characteristics. With regard to research approaches, iterative use of theory and empirical information is typical to hybrid exploration or the theory-bound approach, and to the conceptual approach that provided the basis for this phase of the study (Näsi 1980, p. 31; Charrieire & Durieux 2001, p. 61; Saaranen-Kauppinnen & Puusniekka 2006). Additionally, iterative progress and alternation between the developing and evaluating phases are typical to the design science and constructive research approaches used in this study (Kasanen et al. 1993; Lukka 2001; Hevner et al. 2004; Vaishnavi & Kuehler 2004).

4.3.3. Sources of information

In developing the set of key characteristics of a well-performing production system, information collected from literature, conferences, interviews, and observation of production systems was used. Literature mainly provided a theoretical perspective and information, while interviews and observations provided a practical perspective and enabled collection of empirical information. The conferences contributed both to practical and empirical information collection.

Books and journal and conference articles in both printed and electronic format were included in the literature reviews that covered production strategy, production paradigms, and more specific aspects of production and its improvement. In terms of the tasks and objectives of this phase of the study, identifying and developing the key characteristics of a well-performing production system was mainly based on the literature on production paradigms, such as lean production, agile manufacturing, and mass customization, and on the review of available tools for assessing and improving production and production systems (Chapter 3). Additionally, in modifying the key characteristics literature related to the topic or aspect of production considered, such as product architecture or human resources, was used. Production strategy classifications presented in literature (Section 2.1.2.) were the main sources of information used in identifying the decision areas and the objectives of production. Finally, literature on production paradigms was used in determining the linkage, i.e. the expected positive effect, between each key characteristic and the objectives of production.

International conferences on production and production systems in which the author participated also provided information for this phase of the study. The conference articles and presentations provided both theoretical and empirical information for developing the set of key characteristics of a well-performing production system. Additionally, industrial visits conducted in connection with some of these conferences enabled observation and identification of production system practices and characteristics.

Interviews and observations of production systems were conducted to complement the information collected from literature and to provide practical information and a practical perspective on the process of developing the set of key characteristics. In evaluating and modifying the set of key characteristics, two rounds of interviews and factory tours were carried out. The first round, in autumn 2006, aimed at quick identification of evident and obvious modification needs. To serve this purpose, a relatively small sample was selected to enable analysis and evaluation to be carried out with reasonable effort. Eight persons from five companies belonging to the target group of the study were interviewed and factory tours were conducted at each of the companies. Table 3 presents the titles of the persons interviewed, the companies visited and their business area or products.
Table 3. Companies and persons participating in the first round of interviews and observations

<table>
<thead>
<tr>
<th>Company</th>
<th>Title of interviewees</th>
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<tr>
<td>Avant Tecno Oy</td>
<td>Vice President, Production</td>
</tr>
<tr>
<td>Avant loaders.</td>
<td></td>
</tr>
<tr>
<td>Ponsse Oy</td>
<td>Quality and IT Manager</td>
</tr>
<tr>
<td>Cut-to-length forest machines.</td>
<td>Industrial Manager</td>
</tr>
<tr>
<td>Profile Vehicles Oy</td>
<td>Engineering Director</td>
</tr>
<tr>
<td>Special vehicles.</td>
<td></td>
</tr>
<tr>
<td>Sandvik Mining and Construction Oy</td>
<td>Business Process Development Manager</td>
</tr>
<tr>
<td>Rock-excavation equipment and tools for mining and civil engineering.</td>
<td>Manager, Inbound logistics</td>
</tr>
<tr>
<td>Volvo Bus Finland Oy</td>
<td>Production Manager</td>
</tr>
<tr>
<td>Bus bodies and Volvo buses.</td>
<td></td>
</tr>
<tr>
<td>5 companies</td>
<td>8 participants</td>
</tr>
</tbody>
</table>

The second round of interviews and observations was conducted in 2007 after the initial set of key characteristics was modified based on the first round of interviews and observations. The aim of the second round was to collect more information and to provide a broader view of the set of key characteristics of a well-performing production system than during the first round. Thus, a larger and more heterogeneous sample was used. Table 4 below presents the titles of the persons interviewed and companies they represent, and indicates in which companies a factory tour was made.
Table 4. Companies and persons participating in the second round of interviews and observations

<table>
<thead>
<tr>
<th>Company</th>
<th>Title of interviewees</th>
<th>Factory tour</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABB Oy</td>
<td>Process owner, Order fulfilment process</td>
<td>X</td>
</tr>
<tr>
<td>Motors and generators.</td>
<td>Process Development Manager, Order fulfilment process</td>
<td></td>
</tr>
<tr>
<td>Bromma Conquip</td>
<td>Director, Bromma Tampere</td>
<td>X</td>
</tr>
<tr>
<td>Spreaders.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delfoi Oy</td>
<td>Business Development Manager</td>
<td></td>
</tr>
<tr>
<td>Digital manufacturing solutions and related consulting and integration services for the Product and Process Lifecycle.</td>
<td>Project Manager</td>
<td></td>
</tr>
<tr>
<td>Fastems Oy Ab</td>
<td>Director, Marketing and Business Development Manager, Technical Support</td>
<td>X</td>
</tr>
<tr>
<td>Flexible manufacturing systems, machine tools and industrial robots.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formia Technology Group</td>
<td>Chairman</td>
<td></td>
</tr>
<tr>
<td>Construction machines and sheet metal and machine shop solutions.</td>
<td>Chief Technology Officer</td>
<td></td>
</tr>
<tr>
<td>Forte Engineering Oy</td>
<td>Managing Director</td>
<td></td>
</tr>
<tr>
<td>Production development consultant.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huurre Insulation Oy</td>
<td>Production Manager</td>
<td></td>
</tr>
<tr>
<td>Insulation elements, doors and related accessories.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>John Crane Safematic Oy</td>
<td>Production Manager</td>
<td></td>
</tr>
<tr>
<td>Seals and associated products.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metso Minerals Oy</td>
<td>Development Manager, Global sourcing</td>
<td>X</td>
</tr>
<tr>
<td>Equipment for rock and minerals processing and metal recycling.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moventas Oy</td>
<td>Vice President, Technology</td>
<td></td>
</tr>
<tr>
<td>Wind and industrial gears</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nomet Oy</td>
<td>Production Manager</td>
<td></td>
</tr>
<tr>
<td>Machinery subcontracting company.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normet Corporation</td>
<td>Manufacturing Manager</td>
<td>X</td>
</tr>
<tr>
<td>Manufacturer of mining equipment.</td>
<td>Vice President, Production</td>
<td></td>
</tr>
<tr>
<td>Sisu Diesel Inc.</td>
<td>Production Manager</td>
<td>X</td>
</tr>
<tr>
<td>Off-highway diesel engines.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oy SKF Ab</td>
<td>Manufacturing Operations Director</td>
<td></td>
</tr>
<tr>
<td>Lubrication systems.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulzer Pumps Finland Oy</td>
<td>Process Engineering Manager</td>
<td>X</td>
</tr>
<tr>
<td>Pre-engineered process pumps.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oy SWOT Consulting Finland Ltd</td>
<td>Partner</td>
<td></td>
</tr>
<tr>
<td>Consulting company focusing on continuous development of competitiveness, profitability and efficiency.</td>
<td>Partner</td>
<td></td>
</tr>
<tr>
<td>Toolfac Oy</td>
<td>Managing Director</td>
<td></td>
</tr>
<tr>
<td>Manufacturer and supplier of precision mechanical parts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP-Yhtiö</td>
<td>CEO</td>
<td>X</td>
</tr>
<tr>
<td>Subcontractor and contract manufacturer for the heavy engineering and metal industries.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VTT</td>
<td>Vice President, R&amp;D, Industrial systems</td>
<td></td>
</tr>
<tr>
<td>Technical Research Centre of Finland.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEMIgroup Oy</td>
<td>President</td>
<td></td>
</tr>
<tr>
<td>Custom-made parts and assemblies for special-purpose vehicles.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wärtsilä Finland Oy</td>
<td>Development Manager, product factory W32</td>
<td>X</td>
</tr>
<tr>
<td>Manufacturer of engines, propulsors and related equipment.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 companies</td>
<td>27 participants</td>
<td>9 tours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In both rounds of interviews and observations, non-probabilistic judgement sampling was used to generate the sample, i.e. to select the persons interviewed and companies visited. The main advantage of non-probabilistic sampling compared to probabilistic sampling is the possibility to generate the sample according to certain criteria, for example, to select persons who are known or assumed to be able to provide useful information related to the topic and objectives of the research project (Royer & Zarlowski 2001, p. 148-149; Tuomi & Sarajärvi 2002, p. 88-89; Saaranen-Kauppinen & Puusniekka 2006). Furthermore, putting together a non-probabilistic sample is typically simpler than a probabilistic sample, for example because neither a sampling frame nor a specific and often rather complicated sampling procedure is needed (Royer & Zarlowski 2001, p. 151). On the other hand, compared to non-probabilistic judgement sampling, probabilistic sampling provides better statistical representativeness of the population considered and also enables generalisation of the findings and results from the sample to a certain population using mathematical properties (Royer & Zarlowski 2001, p. 148-149; Crouch & Housden 2003). In this case, the aim was to evaluate the appropriateness and usefulness of the key characteristics of a well-performing production system to the target companies in this study, and to collect information for modifying the set of key characteristics. Thus, it was essential that the interviewees had good knowledge and experience of production, production systems and their improvement, especially in the company types considered. Judgement sampling enabled and ensured the fulfilment of this requirement more effectively than probabilistic sampling. Furthermore, the research setting and objectives were seen to reduce the importance of the advantages of probabilistic sampling, i.e. sample representativeness and ability to generalise the results. The interviews and information collected were not tied to the company in which the interviewee worked, rather the key characteristics of a well-performing production system were evaluated and improved at more general level with regard to the target companies of this study. This reduced the importance of sample representativeness. With regard to generalising the results, it was assumed that if the set of key characteristics are evaluated and modified with the help of a sufficiently large number of experienced and knowledgeable persons, the results are likely to be applicable and useful to the target companies of this study. As a result, non-probabilistic judgement sampling was seen to be a more useful and appropriate sampling approach for the purposes and objectives of this phase of the study than probabilistic sampling.

Regarding the sample structure, in the first round of interviews and observations the sample consisted of interviewees and companies belonging to the target group of the study, whereas for the second round a more heterogeneous sample was selected. In the second round, in order to gain a broader perspective for evaluating and improving the set of key characteristics, consulting companies, subcontracting companies and one research institute were included in the sample. The consultants and the research institute interviewee were expected provide broader perspectives that are not tied or limited to a certain company. Furthermore, persons from subcontracting companies not belonging to the target companies of this study were selected to provide additional views and perspectives on the development of the set of key characteristics. These interviews also enabled consideration of the applicability and usefulness of the key characteristics to companies that do not meet the specifications and requirements presented for the target companies. However, the majority of the sample, i.e. 18 of the 26 companies and 25 of the 35 interviewees, belong to the target company types of this study. This served to ensure that the developed set of key characteristics of a well-performing production system is applicable and beneficial to the industrial sector and company types targeted.

With regard to the sample size, in the first round a small sample containing five companies and eight persons was selected for the purpose of rapidly and easily identifying obvious improvement needs with reasonable effort, while in the second round, the principle of theoretical saturation was used to determine the appropriate sample size. The principle is based on the law of diminishing returns and suggests that data collection can be stopped once the saturation point is
reached, i.e. the point at which increasing the sample size, for example by conducting more interviews, is no longer expected to provide new, enriching information (Eskola & Suoranta 1998, p. 62-63; Glaser & Strauss 1999, p. 61; Royer & Zarlowski 2001 p. 165-166). In this case, the sample size and number of interviews was seen to be sufficient when the opinions and perspectives presented in the interviews were similar to those presented in previous interviews. As a result, the sample in the second round of interviews consisted of 27 persons from 21 companies. However, as Royer and Zarlowski (2001, p. 166) point out, it is impossible to know with absolute certainty when the saturation point has been reached and whether further interviews will provide new, valuable information. Therefore, while the sample size was ultimately determined by the judgement of the researcher, it remains questionable as to whether a larger sample would have been beneficial. The sample size was, naturally, also affected by the accessibility to companies and people’s willingness to participate, although only a few persons contacted declined the request for a visit and interview. While production system observations were not carried out at all of the companies included in the sample, a total of 14 factory tours were conducted during the two rounds.

4.3.4. Information collection method

The principal method for collecting empirical and practical information data for developing the set of key characteristics of a well-performing production system was the interview. Interviews were used to evaluate and improve the appropriateness and usefulness of the key characteristics to the target companies of the study. Information was collected for one of two purposes: to demonstrate that the key characteristics meet the appropriateness and usefulness criteria, or to enable modification and improvement of the key characteristics to better fulfil these criteria.

In the interviews, open-ended questions were used and the general interview guide approach (Patton 2002, p. 342) was followed. The interviews can be categorised as theme interviews (Hirsjärvi & Hurme 2001), since although the same topics and issues were covered in each interview, the questions and their order could vary between interviews. The set of key characteristics provided the basis and structure for the interviews. In the first round of interviews the initial version of the set of key characteristics was used, while in the second round the set of key characteristics that had been modified based on the first round was used. The themes and topics covered in the interviews were the objectives of production, the decision areas, and the key characteristics of a production system. The interviewees were also able to present additional aspects and issues that they considered to be important and relevant in assessing and improving production systems. Prior to interview, the participants were provided with documents that introduced the study and briefly presented the set of key characteristics that was to be discussed and evaluated during the interview. The interviews were facilitated by the researcher, and Professor Seppo Torvinen, the supervisor of this study, also participated in some of the interviews. The duration of an interview ranged from two to eight hours. The interviews were documented by notes made by the researcher, and after each interview a recapitulation and summary of the interview, made by the researcher, was sent to the interviewees for comments. The aim was to ensure that all important comments and issues had been noticed, and that possible misunderstandings and misinterpretations could be corrected.

The appropriateness of using the general interview guide approach and theme interviews can be gauged by considering alternative interview approaches and data collection methods. Firstly, the adopted approach and method enable more flexible interviewing and questioning and more open and informal discussion than structured interviews or standardised open-ended interviews would allow (Hirsjärvi & Hurme 2001, p. 43-48; Patton 2002, p. 342). For instance, the used approach enabled additional and clarifying questions to be presented as necessary. Thus, compared to more structured and standardised interviews, the adopted approach and method were intended and seen to ensure that all relevant information can be presented, discussed, and collected during
the interviews. In addition, compared to open, informal discussions or interviews, the general interview guide approach and theme interviews enable the discussion to be focused on and limited to certain topics and themes, which supports and simplifies both the collection and analysis of information. The selected interview approach and method were hence seen to be the most appropriate of the available approaches and methods.

Also other methods for collecting information than interviews were considered, and based on that the chosen method can be reasoned at a more general level. The main alternatives were seen to be either a more quantitative or a case-based approach. A typical example of a quantitative approach is using a questionnaire survey to evaluate the key characteristics, and to identify the need and collect information for modifying the key characteristics to be better applicable and more useful to the target companies. Compared to the interview, the questionnaire offers the advantage of being able to cover a larger sample of companies and respondents, which may have resulted in more reliable and comprehensive evaluation of the set of key characteristics. The success of the quantitative questionnaire approach is, however, dependent on the response rate, and it was seen to pose also other problems and challenges. Firstly, questionnaires do not enable explanation or description of the key characteristics and related questions at the same level of detail than is possible in interviews. The need for that was demonstrated by the observation that, although the interviewees were provided with a document introducing and explaining the key characteristics prior to the interview, in each case there was a need to further clarify them. Thus, in using questionnaires the risks of misunderstanding or misinterpreting the questions, which would have a negative effect on the reliability and usefulness of the responses received, were seen to be greater than in interviews. Furthermore, interviews were seen to be better suited to collecting the information needed to modify and improve the set of key characteristics than questionnaires, because the interviewer can present additional questions and the respondents are able to present additional opinions and aspects they regarded useful and important. Several changes were made to the set of key characteristics on the basis of the interviews (see Tables 5-7, Section 4.3.6.), which demonstrates the importance of the ability to easily collect information for modifying the key characteristics. As a conclusion, the interview approach was regarded better suited and more beneficial than a quantitative approach and use of questionnaires.

Another alternative for interviews, a case-based approach, would have involved developing the set of key characteristics by observing the design and operation of production systems in the target companies. Additionally, interviews and discussions conducted in the companies could have been included in the approach. Compared to the interview approach, a case-based approach could have provided more detailed and practical information and ideas on the design and operation of production systems and for production system improvement. On the other hand, a narrower sample of companies could have been covered, as the cases and observations are more time-consuming to conduct than interviews. This might have had an effect on the usefulness and applicability of the results to the target companies of the study. Furthermore, developing the set of key characteristics of a well-performing production system using the case-based approach would have presupposed observing state-of-the-art production systems. Thus, the approach would have required identifying and gaining access to companies with such production systems, which might have been difficult. In contrast, interviews are not limited to the production system of a certain company, but interviewees were able to present all ideas and opinions that they consider to be useful and applicable for the types of company considered. The selection of interviewees was therefore freer, and the interview approach could also reveal ideas, practices and characteristics that were not yet implemented, but were viewed by the production and production system professionals as being useful and applicable to the target companies of the study. Finally, constructing the set of key characteristics of a well-performing production system based on observations was seen to be more difficult than constructing an initial set of key characteristics based on literature and then evaluating and modifying the characteristics based on
interview findings. Based on the above comparisons, the interview approach was seen to be more applicable to this phase of the study than the case-based approach.

The selected approach and method for collecting information, as well as the interview plan showing the types of questions to be used and topics to be covered in the interviews were discussed with two persons with experience in designing and conducting interviews. In these discussions the applicability of the interview approach and the ability of the planned interviews to provide relevant and useful information for pursuing the objectives of this phase of the study were considered, and the selected approach and methods were seen to be appropriate for this phase and its objectives.

4.3.5. Analysis and use of information
The analysis and use of the information obtained can be divided into two phases: development of the initial set of key characteristics, and evaluation and modification of the key characteristics. Slightly different approaches and guidelines for analysis and use of collected information were applied during each phase.

The process of developing the initial set of key characteristics involved both analysis and synthesis of information that was collected from literature covering production strategy, production paradigms, and available assessment and improvement tools. Firstly, the collected information was analysed in detail and information from different literature sources was then compared, combined, and synthesised into common concepts and themes. Subsequently, the relevancy and usefulness of an identified concept, theme or key characteristic was evaluated. To be included in the initial set of key characteristics, a characteristic was required to be useful and applicable to the target companies in this study, to be within the focus of this study, and to be in agreement and accordance with the definition and objectives of the key characteristics. Also, the number of sources in which a characteristic was discussed was considered, and typically only those characteristics that were presented by more than one author were included. Then, in identifying the decision areas and the objectives of production, the relevancy of available categorisations (e.g., Wheelwright 1984; Slack et al. 2004; Miltenburg 2005) to this study and its focus were considered. With regard to the decision areas, the aim was to develop a categorisation that clearly focuses on the design and organisation of the production system, but also enables consideration of certain aspects of product architecture and production processes. In terms of production objectives, the aim was to identify and define objectives that are important and relevant in designing, operating and improving a production system based on the reviewed categorisations of production objectives.

The evaluation and modification of the set of key characteristics were based on information collected from interviews, factory tours and literature. The aim was to evaluate and improve the appropriateness and applicability of the set of key characteristics to the target companies in this study. Hence, the analysis and use of information focused on two aspects: justification and modification. Firstly, support and justification for appropriateness and applicability of the key characteristics, the decision areas, and the objectives of production were sought. If the interviews indicated relevancy and applicability and no modification needs were identified, no changes were made. On the other hand, the interviews could indicate a need for modification, i.e. a need to remove or rephrase an existing key characteristic, decision area or objective of production, or to add new ones. In this case, further analysis of information was required. The suggested modifications were analysed and evaluated with the help of information collected from interviews, observation of production systems, and literature. In general, if similar modifications or issues were presented in several interviews, and literature and observations supported them, the set of key characteristics was modified. On the other hand, issues that were discussed only in one or two interviews, and for which no further evidence or support from other sources were
found, were seen as less important and modifications were not made or they were left for later
consideration in the subsequent phases. Determining the changes and making modifications to
the set of key characteristics required comparing, combining, and synthesising information from
interviews, literature, and observations in order to identify or develop common concepts and
themes that enabled the rephrasing of an existing key characteristic, decision area or production
objective, or the formulation and addition of a new one.

4.3.6. Progress and results
The set of key characteristics were developed in an iterative process, an initial version was
developed on the basis of literature, and then two rounds of evaluation and modification were
conducted. Table 5 presents the initial version of the key characteristics.

Table 5. Initial set of key characteristics of a well-performing production system

<table>
<thead>
<tr>
<th>Decision areas</th>
<th>Best practices</th>
<th>Production objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q</td>
</tr>
<tr>
<td>Product architecture and product structure</td>
<td>Product architecture and product structure are modular</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>The number of levels in the bill of material is minimised</td>
<td>X</td>
</tr>
<tr>
<td>Production system structure</td>
<td>Production system structure and product structure correspond to each other</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production system consists of production units that are responsible for certain parts of the product</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between machines are short</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Relationships between the units of the production system are based on long-term partnerships</td>
<td>X</td>
</tr>
<tr>
<td>Production equipment</td>
<td>Right-sized and general-purpose equipment is used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Set-up of equipment is rapid</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production equipment reliable and available</td>
<td>X</td>
</tr>
<tr>
<td>Production operations, production control</td>
<td>Production prerequisites are created and in place before an order is received</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lean production and agile manufacturing principles are combined in the production system</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production operations are standardised</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Reserve capacity, i.e. 70-80% utilisation, is secured by production planning and control</td>
<td>X</td>
</tr>
<tr>
<td>Information and communication</td>
<td>Useful and relevant information is available to all units and members of the production system</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Information flow within the production system is rapid and reliable</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used to communicate the status of production</td>
<td>X</td>
</tr>
<tr>
<td>Human resources</td>
<td>Multifunctional teams and teamwork are used in production</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and multi-skilled</td>
<td>X</td>
</tr>
</tbody>
</table>

In this initial version, the key characteristics of a well-performing production system were
referred to as best practices and they were grouped on the basis of six decision areas and linked
to four objectives of production. The first decision area, product architecture and structure, was
included because the effects and importance of those aspects to production system design and to
production performance are emphasised, for example, in literature on mass customization (e.g.,
Pine 1993; Blecker & Abdelkafi 2006) and by Lapinleimu (2001). The other five decision areas
were developed by using the categorisations presented by Wheelwright (1984, p. 84) and
Miltenburg (1995) (see Section 2.1.2.). The initial version included four production objectives:
quality (Q), lead or delivery time (T), cost (C) and flexibility (F). The checkmarks on the right-
hand side of the table indicate the expected positive effect of a practice or characteristic on those. The production objectives were identified on the basis of literature on production strategy (e.g., Wheelwright 1984; Voss 1995; Slack & Lewis 2002; Slack et al. 2004; Miltenburg 2005; Kaplan & Norton 2005) and are defined as follows:

- **Cost**: expenditures on resources, such as labour and material, used to produce a product.
- **Quality**: the ability of materials, products and operations to conform to specifications and to meet the expectations of customers.
- **Time**: consists of two sub-objectives: first, the time required to produce and to deliver a product, and second, the reliability of delivery time.
- **Flexibility**: refers primarily to product variety, i.e. the range of products the company and the production system are able to produce.

The initial version of the set of key characteristics was presented in a conference article and a presentation (Koho & Torvinen 2006), and was subsequently evaluated during the first round of interviews. After the interviews, the set of key characteristics was modified to be more applicable and appropriate to the target companies of this study. In the modified version (Table 6), the term best practices was changed to desired characteristics. Modifications were made to the characteristics and the production objectives, but the six decision areas remained unchanged. The modified characteristics are shown in italics.
Table 6. The modified set of key characteristics of a well-performing production system

<table>
<thead>
<tr>
<th>Decision area</th>
<th>Desired characteristics</th>
<th>Production objectives</th>
<th>Q</th>
<th>T</th>
<th>R</th>
<th>VF</th>
<th>PF</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product architecture</td>
<td>Product architecture and product structure are modular</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Product structure consists of predefined parts and components</em></td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>The number of levels in the BOM is as low as applicable</em></td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production system structure</td>
<td>Production system structure and product structure correspond to each other</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production system consists of production units that are responsible for certain parts of product</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relationships between units of the production system are based on long-term partnerships</td>
<td>X X X X X X X X</td>
<td></td>
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<tr>
<td>Production equipment</td>
<td><em>Right-sized equipment is used</em></td>
<td>X X X X X X X X</td>
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<tr>
<td></td>
<td>Equipment provides required product and volume flexibility</td>
<td>X X X X X X X X</td>
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<tr>
<td></td>
<td>Set-up of equipment is rapid</td>
<td>X X X X X X X X</td>
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<tr>
<td></td>
<td><em>Production methods support integration and reduction of production phases</em></td>
<td>X X X X X X X X</td>
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<tr>
<td></td>
<td>Production equipment is reliable and available</td>
<td>X X X X X X X X</td>
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<td></td>
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<tr>
<td>Production operations, production control</td>
<td>Production prerequisites are created and in place before an order is received</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>X X X X X X X X</td>
<td></td>
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<tr>
<td></td>
<td>Lean and agile manufacturing principles are combined in the production system</td>
<td>X X X X X X X X</td>
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<tr>
<td></td>
<td>Production operations are standardized</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Reserve capacity, i.e., 70-80% utilization, is secured by production planning and control</td>
<td>X X X X X X X X</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Information and communication</td>
<td>Useful and relevant information is available to all units and members of the production system</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information flow within the production system is rapid and reliable</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Visual information and control systems are used to communicate the status of production</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human resources</td>
<td>Multifunctional teams and teamwork are used in production</td>
<td>X X X X X X X X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and multi-skilled</td>
<td>X X X X X X X X</td>
<td></td>
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</table>

With regard to the objectives of production, the interviews indicated that reliability of lead or delivery time should be added and considered separately from length of lead or delivery time. Furthermore, dividing flexibility into two parts: product flexibility, which considers product variety, and volume flexibility was deemed to be beneficial. Thus, the new version presented six categories of production objectives: quality (Q), lead or delivery time (T), reliability of lead or delivery time (R), volume flexibility (VF), product flexibility (PF), and cost (C). Two practices or characteristics of a production system were rephrased and three new ones were added as a result of the analysis and synthesis. Modifications were made to the product architecture and production equipment decision areas. With regard to the product architecture decision area, the interviews revealed a need to emphasise the use of predefined parts and components in products, which was seen to support and simplify configuring order-specific products. The modification was considered useful and relevant also on the basis of literature, as the aspect was presented and emphasised, for example, by Tiihonen et al. (1998) and Nummela (2006, p. 56-57). Furthermore, the initial version required that the number of levels in the bill of materials (BOM) is minimised. This was not agreed with in the interviews and it was pointed out that the minimal number of levels in the BOM does not support similarity between product and production system structure.
Thus, it was argued that the number of levels needs to be greater than one. On the other hand, as Maskell (1991, p. 189-190) and Lapinleimu (2001, p. 97, 138, 146) point out, reducing the number of levels in the BOM provides several advantages, such as reduced complexity and inventory level and shorter lead time. As a result, the characteristic was modified so that an optimal number of levels is sought, i.e. product and production system similarity is supported, but unnecessary levels are removed. In the production equipment decision area, the initial version stated that equipment should be general-purpose and right-sized. However, the interviewees argued that the use of general-purpose equipment easily results in common resources that are difficult to control. Therefore, the key characteristic was modified by removing the general-purpose requirement. Furthermore, flexibility of equipment in terms of product variety and production volume was seen to be important, and a new characteristic focusing on flexibility was consequently added. Finally, the importance of production technology and methods was discussed and emphasised in the interviews, and although identifying one best practice or characteristic related to this aspect was difficult, a characteristic aimed at production phase integration was added. The modifications made and the resulting set of key characteristics were summarised in a document sent to all interviewees, and the characteristics were also presented in two conference articles and presentations (Koho 2006; Koho & Torvinen 2007a). These were intended to provide an opportunity to verify and comment on the decisions made by the researcher.

The modified version of the key characteristics of a well-performing production system was then further evaluated and improved. A second round of interviews and observations was carried out to evaluate and improve the usefulness and applicability of the key characteristics to the target companies of the study. Similarly to the first round of interviews, the changes made were summarised and reported back to the interviewees and presented in a conference article and a presentation (Koho & Torvinen 2008). Furthermore, the set of key characteristics were also modified during the next phase of the study, in which the methods and measures for assessing a production system were developed. The measures, methods and the set of key characteristics were evaluated by and discussed with three persons who have broad experience in designing, evaluating, and improving production processes and production systems. These discussions and the comments received provided the basis for further modification and improvement of the applicability and usefulness of the set of key characteristics for assessing and improving the production systems of the companies considered in this study. During these final phases, modifications were made to the decision areas and production system characteristics. Table 7 below presents the final set of key characteristics, with the changes made shown in italics.
Table 7. The final set of key characteristics of a well-performing production system

<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristics</th>
<th>Production objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q</td>
</tr>
<tr>
<td><strong>Product architecture</strong></td>
<td><strong>Product architecture is modular</strong></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>X</td>
</tr>
<tr>
<td><strong>Production system structure</strong></td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>X</td>
</tr>
<tr>
<td><strong>Production processes and management</strong></td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>X</td>
</tr>
<tr>
<td><strong>Production equipment</strong></td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>X</td>
</tr>
<tr>
<td><strong>Information and communication</strong></td>
<td>Information and communication support and enable decision-making</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>X</td>
</tr>
<tr>
<td><strong>Human resources</strong></td>
<td>Teamwork and team organisation are used in production</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and ensured</td>
<td>X</td>
</tr>
</tbody>
</table>
The order of the decision areas was changed to better fit the order in which a production system is designed and implemented. Also, the decision area focusing on processes was renamed, and the term desired characteristic was changed to key characteristic of a well-performing production system. Finally, several key characteristics were rephrased, some were removed, and new ones were added. These modifications are explained and discussed in more detail in Chapter 5 in which the final set of key characteristics is presented.

4.4. Assessment scale

An assessment scale is needed in assessing a production system and presenting the results of an assessment. The main objective or requirement of the scale is to enable consideration of the correspondence between the assessed production system and the key characteristics of a well-performing production system. Such comparison also enables identification of the improvement potential of a production system. To identify or develop an assessment scale suitable for the new production system assessment tool, available assessment tools and models and the scales used in them were reviewed. The reviewed approaches included performance measurement, level-based assessment of processes and performance, and maturity models. In addition to books and journal articles, presentations and articles on various assessment tools in international conferences to which the author participated provided useful information and ideas for the development process.

Performance measurement, involving individual measures of performance as well as frameworks for organising these measures, such as Balanced Scorecard, did not offer useful means of developing the assessment scale. The main reason for this is that the focus of performance measurement is different from this study. Performance measurement considers processes and measures their performance and results, while the assessment tool and the key characteristics of a well-performing production system developed in this study focus mainly on design and organisation of production systems. Furthermore, in performance measurement the performance of production is assessed on the basis of the measurement results that can be summarised and combined, for example, by means of measurement frameworks. Therefore, a general assessment scale is not necessarily needed as the current status and performance of production can be determined directly from the measurement results, or by comparing them with targets, results of other companies, or industry standards.

Another approach that was reviewed and considered in developing the assessment scale is termed here as level-based assessment. In this approach, the assessment of a process or a system is based on predefined objectives, criteria, or standards to which the results or characteristics of the assessed process or system are compared. The results are presented on a percentage scale or a scale consisting of levels that indicate how well the objectives, criteria, or standards have been achieved. An example of a tool belonging to this group is the Lean Assessment tool (Strategos Inc. 2009), which considers nine areas of production. For each area, three to six questions relating to the practices, characteristics or results of the area are presented, and these are answered by selecting multiple-choice options based on identified best practices or standards. On the basis of the responses, a percentage score from 0 to 100% is determined. This group also includes, for example, the EFQM Excellence Model, in which 32 sub-criteria defined for nine higher-level criteria are scored on a five-point scale (Nabiz et al. 2000; EFQM 2003), and the Baldrige Criteria for Performance Excellence, in which a percentage score is assigned to two evaluation dimensions, processes and results on the basis of statements and descriptions presented to six scoring ranges (BNQP 2009). It was considered that this approach might provide useful advice and a starting point for developing the assessment scale. It enables the consideration and evaluation of a system and its characteristics based on predefined criteria or best practices. However, defining and using a percentage scale, as is often used by tools belonging to this group, for assessing the realisation of the key characteristics of a well-
performing production system was seen to be difficult. Therefore, the maturity model approach was also considered.

The third approach considered consisted of maturity models that evaluate the maturity of the object of assessment. A wide variety of maturity models focussed on assessing and improving various areas such as the processes, operations or management of a company are available. In general, maturity models present levels of maturity that briefly describe typical behaviour or performance of the aspect or aspects considered (e.g., Fraser et al. 2002). The highest levels and their descriptions usually indicate good or best practice, while the other levels indicate intermediate or transitional stages towards the highest level of maturity. Thus, a maturity model can assist a company in assessing its current state or behaviour, and in identifying and prioritising improvement activities (Paulk et al. 1993, p. 4). Compared to the two other approaches considered, this is an important advantage of maturity models. One of the best known maturity models is the Capability Maturity Model (CMM) for Software which measures the maturity of a software process. In the model, software process maturity is defined as the extent to which a specific process is explicitly defined, managed, measured, controlled, and effective. These aspects are assessed and evaluated using five maturity levels: initial, repeatable, defined, managed, and optimising. (Paulk et al. 1993, p. 4, 8) The CMM has been further developed as the Capability Maturity Model Integration (CMMI) model, which comprises a process improvement approach that can be used in different areas of interest, for example, product and service development, service establishment, management and delivery, and product and service acquisition (SEI 2009). The model includes levels that characterise improvement from an ill-defined state to a state that uses quantitative information for determining and managing improvements necessary to meet business objectives. Six capability levels: incomplete, performed, managed, defined, quantitatively managed, and optimising, relate to continuous representation, while five maturity levels: initial, managed, defined, quantitatively managed and optimising, relate to staged representation. (CMMI Product Team 2006, p. 29-31)

In the production and supply chain context, the LESAT tool, which focuses on assessing the degree of maturity of an enterprise in its use of lean production principles and practices, includes five maturity levels from least capable to world-class. For each level, a generic statement and description of maturity is presented, and these are used to develop specific maturity statements for each of the practices of lean production included in the tool. (Nightingale & Mize 2002, p. 23-24) Furthermore, in the SCMAT tool five maturity levels: never or does not exist, sometimes or to some extent, frequently or partly exist, mostly or often exist, and always or definitely exist, are used to consider the extent to which a stated best practice is used in the assessed supply chain (Netland et al. 2007, p. 4). Thus, different versions and variations of maturity models are widely used in various assessment tools. This is noted also in the review of available assessment and improvement tools and models in Chapter 3.

Based on the review of available assessment scales and approaches, maturity models were seen as best suited and most advantageous for this study. However, the available maturity models cannot be directly integrated with the developed production system assessment tool, since the available models have a different focus. For example, the CMM and the LESAT tool focus on processes and their improvement, and the SCMAT tool considers supply chain best practices, whereas this study and the developed production system assessment tool focus mainly on the production system. Due to the differences in focus, the levels and definitions used in the available maturity models are suitable and useful for the developed production system assessment tool. The development of a new assessment scale with more suitable levels and their definitions and descriptions was therefore necessary.

The developed assessment scale follows the logic of maturity models and consists of four levels. In contrast to the majority of available maturity models, the assessment scale and the definitions and descriptions of the levels are intended for assessing the characteristics of a production
system rather than the practices and processes of production. The four levels of the developed assessment scale and their brief definitions are (for more detailed definitions see Section 5.2.):

- **Level 1: No correspondence.** The key characteristic is not realised in the assessed production system.
- **Level 2: Partial correspondence.** The key characteristic is partly realised in, or is realised in some parts of, the assessed production system.
- **Level 3: Full correspondence.** The key characteristic is realised in the assessed production system.
- **Level 4: Adaptability.** The key characteristic is realised in the assessed production system and the correspondence can be maintained even if customer requirements change.

The assessment scale levels enable determination of the degree to which the characteristics of the assessed production system correspond with the key characteristics of the well-performing production system included in the assessment tool. Additionally, the assessment scale also addresses the adaptability of the production system. The developed assessment scale and its use as a part of the production system assessment tool are discussed in more detail in Section 5.2.

### 4.5. Production system assessment methods and measures

The key characteristics of a well-performing production system provide the basis for the production system assessment, and the assessment methods were required to enable assessment and identification of the correspondence or differences between the characteristics of the assessed production system and the key characteristics of a well-performing production system. The assessment is based mainly on questions and claims related to the key characteristics and their realisation in the assessed production system. These were seen to ensure the validity of the assessment and to enable focusing on the production system and its characteristics. However, quantitative measures and other sources of information that assist the assessment have also been identified and included in the assessment tool.

The use of quantitative performance measures as the main assessment method was also considered, but their usefulness and validity was seen to be limited, mainly due to differences in focus and objective of assessment. Performance measurement and quantitative measures typically focus on production performance and on the operation and outputs of production processes, whereas this study and the production system assessment tool focus on the organisation and characteristics of a production system. Therefore, although the characteristics of a production system are seen as enablers of and as having an effect on production processes and production performance, performance measures were not considered valid indicators or measures of how well a production system is designed and implemented. To clarify the issue of validity, production lead time and issues and decisions affecting lead time can be considered as an example. Decisions related to the design and organisation of a production system, such as functional or product-based layout and distances between production units, have an effect on the lead time of production, which suggests that lead time could be used to evaluate decisions related to the design and organisation of a production system. However, decisions and characteristics related to production processes, such as scheduling, batch sizes, work shift arrangements and efficiency of equipment and employees, also have an important effect on production lead time. Thus, lead time measurement results cannot be directly connected to production system related decisions, and therefore the validity of lead time as a measure or indicator of the design and organisation of a production system is poor.

The development process of the assessment methods and measures was based on the previous phases of this study and the review of available assessment and improvement tools. The
assessment questions and claims were developed on the basis of the key characteristics, their definitions and breakdown points, and the methods used by available assessment and improvement tools provided ideas for the development. The questions and claims have been divided into three sets. The first set includes one question or claim that considers the realisation of a key characteristic at a relatively general level. Either the key characteristic or a question developed based on the definition and description of the key characteristic is used. The second set assess a key characteristic and its realisation in more detail, and either the breakdown points of a key characteristic or questions related to the breakdown points and the definitions of a key characteristic are used. Then, for those key characteristics that are connected with adaptability of the production system, a third set of questions and claims considers the ability to make changes related to production volume and product mix. As a result, the three sets of assessment questions and claims can be summarised as:

- Set 1: General level question or claim related to each key characteristic
- Set 2: Questions and claims related to detailed descriptions and criteria for each key characteristic
- Set 3: Questions and claims that consider adaptability of the production system

In addition to the assessment questions and claims, performance measures and other sources of information have been included in the assessment tool. These are intended to assist in the assessment process by providing additional information and examples related to the characteristics of the assessed production system, and were identified by means of a review of available assessment tools and literature on assessing and improving production systems and processes. However, the development process was carried out at rather general level and the results are not exhaustive. Only typical, often used, and easily identifiable measures and sources of information have been included in the assessment tool. Once the assessment methods and measures were developed they were presented to three experts, and based on their comments, the questions and claims, and the additional measures and methods were modified in order to improve and ensure their usefulness and applicability in assessing production systems. Section 5.3. presents and discusses the assessment methods and measures and their use in more detail.

4.6. Practical tests and evaluation

Development of the production system assessment tool also involved testing and demonstrating its applicability and usefulness in practice. The need and importance of this is emphasised in both the design science (March & Smith 1995, p. 254; Järvinen 2008, p. 31) and constructive research approach (Kasanen et al. 1993, p. 246). The developed production system assessment tool was used in pilot cases, and feedback was collected from the participants and from consultants that are considered to be potential users of the tool.

The pilot cases aimed to demonstrate that the developed production system assessment tool can be used in assessing a production system, and in identifying its strengths and potential and means for improvement. Hence, the pilot cases and the practical testing of the tool were linked to the primary objective of this study, i.e. to develop a tool to assess the current state of a production system and to identify potential and means for improvement. Six pilot cases were considered sufficient for demonstrating the applicability and usefulness of the developed production system assessment tool to the target companies of the study, and the number of cases was also suitable for the planned schedule of the study. In selecting the pilot companies, the aim was to include companies that meet the requirements and specifications set for the target group of the study (Section 1.3.). Furthermore, the aim was to include companies and persons who had not been involved in developing the set of key characteristics of a well-performing production system. However, due to reasons related to accessibility to companies, this was fully achieved only in
two pilot cases. In one pilot case, both the participant and the company had also participated in the evaluation and development of the key characteristics. Two of the pilot companies were visited during development of the key characteristics, but the pilot case participants were not included among the interviewees. One person participated in a key characteristics interview as well as a pilot case, but worked in different companies during these two phases. The six pilot cases and their results are presented in Section 6.3.

In addition to the pilot cases, feedback on the production system assessment tool, the assessment process and its results was collected from the participants of the pilot cases and consultants working in the field of production and its improvement. The questionnaire for the participants of the pilot cases consisted of both open-ended questions and multiple-choice questions which were answered by selecting the most appropriate option from 1 to 4 (1: disagree, 2: partly disagree, 3: partly agree, and 4: agree). The questions focused mainly on the applicability and usefulness of the production system assessment tool and the assessment process, although the novelty of the tool was also considered. The questionnaire was completed by the participants after the assessment process had been carried out and its results had been reported back to the company. The questionnaire and the feedback provided by the participants of the assessment cases are presented in Appendices 5 and 6. The developed production system assessment tool, the assessment process, and the results of an assessment case were presented to three consultants, whose title and company are presented in Table 8. Based on the presentation, they were asked to respond to open-ended questions focused on the usefulness and applicability of the developed tool to the target companies of this study and to their own companies. They were also asked to compare the developed tool with available tools for assessing and improving production and production systems. This questionnaire and the feedback received are presented in Appendices 7 and 8.

Table 8. Consultants who participated in evaluating the developed production system assessment tool

<table>
<thead>
<tr>
<th>Title of participant</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partner, Consultant Director</td>
<td>Oy Swot Consulting Finland Ltd</td>
</tr>
<tr>
<td>President</td>
<td>T2O Consulting Oy</td>
</tr>
<tr>
<td>Managing Director</td>
<td>Forte Engineering Oy</td>
</tr>
</tbody>
</table>

The feedback collected from the participants of the pilot cases and the consultants enabled evaluation of the developed production system assessment tool. The evaluation and the criteria used are presented in Chapter 7.

4.7. Summary

This chapter presented the approach, process and methods used in pursuing the objectives of this study and developing the production system assessment tool. Firstly, the research approaches and the research and development process were described. Then the development of the three parts of the production system assessment tool, the set of key characteristics of a well-performing production system, the assessment scale, and the assessment methods, were presented in detail. Finally, the testing and evaluation of the assessment tool were discussed.

In terms of epistemological foundations and presuppositions, this study was based on the constructive approach. The innovation-building design science research and constructive research approaches were identified as appropriate research approaches based on the objectives and characteristics of the study. Furthermore, the type of information used and the methods and tools for collecting and analysing the information connected this study with qualitative research. These approaches are consistent with the epistemological foundations adopted and described.
The progress of the study was divided into five phases and compared to the structures of design science and constructive research projects. The study started with identifying and defining the research problem and objectives, which was followed by developing, testing and evaluating the production system assessment tool, and finally evaluating and reporting the study. With regard to the parts of the production system assessment tool, the key characteristics of a well-performing production system were developed in an iterative process that involved identifying, evaluating, and modifying the key characteristics. Information was collected from literature, theme interviews and observation of production systems, and non-probabilistic judgement sampling and the saturation principle were used in selecting the interviewees and companies visited. The assessment scale and methods were then developed based on the key characteristics and a review of available assessment and improvement tools and approaches. Finally, to enable evaluation and justification of the production system assessment tool, the tool was tested in six pilot cases, and feedback was collected from the participants of the cases and three consultants. The sections presenting the research and development process aimed to provide sufficiently detailed descriptions to enable the process and its progress to be followed and evaluated. In presenting the development of the key characteristics of a well-performing production system, in particular, the methods used and the decisions made were compared and contrasted with available options, and the different versions developed and the modifications made during the process were presented and briefly explained.

The majority of the research work was focused on developing the set of key characteristics of a well-performing production system, and this phase can be summarised in more detail from the perspective of the research approaches used, i.e., conceptual research and design science. As is typical to conceptual research (Näsi 1980, p. 12), the development process was based on thinking, analysis and argumentation by the researcher, and hence specifying and describing the process and methods clearly and in detail is difficult. However, the four phases of conceptual research, i.e. formulating a knowledge base and theoretical framework, internal analysis, external analysis, and conclusions, proposed by Näsi (1980, p. 12-13) can be identified also in this phase of the study. In developing the initial set of key characteristics, characteristics related to production and production systems were identified and collected by conducting a literature review, which corresponds to formulating a knowledge base and theoretical framework. Then, as an internal analysis, each characteristic was broken down into more detailed definitions and considered from different perspectives. Furthermore, an external analysis, i.e. comparing, contrasting, and combining the characteristics with other characteristics and with the objectives and operation of a production system, was carried out. Finally, in the conclusion phase, the decision to include the assessed characteristic into the set of key characteristics was made. Similar phases can also be identified in the process of evaluating and modifying the set of key characteristics. Furthermore, the process of developing the set of key characteristics can be divided into phases of building and evaluation that were repeated and iterated. According to March and Smith (1995, p. 254) and Hevner et al. (2004, p. 78-80), such an iterative process consisting of building and evaluation is typical of a research project following a design science approach.
5. The TUTKA production system assessment tool

This chapter presents the results of the study, i.e. the developed TUTKA production system assessment tool. The name of the tool, TUTKA, derives from the Finnish “tuotantojärjestelmän kehittäminen ja arviointi” meaning production system improvement and assessment. The word “tutka”, meaning radar in English, is also a reference to the process of production system assessment using the tool, since, firstly, the results overview is presented as a radar chart. Additionally, by definition, a radar provides its user with information on their current location and can be used to guide their transition or journey to a desired location. Similarly, the TUTKA tool provides information and overview of current status and assists in the journey towards improved production system and production performance. The tool was developed and intended for use mainly by Finnish companies, hence the use of the Finnish acronym TUTKA.

As the objectives of this study and the development process presented in the previous chapter indicate, the TUTKA tool can be divided into three main parts (Figure 24).

![Figure 24. The three parts of the TUTKA tool](image)

The structure of this chapter corresponds to the structure of the developed tool. The key characteristics of a well-performing production system are first presented and discussed in detail, followed by an overview of the assessment scale and assessment methods.

### 5.1. Key characteristics of a well-performing production system

The set of key characteristics of a well-performing production system provide the basis for the TUTKA tool. As defined in Section 4.3., the key characteristics focus mainly on the production system and on the arrangement and organization of production resources, and aim to enable cost-efficient, rapid, and reliable production processes. The key characteristics present a desired state with which the production systems of the target companies should comply. With regard to production system assessment, the set of key characteristics provides a reference against which a production system can be compared, and thus forms the basis for the assessment process and the TUTKA tool. Table 9 presents the key characteristics of a well-performing production system, which are grouped into decision areas and connected to production objectives.

The key characteristics are grouped into six decision areas to which production-related decisions, changes and improvements can be made and categorised. With regard to assessment and improvement, the decision areas are intended to ensure that all relevant areas are considered. The decision areas also clarify the results of an assessment as the identified potential and means for
improvement can be connected to a certain area or subsystem of a production system. The six decision areas are:

- Product architecture
- Production system structure
- Production processes and management
- Production equipment
- Information and communication
- Human resources

The decision areas are also related to the focus of this study and the assessment tool (Section 1.2., Figure 1). The main focus area, the production system, is divided into four areas or subsystems: production system structure, production equipment, information and communication, and human resources. Additionally, aspects of product architecture and production processes are considered. To provide more detailed descriptions of the decision areas, product architecture considers the structure of the products, the allocation of functional elements to physical components or building blocks of a product, and the interfaces between components or building blocks. Hence, the definition of product architecture presented by Ulrich (1995, p. 420) is followed. Then, the production system structure area covers the arrangement of production units and resources; the production processes and management area covers certain general principles and characteristics related to the design, operation and management of production processes; the production equipment area covers characteristics related to the machines and equipment used in production; the information and communication area considers information and communication and related systems from the perspective of production and production control; and the human resources area includes characteristics related to the organisation and skills of employees.

Table 9 also presents six production objectives and the linkages of each key characteristic with them. The expected positive effect of a key characteristic on the production objectives is indicated with the checkmarks. In keeping with the definitions presented by Slack and Lewis (2002, p. 36) and Miltenburg (1995, p. 13), production objectives are regarded as dimensions or categories of production performance with which the company and production attempt to satisfy customer requirements and compete with customers. The six production objectives are defined as follows:

- Quality (Q): the ability of materials, products and operations to conform to specifications and to meet the expectations and requirements of customers.
- Time (T): lead time of production or delivery time of an order to customers, i.e. the time required to produce a product or the time from placing the order to delivery of the product.
- Reliability of lead or delivery time (R): ability to meet the defined lead or delivery time.
- Volume flexibility (VF): range of product volume that can be produced profitably. Covers also the ability to profitably change the production volume according to demand.
- Product flexibility (PF): range of products or product variety that the production system and production processes are able to produce profitably. In this study, instead of increasing product variety and aiming to produce the broadest possible product range, the focus is on the ability to produce the product variety offered to customers using controlled and stable production processes. In addition to product variety, also the ability to change the production schedule and product mix are considered.
- Cost (C): costs and expenditures derived from resources such as labour, equipment and material, used to produce a product.
The production objective definitions were developed to be applicable and suitable for this study and the TUTKA tool based on definitions and descriptions presented in literature (e.g., Wheelwright 1984; Skinner 1992; Voss 1995; Slack & Lewis 2002; Slack et al. 2004; Kaplan & Norton 2004).

In addition to the production objectives, production controllability is considered in discussing the effects of key characteristics on production in the following sections. Production controllability is connected to effort required to control the production units and production process. Good production controllability or simple production control means that the production schedule can be carried out easily and without exceptional effort. Similar descriptions have been presented, for example, by Lapinleimu et al. (1997, p. 230) and Torvinen et al. (2004, p. 71).
<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristics</th>
<th>Production objectives</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Q</td>
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<tr>
<td><strong>Product architecture</strong></td>
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<tr>
<td>Product architecture is modular</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Product platforms are used</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Product structure consists of predefined parts and subassemblies</td>
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<td>X</td>
</tr>
<tr>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
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<td>X</td>
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<tr>
<td><strong>Production system structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Production system structure corresponds to the structure and production process of products</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Distances between production units and distances between production equipment are short</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Production processes and management</strong></td>
<td></td>
<td></td>
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<tr>
<td>Dissimilar main processes of production are identified and separated from each other</td>
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<td>X</td>
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<tr>
<td>Processes of production units are defined</td>
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<td>X</td>
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<tr>
<td>Processes and procedures between production units are defined</td>
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<td>X</td>
</tr>
<tr>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
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<td>X</td>
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<tr>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
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</tr>
<tr>
<td>Responsibility for production control is allocated to production units</td>
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<td>X</td>
</tr>
<tr>
<td>Close cooperation between production units is supported and enabled</td>
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<td>X</td>
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<tr>
<td><strong>Production equipment</strong></td>
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<td></td>
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<tr>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
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<td>X</td>
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<tr>
<td>Changeover and set-up times of equipment are short</td>
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<tr>
<td>Production equipment enables integration and reduction of production phases</td>
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<tr>
<td>Production equipment is reliable and available for use</td>
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<td>X</td>
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<tr>
<td>Production equipment is easy to use</td>
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<td>X</td>
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<tr>
<td>Production equipment supports occupational safety and ability to work</td>
<td></td>
<td>X</td>
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<tr>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
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<td>X</td>
</tr>
<tr>
<td><strong>Information and communication</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information and communication support and enable decision-making</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Information and communication systems are reliable and available for use</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Visual information and control systems are used in the production system</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Human resources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teamwork and team organisation are used in production</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Occupational safety and ability to work are emphasised and ensured</td>
<td></td>
<td>X</td>
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</tbody>
</table>

The key characteristics can also be considered at more detailed level and, on the other hand, connected to each other. This results in the hierarchy presented in Figure 25. The most detailed level presents definitions and descriptions and breakdown points for each key characteristic.
These assist in assessing the realisation of the key characteristics and in identifying potential and means for improvement. At the higher levels, the key characteristics can be combined into production system and process themes, and linked with production objectives. These assist in summarising and presenting the assessment results.

![Hierarchy and different levels related to the key characteristics of a well-performing production system](image)

Figure 25. Hierarchy and different levels related to the key characteristics of a well-performing production system

The following sections present and discuss the key characteristics of a well-performing production system in detail. First, the key characteristics included in the decision areas are presented (Sections 5.1.1.-5.1.6.). For each key characteristic, its breakdown points and a definition and description are presented. Also, the effects of each key characteristic on the production system, production processes and production objectives are discussed, the reasons for including each key characteristic in the final version are presented, and the modifications made during the development process are explained. Combining the key characteristics into production system and process themes, and connecting the key characteristics with production objectives are then discussed in Sections 5.1.7 and 5.1.8.

### 5.1.1. Product architecture

This decision area covers product architecture and structure and considers the decomposition of a product into physical building blocks and components, their interfaces, and the allocation of functional elements to these. Although product architecture and structure are closely related to and dependent on the product design, they are considered only from the production point of view, and product design as a function or a process is not considered in this study. The following key characteristics are included in the decision area:

- Product architecture is modular
- Product platforms are used
- Product structure consists of predefined parts and subassemblies
- Levels in product structure simplify the structure of the production system and support production control

In general, these key characteristics aim to enable rapid configuration of an order-specific product and production of the product variety offered to customers using efficient and controllable production processes. Thus, in terms of production objectives, the key characteristics mainly focus on cost, lead time and product flexibility.
• Product architecture is modular
  o Products consist of building blocks (modules) that have specified interfaces
  o The interfaces of the modules enable interchangeability, i.e. changing a module or its
    functions or features in such a way that the change does not affect other modules of
    the product
  o Modules of a product can be tested separately before assembling the product

Modularity or modular product architecture has been widely discussed in literature and, for example, Lehtonen (2007) presents an overview of different definitions of and approaches to modularity. With regard to definitions, Ulrich (1995, p. 422) emphasises the allocation of functions to physical parts of a product and states that a modular product architecture includes one-to-one mapping from functional elements to physical parts of a product and decoupled interfaces between interacting parts. On the other hand, Erixon (1998) puts less emphasis on functionality and defines modularisation as the decomposition of a product into building blocks (modules) with specific interfaces, driven by company-specific needs. He then presents 12 reasons or drivers that can be used as a basis for decomposition. These include, for example, carry over, planned design changes, process/organisation, and separate testing. (Erixon 1998, 1996) In the context of configuration and configurable products, Lehtonen (2007, p. 88) defines that “A block (any assembly of the product or part of the system) is a module if it has an assigned interface and it is a part of a modular system” and that “A modular system is a system consisting of blocks which involves the interchangeability of the blocks”.

The definition of modular product architecture used in this study is presented by the two first breakdown points of this key characteristic and follows the definition presented by Lehtonen. The requirement of products consisting of building blocks, presented in the first breakdown point, is related to creating a unit structure for a production system. According to Lehtonen (2007, p. 92-93), such building blocks, or modules that are physical assemblies, result from assembly-based modularity that aims to support production. On the other hand, regarding the module types presented by Lapinleimu (2001, p. 143), such building blocks correspond to structural modules. Structural modules provide the basis for forming a clear unit structure in a production system and they can be handled in production as individual entities (Lapinleimu 2001, p. 143). Hence, such a modular structure simplifies production control and enables a branch-type production process in which modules can be produced in parallel. The requirement for specified interfaces, presented in the second breakdown point, aims to enable interchangeability, to simplify the configuration process, and to support efficient production of the product variety offered to customers.

With regard to the definition of and requirements for modular architecture, the ideal situation in terms of the module types and modularity presented by Lapinleimu (2001, p. 143) would be that the same structural modules could be used in sales, configuration, and production. However, Lapinleimu (2001, p. 143) and Lehtonen (2007, p. 93) point out that some functions and features, for example, hydraulics and electricity, have an effect on and must be divided and located into several assemblies. This may result in function-based modularity and functional modules, i.e. modules that are designed, functional entities of the product. Such functions and features, and functional modularity make it more difficult to define and standardise the interfaces of modules, to enable interchangeability of modules, and to limit the order-specific functions and features to certain modules. From the point of view of production, function-based modularity and functional modules are not desirable because whereas this approach aims to assist sales, product design and configuration, production is not capable of operating on the basis of functional modules. (Lehtonen 2007, p. 93; Lapinleimu 2001, p. 143)

Finally, the third breakdown point focuses on testing. The aim is to simplify the testing of the final product and to ensure that the modules meet quality requirements by testing the modules
before final assembly. The need to emphasise this aspect was identified in the theme interviews in the target companies of the study. Testing modules independently, and its advantages and effects on final testing are also highlighted by Ulrich (1995, p. 435).

The advantages of modular product architecture in configuring and producing an order-specific product are addressed by many authors (e.g., Pine 1993; McCutcheon et al. 1994; Ulrich 1995; Jahnukainen et al. 1996; Lapinleimu 2001). For example Jahnukainen et al. (1996, p. 57) and Lapinleimu (2001, p. 142-146) state that in an ideal or optimal situation, a modular product architecture enables configuring an order-specific product by selecting the module variant that meets the requirements of the customer. Additionally, Pine (1993, p. 196-203) and Slack and Lewis (2002) maintain that a relatively wide variety of products can be configured using relatively few modules. Furthermore, the specified interfaces of modules simplify the production of the order-specific product and the product variety offered to customers by making it possible to limit the order-specific features and functions to certain modules, to easily change the modules of a product, and to share modules between different products. These ideas are illustrated in the following figures.

Figure 26. Configuring an order-specific product by selecting the appropriate module variants (Soronen 1999, p. 19)

Figure 26 presents the idea of configuring and creating an order-specific product by selecting an appropriate variant of a module. Figure 27 illustrates the interfaces of modules and different types of modularity.

Figure 27. Module sharing and swapping enabled by interfaces (Pine 1993)

Modular product architecture is expected to have a positive effect on several objectives of production. Firstly, a modular product architecture assists in designing a clear unit structure of the production system and in configuring an order-specific product. Furthermore, it supports producing the required product variety in a controlled and efficient way. Similar objectives and advantages of modular product architecture are presented, for example, by Lapinleimu (2001, p. 140) and Lehtonen (2007, p. 92-93). In terms of objectives of production, modular product architecture can be connected to product flexibility, lead time, quality, and cost-efficiency. It supports product flexibility, which in this study is defined as ability to produce the product variety offered to customers efficiently and reliably, by simplifying the configuration and production process of an order-specific product. The ability to produce modules in parallel rather than in sequential production units shortens lead times. Furthermore, Ulrich (1995, p. 431) states that a modular product architecture supports part-level standardisation, which has a positive
effect on cost-efficiency. Finally, the positive effect on quality, for example achieving a consistent quality level, results from the ability to test modules independently.

The key characteristic concerning modular product architecture was identified in the literature review carried out in developing the first version of the set of key characteristics. In the theme interviews the key characteristic was agreed on and recognised as being beneficial to the target companies of the study, and has therefore not been modified.

- Product platforms are used
  - Products of a certain product family or a product model have a common entity (e.g., a subassembly or subassemblies) which is independent of the customer order
  - The same production process for producing the product platform can be used for all the products of a product family

Product platforms have been defined in various ways in literature. Stake (2001, p. 171) summarises two main viewpoints regarding product platforms: the commonality-based viewpoint, which regards the common elements of the product family to be the product platform, and the resource-based viewpoint, which regards all the resources necessary to build the product family to be the product platform. Muffatto and Roveda (2000, p. 618) point out that earlier, production-oriented definitions emphasised the physical commonality between the products of a product family, which, for example, enables the use of the same production processes to produce different products. More recent definitions present the product platform as a multifaceted concept that has an effect on production and logistic processes, development process, project organisational structure and knowledge (Muffatto & Roveda 2000, p. 618-619). An example of a broad definition of a platform is presented by Robertson and Ulrich (1998, p. 20), who state that a platform is “the collection of assets that are shared by a set of products. These assets can be divided into four categories: components, processes, knowledge and people and relationships.”

In this study, product architecture is considered from the point of view of production and, therefore, the component and process categories presented by Robertson and Ulrich (1998), and the commonality-based viewpoint and physical commonality (Muffatto & Roveda 2000, p. 618; Stake 2001, p. 171) are emphasised. Here, the product platform is defined as a set of parameters, features, parts, or modules that are independent of a customer order and common to products belonging to a product family or product model. This definition is similar to that of Simpson et al. (2001, p. 3) and is included in the first breakdown point. The second breakdown point emphasises the ability to standardise the production process of the product platform and the ability to use the same platform and its production process for all products of a product family or model.

Use of product platforms simplifies configuring and producing order-specific products, and supports efficient production of the product variety offered to customers. The main advantage is that a product platform supports standardization of parts, and reduces the variety and increases the volume of parts and modules needed to produce the product variety offered to customers (e.g., Robertson & Ulrich 1998, p. 20; Muffatto & Roveda 2000, p. 617). Furthermore, the configuration process of an order-specific product is simplified because the product platform provides the common core of products on which the order-specific features and functions of the product can be built. Modular product architecture can also be linked to this because it supports and simplifies the configuration and production of the order-specific functions and features for the product as discussed in the context of modular product architecture. This idea of dividing a product into a standard part, i.e. platform and variant part, and utilising modular architecture in configuring and producing the order-specific part of the product is also presented, for example, by Lehtonen et al. (2003) and Lehtonen (2007, p. 92-93). They term the approach platform-based modularity, and it is seen to contribute towards controlling variation and towards cost-efficient
production of order-specific, configured products (Lehtonen et al. 2003; Lehtonen 2007, p. 92-93). Finally, the use of product platforms also supports and enables postponement of product differentiation, the aim being to differentiate products at the latest possible stage of the production process. In other words, the aim is to incorporate order-specific characteristics and functions into the product only after customer orders are received. (van Hoek 2001, p. 161; Yang et al. 2004, p. 468, 472) Figure 28 presents the advantages and objectives of using product platforms, i.e. the ability to produce a relatively wide variety of products using a relatively limited variety of parts.

Figure 28. Product design approaches and advantages of postponing differentiation of products (Maskell 1991, p. 187)

With regard to production objectives, the use of product platforms is connected here to flexibility and efficiency. Considering product flexibility, product platforms contribute towards simple and rapid configuration and production of an order-specific product, as discussed above. Thus, with regard to product flexibility, the product platform supports controlled and efficient production of a product variety offered to customers rather than producing and offering the widest possible product variety. With regard to efficiency, advantages and possibilities related to the use of platforms, such as reducing variety, increasing volume, and supporting standardisation of the parts needed to produce the required products, contribute towards economies of scale and reduced production costs (Robertson & Ulrich 1998, p. 20; Muffatto & Roveda 2000, p. 617). Furthermore, the postponement approach and the ability to use the same platform and its production process for all products of a product family support the standardisation of processes and reduce uncertainty and variation in the process. This is expected to result in quicker and more cost-efficient production compared to a situation where the entire production process is dependent on the customer order. This effect of the postponement approach on cost-efficiency of production is also pointed out by van Hoek (2001, p. 162). Finally, compared with producing or even designing the entire product based on customer requirements, the shorter order-specific part of the production process should result in shorter delivery time.

The advantages of using product platforms were identified in the literature review in developing the initial set of key characteristics of a well-performing production system. The key
characteristic was accepted and seen to be beneficial in the theme interviews, and has therefore not been changed.

- Product structure consists of predefined parts and subassemblies
  - An order-specific product consists of predefined parts and subassemblies
  - Compatibility of and interaction between the predefined parts and subassemblies are known

The key characteristic suggests using predefined parts and subassemblies in the products offered to customers. According to Salvador and Forza (2004, p. 275) a predefined part can be either a standard part, a standard part with variants, or a parametric part, i.e. a part for which one or more attributes vary continuously. However, Pulkkinen (2007, p. 56) shows that in the context of product differentiation, the use of parametric parts locates the point of differentiation at the part production stage, whereas standardised parts or standard parts with variants enable product differentiation at the assembly stage. Thus, from the point of view of production, standard parts, possibly with variants, are more preferable than parametric parts.

The aim of the key characteristic and its breakdown points is to eliminate the need for order-specific product design, which simplifies defining and configuring the order-specific product. The first breakdown point requires that the parts, and possibly subassemblies, used in products are predefined, which removes the need for part-level design in the order-to-delivery process. Furthermore, the second breakdown point states that the relationships and interactions between parts and between subassemblies are known, which enables configuring rather than designing an order-specific product. The key characteristic is also connected to sales and marketing, because realising it requires that the company defines in advance the product variety it offers to customers (e.g., Salvador & Forza 2004, p. 275).

Implementing the key characteristic provides several advantages to production and to the order-to-delivery process. If predefined parts are used and the available product variety is known and defined, variety and uncertainty related to orders and product characteristics required in them are reduced. Consequently, variation and uncertainty related to production processes and operations required to comply with an order are reduced. (Salvador & Forza 2004, p. 276) Thus, designing, implementing and stabilising the required production processes, and improving their efficiency is easier than in a situation where products are designed and produced on the basis of an order. Furthermore, applying the key characteristic improves production controllability, as a relatively small number of recurrent parts or subassemblies instead of order-specific parts or subassemblies are controlled (Lehtonen 2007, p. 75). With regard to production objectives, these advantages can be connected with production costs as well as lead time and its reliability. The reduced variety and uncertainty of orders and product characteristics, and improved stability and controllability of processes contribute towards lead time reliability. The ability to improve the efficiency of production processes is connected with cost-efficiency and short lead time. Furthermore, the delivery time to customer should be shorter than in situations where product design at the part level is required. Finally, the key characteristic can be connected with product flexibility as it supports controlled and efficient production of the predefined product variety.

The advice of using predefined parts as well as the resulting advantages in the context of configuring and producing order-specific products have also been presented by Tiihonen et al. (1998, p. 2), Nummela (2006, p. 56-60) and Pulkkinen (2007, p. 74-75). The need and advantage of defining and limiting the offered product variety is also presented in mass customization literature. There, the term “stable solution space” is used to refer to stable production processes and product architectures, and to pre-existing and predefined capabilities and degrees of freedom in a production system (Pine 1995; von Hippel 2001; Tseng & Piller 2003, p. 6; Piller 2004, p. 316).
This key characteristic was added after the first round of theme interviews, during which its importance as an enabler and prerequisite for configurable products and simple configuration process was emphasised. In the second round of interviews the key characteristic was accepted and seen to be useful, therefore it was not modified. The key characteristic is also closely related to the definition of the target companies of this study. The target companies were assumed or required to operate on the basis of the make- or assemble-to-order approach and, with regard to the product variety offered to customers, the products were assumed or required to be configured, not designed, on the basis of a customer order (Section 1.3.). Thus, this key characteristic should be implemented if the company meets the criteria presented. However, including this issue in the set of key characteristics and in the assessment process was seen to be important because it enables consideration of the correspondence between process and product adaptability, or between the type of product and production process. This aspect is emphasised also, for example, by Juuti (2005, p. 124) and Pulkkinen (2007, p. 85-86). The key characteristic also assists in evaluating whether the products and product variety of the assessed company and production system are consistent with the characteristics presented in the other decision areas.

- Levels in product structure simplify the structure of the production system and support production control
  - Product structure does not contain excess or unnecessary levels (i.e. all levels in the product structure are useful in terms of structuring the production system and controlling production)
  - The levels of product structure enable correspondence between product structure and production system structure
  - The levels of product structure simplify and support production management by enabling procurement and production control at the level of subassemblies or building blocks of the product

This key characteristic emphasises the need to optimise the number of levels in the product structure by considering different perspectives. The aim is to eliminate unnecessary levels in the product structure while also ensuring that the levels support the design of a clear unit structure for the production system, and also serve to support production control and purchasing.

The breakdown points present more detailed requirements related to the product structure levels. Firstly, minimising the number of levels in the bill of materials (BOM) and product structure in order to reduce the complexity of the product and the required production system is emphasised. This is based on the view that a level in the product structure corresponds to a phase in the production process. Hence, a simple product structure with few levels results in a simple production process with few phases. Thus, reducing the levels in the bill of materials and in the product structure simplifies production control, improves controllability of production, and shortens production lead time (Lapinleimu 2001, p. 118, 146; Torvinen et al. 2004, p. 73). The need to and advantages of reducing the number of levels in the product structure are also emphasised, for example, by Maskell (1991) and Stonebraker (1996). On the other hand, in the first round of theme interviews the interviewees pointed out that the number of levels must be sufficient to identify the building blocks of the product and to create similarity between the product structure and the production system structure. This is mentioned also by Stonebraker (1996) and is presented in the second breakdown point. The issue is discussed and emphasised also in the next decision area, which addresses the production system structure. Finally, the last breakdown point requires that the levels of the product structure support production control and purchasing by enabling identification of manageable entities of a product. The aim is to simplify production management by reducing or eliminating the need for purchasing and production control at the part level. This perspective was emphasised in the theme interviews.
With regard to the objectives of production, the key characteristic is connected with lead time and its reliability. Reducing the levels in the product structure and the number of phases in the production system and process contributes towards a shorter lead time. This can result, for example, from a reduced number and duration of non-value-adding operations, such as handling and storage between production phases. Furthermore, reducing the number of levels is also seen to improve both controllability of production and reliability of lead time. On the other hand, correspondence between the production system structure and the product structure creates a clear material flow, which simplifies production control and contributes towards a short and reliable lead time. This aspect is also discussed in the production system structure decision area.

In the earlier versions of the set of key characteristics, this key characteristic emphasised reducing or minimising the number of levels in the product structure. However, in the interviews it was pointed out that an optimal rather than minimal number of product structure levels should be sought and emphasised. Therefore, the key characteristic has been rephrased to emphasise the objectives and use of the levels in the product structure, and the breakdown points aim to present the viewpoints on optimising the number of levels.

5.1.2. Production system structure

In this decision area the focus is on the structure and layout of the production system, i.e. the physical arrangement of the production system, production units and production resources. The following key characteristics are included in the decision area:

- Production system consists of production units that are responsible for certain parts of a product
- Production system structure corresponds to the structure and production process of products
- Distances between production units and distances between production equipment are short
- Production system structure makes it possible to observe the state of and the prerequisites for production
- Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work

The general purpose of the key characteristics related to production system structure is to enable rapid, controllable and predictable flow of products, and efficient and controlled production of the required product variety and volume. Thus, the key characteristics are related to production costs, lead time and its reliability.

With regard to the terms used in this decision area, the production system is defined to consist of production units, and the production system can be considered at different levels. As mentioned in Section 1.2., this study focuses mainly on one company, i.e. the company responsible for assembling the final product and delivering it to the customer. Thus, the production system consists typically of a single factory in which the production units are, for example, part production or assembly cells or units, or functional departments such as painting. However, the production system can also consist of several factories, in which case the factories are seen as production units of the production system. Furthermore, a production system can be considered in a narrower and more detailed context. In such a case, for example an assembly cell is considered as a production system, and workplaces or work stations are seen as production units of the production system. Of the key characteristics included in this decision area, the first three, in particular, can be considered and assessed at these different levels.
Production system consists of production units that are responsible for certain parts of a product
- Production system consists of production units that have defined products
- The product(s) of a production unit can be completed in the production unit
- Production units enable a branch-type production process, i.e. building blocks of a product can be produced in parallel processes/production units

This key characteristic seeks for a clear unit structure of a production system, i.e. that a production system consists of production units that are responsible for products that have been determined and allocated to them. Similar advice on structuring a production system has been presented by Suri (1998, p. 90) and Lapinleimu (2001, p. 96, 98) who state that a production system should consist of production units that are independent in terms of resources and that are responsible for one or more parts of the product.

The breakdown points provide more detailed definitions and requirements for the production units and their operation. The first breakdown point states that the production system should consist of production units that are responsible for their own products, such as parts, or subassemblies of the end product of the production system. The second breakdown point aims to ensure that the production unit has the resources and capabilities required to produce the products that have been dedicated to it. Finally, with regard to the production process, the production units should enable parallel rather than sequential production of the parts and entities of the end product. These aspects and requirements related to the structure of a production system have also been emphasised by Lapinleimu (2001, p. 86-87, 98, 117-118), who also argues that the applicability and functionality of the unit structure of a production system has been proven in cellular production.

In terms of production objectives, Suri (1998, p. 105) summarises that the unit structure of a production system provides advantages in terms of costs, lead time, and reliability of lead time. These result mainly from simpler material flow and production control, and reductions in material handling when compared to functional layout (Suri 1998, p. 105; Lapinleimu 2001, p. 138). Lapinleimu (2001, p. 118) also points out that a branch-type production process enabled by the unit structure of a production system shortens the lead time compared to a chain-type production process. Furthermore, the unit or cellular structure of a production system is seen to support operational flexibility and small batch sizes (Lapinleimu 2001, p. 73-74), which is here linked with product flexibility. Finally, clear allocation of responsibilities for products can improve the quality of products and operations (Suri 1998, p. 105).

The key characteristic was identified during the initial literature review and was included in the first version of the set of key characteristics. Its usefulness and applicability were confirmed in the theme interviews, and it has therefore not been modified.

Production system structure corresponds to the structure and production process of products
- Production units are arranged and located based on the structure and production process of the products
- Equipment is arranged and located based on the structure and production process of the products

This key characteristic emphasises the product-based layout of a production system, i.e. arranging production units and resources according to the structure and production process of the products. Figure 29 demonstrates and clarifies the key characteristic by presenting the different levels of a product: final product, module and sub-module, part and blank; as well as the corresponding production system units.
The breakdown points consider the key characteristic at two levels. Firstly, at the production system level, production units should be located on the basis of the structure and production process of the products. The second breakdown point then considers the layout at the production equipment level. These principles and guidelines have also been presented by Maskell (1991, p. 7-8) and Lapinleimu (2001, p. 96, 138) as well as in literature on lean production (Womack & Jones 1996; Ohno 1988; Crabill et al. 2000, p. 25) and cellular layout (e.g., Suri 1998, p. 90).

With regard to production objectives, the key characteristic is expected to have a positive effect on lead time and its reliability, costs and quality. Firstly, the product-based layout is intended to eliminate back- and cross-flow between production units and the delays in the production process caused by these. This contributes towards short lead time. Short lead time can then be linked with cost efficiency, as short lead time typically results in less work-in-progress and lower inventory levels (Lapinleimu 2001, p. 76-78). Furthermore, when compared with functional layout, the product-based layout simplifies and supports production control, which is expected to improve reliability of lead time. The advantages of a product-based layout in terms of short and reliable lead time and controllability of production have been presented by a number of authors, such as Schonberger (1986, p. 102-105), Maskell (1991), Krajewski and Ritzman (1996, p. 402), Suri (1998, p. 105), Lapinleimu (2001, p. 97), Slack et al. (2004, p. 217), and Torvinen et al. (2004, p. 80). Finally, Torvinen et al. (2004, p. 103-104) assert that a product-based layout and clear material flow improves the ability to detect and react to disruptions in production, which in turn assists in achieving required quality and reliable lead times.
The correspondence between production system structure and product structure was identified in the initial literature review and presented in the first version of the set of key characteristics. During the second round of theme interviews, the need to locate production units and equipment according to the production process to ensure rapid and clear material flow was emphasised. The wording of the key characteristic was slightly modified accordingly after the interviews.

- Distances between production units and distances between production equipment are short
  - Sequential production units and production equipment are arranged and located in close proximity to each other
  - Short distances between production units and between production equipment enable and encourage production and transportation in small batches

This key characteristic focuses on distances within a production system and considers both production units and equipment. The aim is to have short distances within the production system and production processes, which has been emphasised by number of authors (e.g., Schonberger 1986, p. 104; Karlsson & Åhlström 1996, p. 27-28; Suri 1998, p. 90). The first breakdown point requires that sequential production units as well as sequential production equipment are arranged and located in close proximity to each other. Exceptions to this do, however, exist, since some processes need to be separated from other processes, for example due to strict requirements on cleanliness, temperature, vibration or humidity. The second breakdown point suggests that, since the distances within a production system can have an effect on the batch sizes used in production, the distances between production units and between equipment should enable, or encourage, small transfer and production batches.

The key characteristic aims to create a clear and simple material flow and production process, and to reduce the need for and distance of transportation in the production process. With regard to production objectives, these are connected with lead time, its reliability, and costs. By removing non-value-adding work and delays caused by transportation and handling, the key characteristic aims to shorten lead time and to reduce production costs. This aspect is stressed, for example, in literature on lean production (e.g., Ohno 1988; Womack & Jones 1996; Liker 2004). Furthermore, implementing the key characteristic enables small transfer batch sizes, which reduces delays and waiting in the production process, and contributes towards short lead time and cost-efficiency. Small transfer batches can also make production process disruptions and part and product defects more easily identifiable. This enables quicker identification and reaction to disruptions and problems and can hence contribute towards lead time reliability and constant, high quality (Torvinen et al. 2004, p. 103-104).

The key characteristic was identified during the initial literature review and included in the first version of the set of key characteristics. The characteristic was confirmed in the theme interviews as being both relevant and useful, and it has therefore not been changed.

- Production system structure makes it possible to observe the status of and the prerequisites for production
  - Production system layout and production unit arrangement enable identification of material flow and production process phases
  - Materials, parts and subassemblies of a production unit have defined locations
  - Required tools have defined and clearly marked locations in production units

This key characteristic aims to improve and ensure the visibility and ability to monitor the status of the production processes and the availability of the required prerequisites for production. The
production process status includes the work load of the production units and their ability to meet and keep up with the production schedule. Also related to this is the progress and status of the products, for example in which phase of its production process the product is currently in, and when it will be completed. The prerequisites of production include the materials, parts and subassemblies as well as the tools, equipment capacity and employees required to produce a product and to complete an order.

The breakdown points of the key characteristic present more detailed requirements and means for the visibility, observation and monitoring of the production processes and prerequisites of production. With regard to the first breakdown point, for example the unit structure and product-based layout of the production system discussed in the previous key characteristic support the identification of material flow and the phases of the production process. Furthermore, clearly defining the locations for both the incoming and outgoing parts, materials and subassemblies of a production unit, and for the tools used in the unit enables observation of the availability of the prerequisites for production. The defined locations also support monitoring of the work load and production schedule of the production units by making it possible to identify shortages or build-ups of materials and parts at the units. The importance of the visibility and ability to monitor the status of the production processes has been emphasised and similar means to those discussed here have been presented, for example, by Greif (1991) and Torvinen et al. (2004, p. 146) as well as in literature on lean production (e.g., Liker 2004, p. 152).

In terms of production objectives, the key characteristic supports lead time reliability and quality. The visibility and ability to monitor the status of the production processes, and the availability of the prerequisites for production make it possible to quickly identify any problems and deviations from planned or standard status. For example, an inability of a production unit to meet the production schedule or a shortage of required parts or materials at a production unit can be observed and identified. Thus, because the key characteristic enables rapid identification of and reaction to problems and deviations, it is expected to have a positive effect on quality and lead time reliability.

The key characteristic was added after the second round of theme interviews. Previously, visibility and visual control and information were considered in the information and communication decision area. However, during the interviews and subsequent analysis it was noted that the production system structure can also contribute towards monitoring the status of the production process and products. Thus, this key characteristic was added and visibility and the means for implementing or ensuring it are considered in two decision areas.

- Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work
  - Required equipment, materials and tools are located in workplaces so that non-value-adding work is minimised and value-adding work is supported
  - Need to handle, e.g., pick up, move, lift or rotate, materials, parts or products before or during work task is minimised
  - Locations of material and tools enable ergonomic working positions

This key characteristic focuses on reducing non-value-adding work and on making value-adding work easier and more efficient. These objectives and their importance are emphasised, for example, in literature on lean production (Ohno 1988; Womack & Jones 1996; Liker & Meier 2006). With regard to production objectives, the key characteristic’s aims of reducing non-value-adding work and improving the efficiency of value-adding-work are expected to have a positive effect on lead time and cost-efficiency.
The breakdown points present means for implementing the key characteristic. One way of reducing non-value-adding work and supporting value-adding work is to remove unnecessary items from the workplace and to locate the remaining tools according to their use, so that they can be found and taken into use easily and quickly. This follows the principles of 5S presented, for example, by Hirano (1996). Further means for implementing the key characteristic include eliminating or reducing typical non-value-adding activities, such as handling and moving parts and products, by means of the layout and organisation of the workplace and by locating tools and materials appropriately. These means and issues are presented and emphasised also in literature on lean production (e.g., Liker & Meier 2006, p. 36) and by Torvinen et al. (2004, p. 145-146). Finally, ergonomics and ergonomic working positions are seen as a way to improve the efficiency and productivity of work, as affirmed by MacLeod (1994, p. 19).

The key characteristic was added to the set of key characteristics after the second round of theme interviews as it was seen to be relevant and important for the efficiency of production processes and work tasks. Elimination of non-value-adding work and supporting value-adding work are also discussed in the production equipment decision area, where the means for that include tools and auxiliary devices.

5.1.3. Production processes and management

In this decision area, the focus is on the processes of the production system and on management of the processes. In accordance with the focus of this study, only rather general characteristics and aspects are considered, and a detailed consideration of processes, their operation and management is omitted. The following key characteristics are included in the decision area:

- Dissimilar main processes of production are identified and separated from each other
- Processes of production units are defined
- Processes and procedures between production units are defined
- Plans and procedures for responding to production disruptions, problems and delays are in place
- Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point
- Responsibility for production control is allocated to production units
- Close cooperation between production units is supported and enabled

The main target of the key characteristics is to ensure reliability of processes and their output, but they also consider and aim to improve efficiency of production. In terms of production objectives, reliability is connected with quality and reliability of lead time while efficiency can be linked with lead time and costs.

Consistent with the defined focus and scope of the study, the assessment and improvement of production processes and their management are limited to a single company, although the key characteristics presented in this decision area can be applied also to production networks consisting of several companies and factories. As mentioned in Section 1.2., the key characteristics and assessment focus on how the processes are designed and planned to be carried out, while the actual operation and results of the production processes are not considered.

- Dissimilar main processes of production are identified and separated from each other
  - Different types of products are produced in separate processes
  - Processes of assembled part production and spare part production are separated

This key characteristic emphasises the characteristics of a process and the products produced in it and suggests that different types of processes should be identified and separated in order to
enable efficient production processes and to support production control. As the breakdown points indicate, the key characteristic is divided into two parts, and processes and products or parts produced in them are considered from two viewpoints.

The first breakdown point focuses on how the products are varied and how order-specific a product is. Products can be classified, for example, as standard products, configured products, and products requiring order-specific design. Another classification presented by Pulkkinen (2007, p. 84-85) consists of standard products, standard products with variants defined by the company, standard products with variants defined by the customer, and one-of-a-kind products. These product types can be linked with different types of production processes and production approaches, such as engineer-to-order, make-to-order and assemble-to-order, and to different degrees of adaptability of a production process (Juuti 2005, p. 124-125; Pulkkinen 2007, p. 86). The breakdown point suggests that the characteristics and properties of a process should correspond to the characteristics and requirements of the products produced in it. For example, products that are designed and produced based on an order require a more adaptable process and engineer-to-order approach, while standard products can be produced in a less adaptable and more standardised process using, for example, a make-to-stock approach. However, if having separate processes and resources for different types of products is not feasible or possible, but different types of products have to be produced in the same process, then defining clear and strict rules for scheduling and controlling the production of different product types is important.

The second breakdown point focuses on assembled and spare parts, and suggests that production of these two types of parts and subassemblies should be separated. This is supported also by Torvinen et al. (2004, p. 77). Similarly to the first breakdown point, if spare parts and assembled parts must be produced in the same process, for example for economical reasons, then clear procedures and rules for scheduling are needed.

The key characteristic is intended to ensure and improve the controllability, reliability, and efficiency of production processes, which each contribute towards short and reliable lead time and cost-efficiency. With regard to different types of products, correspondence between the characteristics of products and processes, for example adaptability and flexibility, contributes towards efficient production processes. As an example, producing standard products in an adaptable process that is designed for producing order-specific products is less efficient than producing the products with a less adaptable and more standardised process. Thus, identifying different types of products and producing them in separate processes supports efficiency of production. Separating different types of products into different processes also simplifies production control because the similarity of the products produced in a certain process is increased compared to a situation where all products are produced in the same process. Additionally, separating spare part production from production of assembled parts simplifies production control because assembled parts production can be planned, balanced and scheduled on the basis of orders or production schedule and product structure, and spare parts do not cause unexpected changes and variation to production volume and schedule (Torvinen et al. 2004, p. 77). The simpler production control supports the reliability of processes and is hence connected with lead time reliability. Finally, as a result of increased similarity between products produced in a certain process and the stability of processes, the key characteristics is assumed to support optimising and improving their efficiency, for example in terms of production costs. The importance and advantages of identifying different types of products and producing them in separate processes have been presented also by other authors, such as Juuti (2005, p. 124-125) and Netland et al. (2007, p. 37).

The key characteristic was added in the final phase of developing the TUTKA tool, when assessment questions and claims were discussed and evaluated with the three experts. They pointed out the importance of separating different kinds of processes, and therefore the key
characteristic was added. Thus, the key characteristic was not evaluated in the theme interviews. However, it was discussed during the assessment cases, and the participants agreed on the applicability and usefulness of the key characteristic, which is seen to justify including it in the set of key characteristics. The type of products is discussed also in defining the target companies of this study, where the focus is limited to companies producing products that are configured based on an order. However, many companies produce more than one type of product, and therefore presenting and assessing this key characteristic is seen to be relevant and important.

- Processes of production units are defined
  o Processes and tasks within production units are defined and described
  o Definitions include all relevant information to carry out the process, e.g., inputs, outputs, duration, tasks and work procedures of a process
  o Process definitions ensure reliable material flow and support improvement and learning

This key characteristic requires that processes within production units are clearly and accurately defined. In keeping with Spear and Bowen (1999, p. 98), Liker (2004, p. 142) and Torvinen et al. (2004, p. 99, 109) the definitions of processes are required to include all relevant information for carrying out the process, such as required inputs, outputs, expected quality level, duration of the process, tasks included in the process and their sequence, and correct work procedures. The third breakdown point presents the advantages and objectives of defining processes, but is also connected to the level of detail of the definitions: definitions should be detailed enough to make the processes repeatable and to ensure reliable output. The definitions and descriptions of processes also assist in teaching the tasks and processes to new employees. Furthermore, defined and repeatable processes support improvement, because the defined way of performing the process provides the basis for improving the process and its performance, and because repeatability and recurrence of processes allows employees to learn and optimise the way the process is carried out (Liker 2004, p. 142; Torvinen et al. 2004, p. 99).

The key characteristic and defined processes are intended to ensure reliable and predictable processes and their outputs. In terms of objectives of production, the key characteristic can be connected with reliability of lead time and quality. With regard to lead time reliability, process definitions aim to ensure the ability of production units to meet the production schedule, to produce the required volume, and to serve the subsequent production units, and hence support achieving reliable material flow and production processes. Preparing the process definitions is also intended to reduce variation in content, duration, and outputs of the processes, which is connected to reliability of lead time and ability to meet required quality levels. Furthermore, defined and more predictable processes improve the controllability of production. As discussed above, defining and standardising processes provide a basis for improving and optimising the processes and performance, for example with regard to quality, cost and lead time. Finally, defining processes and correct work procedures also contributes towards work safety (Stranks 2006, p. 94).

A key characteristic focusing on standardisation of production processes and operations was included in the initial version of the set of key characteristics, but modifications were subsequently made to it. In general, the key characteristic was seen to be useful and relevant in the interviews. However, after the second round of interviews the key characteristic was divided into two parts that consider the processes within and between production units separately. The aim was to simplify and support the assessment process. In the assessment cases this was seen to be useful. Also, in the final version the term “defined processes” is used instead of “standardised processes” presented in the previous versions. The reason for this is that processes are seen to be standardised if the available definitions and descriptions of the processes are followed in practice. However, as assessing the actual production processes and how they are carried out is
excluded from this study, the key characteristic and the assessment focus only on the availability and content of the process definitions and descriptions.

- Processes and procedures between production units are defined
  - Material flow and material processes between production units are defined and definitions cover lead or delivery time, batch sizes and delivery locations
  - Information flow between production units is defined and definition covers communicating order, demand and delivery information

Similarly to the previous key characteristic, the focus is on defined processes, but here processes between production units are considered. The key characteristic is divided into two parts, material flow and information flow. Firstly, material flow and processes are considered, and it is required that processes and issues such as lead or delivery times, batch sizes and delivery locations are defined in advance in order to enable smooth and reliable order-delivery processes between production units. Then, in terms of information flow, it is required that the procedures for transferring orders, demand information, and forecasts from subsequent to previous production units are defined, as well as procedures for informing about deliveries and, in particular, delays. In general, the aim is to ensure that relevant information is transferred in a predefined way so that material processes can be carried out and deliveries made on time.

With regard to the objectives of production, the key characteristic is expected to have a positive effect on lead time reliability and cost-efficiency. Defining the processes and procedures between production units is expected to improve the reliability of processes and their outputs, which is related to reliable deliveries between production units, and the availability of required materials for production units. This, in turn, supports and improves lead time and delivery time reliability. Furthermore, the key characteristic also has the potential to improve cost-efficiency as it supports the optimisation between production units of processes and procedures, such as production and delivery batch sizes.

As mentioned in connection with the previous key characteristic, the definition and standardisation of production processes were initially addressed by a single key characteristic, but to simplify and support assessment, the key characteristic was divided into two parts after the second round of interviews. In the assessment cases, this was seen to be useful both to the assessment and to the presentation of results.

- Plans and procedures for responding to production disruptions, problems and delays are in place
  - Procedures for communicating and solving production problems and disruptions as well as identifying and removing their root causes are defined
  - Production resources and units enable handling production during problems and disruptions
  - Overtime work or extra shifts can be easily used to meet or catch up with the production schedule
  - Time is reserved in the production schedule for maintenance, catching delays etc.

The key characteristic emphasises the need and ability to handle and solve disruptions, problems and delays in production in a predefined way. The importance of this is emphasised also by Cochran et al. (2001, p. 380-381), Torvinen et al. (2004, p. 103-104), Liker and Meier (2006, p. 178-181) and Arnold (2008). The first breakdown point requires that the persons responsible for solving disruptions and problems as well as the methods for informing the responsible persons about disruptions and problems are defined in advance. This is intended to ensure rapid reaction to and correction of problems. In addition to solving problems, efforts should also be made to identify and remove their root causes in order to eliminate recurrence of similar problems or disruptions. Also, in indentifying and removing the root causes of problems, disruptions and delays, a defined approach should be followed. The second breakdown point requires that the ability to handle production during problems and disruptions is ensured, for example through
redundancy of resources and through capabilities that enable alternative routing of products and processes. This is emphasised also by Dove and Hartman (1996, p. 54). In this respect, to ensure that the production schedule is met, and to enable production schedule catch-up after delays, the flexibility of employee resources and capacity is emphasised. The means for this flexibility include the ability to work overtime or extra shifts. Finally, the importance of reserve capacity and reserving time for schedule catch-up, maintenance etc. by scheduling the production system to operate below 100% capacity utilisation is emphasised. This aspect of scheduling and reserve capacity is also addressed by Suri (1998, p. 162-165) and Torvinen et al. (2004, p. 113).

In terms of production objectives, the key characteristic is connected with lead time reliability and the quality of operations and products. Having procedures in place for rapidly reacting to disruptions, problems and delays, and for carrying out production during problems and delays supports the company’s ability to meet promised lead and delivery times. In addition, the number of problems, disruptions and delays in production, and their reoccurrence will be reduced if the root causes are systematically sought and removed. This, in turn, will have a positive effect on lead time reliability and operational and product quality. Similar objectives and effects of rapidly identifying and resolving problems, and hence reducing variation, have been presented by Cochran et al. (2001, p. 378-381).

The key characteristic has been modified from an initial key characteristic which emphasised reserve capacity and below 100% utilisation, and which aimed to ensure reliability and flexibility of production processes. However, the second round of theme interviews indicated that assessing the ability to ensure reliable production processes at a more general level and with a broader perspective would be more beneficial. The key characteristic was therefore rephrased to its current format.

- Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point
  - Standard and order-specific parts of the production system and production processes have been identified and are utilized in managing and controlling production processes
  - Differentiation of products is delayed, i.e. customer-specific features and functions of a product are realised and created in the final stages of the production process

The aim of this key characteristic is to combine efficient and more standardised processes with more flexible processes in the production or order-delivery process in order to achieve optimal combination of cost-efficiency and flexibility. This is enabled by late-point differentiation and appropriate positioning of the order penetration point (OPP). The principle or approach is presented in Figure 30.

![Figure 30. Combining lean and agile processes (adapted from Naylor et al. 1999)](image)

As Figure 30 shows, the idea is that upstream from the OPP, where parts and products are independent of customer orders, efficient and standardized lean processes are used in order to improve cost efficiency. Then, downstream from the OPP, production is based on customer orders and more flexible agile processes are used to create the customer-specific functions and features of the product. This approach is similar to the Leagile paradigm presented by Naylor et al. (1999).
The first breakdown point suggests that the order penetration point or decoupling point, and the
standard and order-specific parts of the production process should be identified and utilised in
controlling, executing, and improving the production processes. In the standard part of the
production process, efficiency, for example rapid and cost-efficient production, can be
emphasised and production control can be simplified, for example by using stock-based control
instead of order-based control. These aspects and the importance of positioning and using the
decoupling point correctly are pointed out, for example, by Naylor et al. (1999), Van Hoek et al.
920), and Netland et al. (2007, p. 5). The following figure presents the concept of identifying and
utilising the standard and order-specific parts of the production process in production control
(Figure 31). It indicates that order-specific parts and processes require detailed order-based
control, whereas standard parts can be controlled using simpler stock-based control.

![Figure 31. Standard and order-specific parts of the production process (adapted from Alfnes et al. 2007)](image)

Furthermore, the second breakdown point emphasises the idea of delayed differentiation, as
discussed in the context of product platforms. The use of product platforms is connected with
this key characteristic as the product platform, i.e. the part of the product that is not dependent on
the customer order, corresponds to the standard part of the production process.

In terms of objectives of production, the key characteristic aims to combine or optimise cost-
efficiency and product flexibility. With regard to product flexibility, the aim is to enable
controlled and efficient production of the product variety offered to customers, for example, by
means of delayed differentiation. Furthermore, the standard part of the process and the emphasis
on its efficiency contribute towards cost-efficient production. The key characteristic also
improves controllability of production by simplifying production control, especially in the
standard part of the production process.

The first two versions of the set of key characteristic presented a key characteristic that
suggested combining characteristics of lean and agile manufacturing in the production system.
However, the second round of theme interviews indicated that the terms lean and agile were not
clear to all interviewees, and therefore the key characteristic was modified to more clearly
present the idea of combining and emphasising efficiency and flexibility in different parts of the
production process. When the main idea and objectives of the initial key characteristic were
explained in the interviews it was seen to be useful and applicable, thus justifying its inclusion in the final set of key characteristic.

- Responsibility for production control is allocated to production units
  - Production scheduling and control is divided into two levels:
    - Higher or general level control is responsible for coordinating production units and generating overall delivery or production schedules
    - At the lower level, production units have, within certain limits, responsibility and ability to decide the scheduling and control of production within the unit

The key characteristic and the breakdown points suggest that production control is divided into two levels: production system and production unit. At the higher, i.e., production system, level the overall production schedule that enables meeting the delivery times is generated, and the production units are coordinated. Then, the production units are given the responsibility and ability to control their own work within certain limits, for example, daily or weekly delivery schedules. A similar logic is presented by Suri (1998, p. 100-101), who states that a central system should be responsible for overall schedules, ordering and assigning materials and coordinating between production units or cells, while the cells are responsible for scheduling at equipment level on the basis of delivery schedules allocated by the central system. Also, Lapinleimu (2001, p. 107-112) divides operational control into generating a production schedule that coordinates the timing and operations of production units; and order impulses that are sent to production units, which then manage and carry out their own share of the overall production schedule. Additionally, decentralising responsibilities to production units or teams, and enabling decision-making related, for example, to production scheduling and work-time arrangements within a production unit at the lowest possible level is emphasised, for example, by Ohno (1988, p. 45-47) and Karlsson and Åhlström (1996, p. 36).

The key characteristic aims to simplify production control and to reduce control work at the production system level. Additionally, it supports the ability to react to changes and problems (Suri 1998, p. 100-102; Ohno 1998, p. 46; Liker 2004, p. 191-194). Thus, in terms of production objectives, the key characteristic is connected to reliability of lead time and to flexibility of production.

The key characteristic was identified in the initial literature review and was included in the first version of the set of key characteristics. Its usefulness and applicability were confirmed in the theme interviews, and it has therefore not been modified during the process of developing the set of key characteristics.

- Close cooperation between production units is supported and enabled
  - There are clear customer-supplier relationships between production units
  - Information flow and communication between production units are open and effective
  - Cooperation between production units aims to ensure rapid and reliable production process and material flow and to enable improvement of the entire production system

This key characteristic emphasises the need for production units to work in close cooperation with the aim of improving the entire production system and its performance. Close cooperation between production units and also with suppliers is emphasised, for example, in lean production (Womack & Jones 1996, p. 21-24, 50-52; Liker & Meier 2006) and by Schonberger (1986, p.102-104, 156). Although this study focuses on single companies, the key characteristic is also useful in the context of production networks consisting of several companies. With regard to the breakdown points, clear customer-supplier relationships, and open communication and information flow between production units are seen to support cooperation. These, for example, make it possible to clearly define and communicate requirements related to products and
deliveries, and enable the provision of feedback on orders and deliveries. In addition, the customer-supplier relationship and open communication are also seen to support joint development and improvement of processes and procedures. The last breakdown point emphasises that cooperation should aim at improving and optimising the processes of the entire production system, and at avoiding sub-optimisation, i.e. focusing only on processes and improvement within a certain production unit.

The key characteristic supports general improvement of the production system and production processes. Cooperation between production units and clear customer-supplier relationships are expected to contribute towards lead time reliability and quality, because the responsibilities of the production units are clarified. Furthermore, joint improvement and development of the production system and production processes are expected to bring efficiency improvements such as shortened lead time and enhanced cost-efficiency.

The key characteristic was modified after the second round of theme interviews from one that emphasised long-term partnerships between production units, and that was presented in the production system structure decision area. The focus of that decision area is on the system layout, whereas in the production processes and management decision area the processes and relationships between production units are considered. The key characteristic is therefore better suited to the latter of these two decision areas. Furthermore, instead of partnership, the key characteristic focuses on close cooperation, as this is considered more suitable when the focus is on a single company and the production units of a production system, rather than on a production network and relationships between companies. In addition, as the assessment and evaluation of operational processes is not included in this study, the phrasing of the key characteristic emphasises the production units’ ability to cooperate, and the support for such cooperation, rather than actual relationships and cooperation between production units.

5.1.4. Production equipment

This decision area focuses on the general characteristics of the equipment, machines and tools used in production. The following key characteristics, intended to ensure rapid and reliable production of the product variety offered to customers, are included:

- Production equipment fits the requirements of the products and processes and the objectives of production
- Changeover and set-up times of equipment are short
- Production equipment enables integration and reduction of production phases
- Production equipment is reliable and available for use
- Production equipment is easy to use
- Production equipment supports occupational safety and ability to work
- Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices

With regard to the target companies of this study, the production equipment decision area is relevant mainly to those companies operating on the basis of the make-to-order approach, i.e. companies that, in addition to assembly, also have part production in-house.

- Production equipment fits the requirements of the products and processes and the objectives of production
  - Production equipment enables continuous production flow and production at a quantity and pace equal to customer demand
  - Production equipment enables achievement of quality standards and cost objectives
This key characteristic considers the production system equipment at a general level and focuses on how the equipment has been selected and its suitability to meet the requirements of the production processes, products and customers. The first breakdown point emphasises that the equipment used should enable continuous production flow and production according to customer demand. These issues are also stressed in literature on lean production. Womack and Jones (1996, p. 176, 308-309), for example, divide equipment into monuments whose characteristics, such as scale and cost, require operation in batch mode, and more favourable right-sized equipment that fit into the process and production flow and enable production according to customers’ needs. In addition, the second breakdown point requires that equipment meets the objectives of production in terms of quality and cost. The costs perspective includes both the capital and operating costs of the equipment, i.e. its purchase cost as well as operating costs in production. The equipment accuracy, its capability to operate within accuracy or tolerance zones, and ability to consistently and repeatedly produce products that meet the specifications and the requirements of customers, are included in the quality perspective.

The key characteristic aims to enable production in small batches according to demand and orders. The ability to produce parts and products in small batches is expected to have a positive effect on cost-efficiency through a lower level of work in progress and working capital. Reduced batch size also supports the achievement of rapid production flow and short lead time, for example by reducing waiting and queuing in production. Furthermore, equipment that enables production in small batches and according to order and demand also supports product flexibility. Additionally, the ability to produce products that meet requirements and specifications supports the achievement of required quality levels and standards. Thus, in terms of production objectives, the key characteristic is connected with costs, lead time, product flexibility, and quality.

The key characteristic has been developed and modified from two key characteristics presented in the earlier versions, which had emphasised right-sized equipment and, hence, focused mainly on capacity. During the first round of interviews, flexibility of production and production equipment was emphasised, and therefore a key characteristic focusing on this aspect was added to the second version of the set of key characteristics. Then, during the second round of interviews, the need was identified to consider equipment at a more general level and to take quality and cost-efficiency also into consideration. As a result, this key characteristic, which aims to cover the aspects presented in the two earlier key characteristics and those highlighted during the interviews, was developed.

- Changeover and set-up times of equipment are short
  - Share of changeover and set-up time of production lead time is small
  - Batch sizes do not depend on changeover and set-up times of equipment
  - Set-up time is short and most of the changeover time is external time, i.e. changeover can be prepared and required activities can be done while the machine is running

This key characteristic focuses on the changeover and set-up times of equipment. Changeover time is the time required to change from producing one part or product to producing an alternative part or product (Figure 32). It can be further divided into set-up time, when no production occurs, and run-up time which starts when production is started again and ends when consistent output at the required capacity is achieved. (McIntosh et al. 1996, p. 6-7)
The division of setup operations into an internal setup that can be performed only when equipment is halted, and an external setup that can be conducted while the equipment is running, as presented by Shingo (1985, p. 22), is also presented in the figure above. However, the figure does not clearly present Shingo’s (1985, p. 22) perspective that an external setup includes operations carried out both before and after the internal setup, such as preparing the setup and then taking old dies to storage.

The breakdown points present more detailed requirements and objectives related to changeover and set-up time. The first two breakdown points emphasise rapid changeover and set-up to enable production in small batches and according to order and demand. It is then indicated that, in particular, the set-up time, i.e. the time that the equipment is halted, should be short. One means of achieving this is to prepare the changeover and perform the necessary actions while the equipment is running, if possible. Additionally, the entire changeover process, rather than only the set-up period, should be considered and shortened. These aspects and methods have also been presented, for example, by Shingo (1985, p. 28-31) and McIntosh et al. (1996).

In terms of production objectives, the key characteristic has a positive effect on lead time and product flexibility. Rapid changeover and set-up reduce delays in the production process, which supports short lead time and rapid production flow. Furthermore, short changeover and set-up times support product flexibility by enabling production of different product variants in small batches based on orders and demand. These advantages are pointed out, for example, by Ohno (1988, p. 31), McIntosh et al. (1996, p. 9), Lapinleimu (2001, p. 75-77, 81), and Torvinen et al. (2004, p. 125-130). Rapid changeover is also an important part of lean and JIT production (e.g., Miltenburg 2005, p. 405; Liker & Meier 2006, p. 72).
The key characteristic concerning equipment set-up was included in the first set of key characteristics. As the theme interviews showed the key characteristic to be relevant and useful to the target companies of the study, it was included in the final set of key characteristics. Only minor wording changes were made in order to emphasise the set-up time and the entire changeover process.

- Production equipment enables integration and reduction of production phases
  - Functionality and arrangement of equipment have made it possible to integrate production phases and to reduce the number of production phases as well as non-value-adding operations between phases of production

This key characteristic seeks to minimise the number of phases in the production process as well as the number of non-value-adding operations, such as handling, transportation and storage, between the phases by means of functionality and arrangement of equipment. One means for achieving this is the use of multifunctional equipment that is capable of performing several production tasks and phases. Equipment can also be combined into one unit, so that the production tasks and phases enabled by the equipment can be completed as a single production phase, without manual work or non-value-adding operations between the tasks and phases.

In terms of production objectives, the key characteristic is expected to have a positive effect on lead time, and can also contribute towards better quality and lead time reliability. Reducing the number of phases and the need for and amount of transportation and handling in the production process contributes towards a short lead time. This advantage is affirmed also by Lapinleimu (2001, p. 118). The lower number of production phases can also have a positive effect on quality and lead time reliability if the quality level and reliability of the multifunctional or combined equipment are as good as or better than those of the original equipment. This view is based on the theory of probability and logic, according to which the lead time reliability or achieved quality level of the entire production process are the result of the level of reliability or quality of the production phases. Thus, if the lead time reliability or quality level of a production phase or equipment is below 100%, then the more production phases or equipment that a production process includes, the lower the expected lead time reliability or quality level of the entire process will be. For example, if the quality level of the equipment is 0.9 and three phases are needed, the total quality level is 0.9*0.9*0.9=0.729. Accordingly, if the three phases can be completed with a single piece of multifunctional equipment that achieves a quality level of 0.9, higher quality level is achieved. This aspect and similar logic are presented also by Juuti (2005, p. 129), and Liker and Meier (2006, p. 91). Finally, Lapinleimu (2001, p. 118) and Torvinen et al. (2004, p. 73), among others, point out that reducing the number of phases in the production process reduces the complexity of the process and therefore simplifies production control.

A key characteristic focused on production equipment and methods and their ability to reduce the number of phases in the production process was added to the second version of the set of key characteristics. In the initial version of the set of key characteristics, reducing the number of production phases was presented in the product architecture decision area. After evaluating the initial set of key characteristics, presentation of the same objective also in the production equipment decision area was seen to be relevant. In the second round of theme interviews, it was pointed out that the number of production phases can be reduced with multifunctional equipment or by combining equipment to form a single production phase. The current wording of the key characteristic and the breakdown points were developed on the basis of these ideas and observations.
- Production equipment is reliable and available for use
  - Breakdowns or malfunctions of equipment do not cause disturbances or delays to production or decrease reliability of production and deliveries
  - Breakdowns and malfunctions of equipment occur seldom and can be repaired quickly
  - Production equipment are maintained based on a preventive maintenance program

This key characteristic emphasises the importance of reliable and available equipment, which is also emphasised, for example, by Maskell (1991, p. 165-166), Cochran et al. (2001, p. 380-381), Torvinen et al. (2004, p. 109), Liker and Meier (2006, p. 91), and Arnold (2008). Equipment reliability and availability ensures that equipment can be used and products can be produced when needed. Conversely, equipment breakdowns and malfunctions mean disturbances and delays to the production process. The aim is, hence, to avoid breakdowns and malfunctions, i.e. to achieve a long mean time between failures (MTBF), and to enable rapid equipment repair. Preventive maintenance also offers an important and effective means of ensuring the reliability and availability of equipment (e.g., Stranks 2006, p. 231; Liker & Meier 2006, p. 60, 91).

The key characteristic aims to enable continuous flow and reliable production processes. The importance of availability and reliability of equipment in achieving this is also presented, for example, by Womack and Jones (1996, p. 308). In terms of production objectives, reliability and availability support lead time reliability and the achievement of required and uniform quality, and enable continuous flow which, in turn, leads to short lead time. These aspects are emphasised also by Cochran et al. (2001, p. 380-381), Torvinen et al. (2004, p. 109-110) and Liker and Meier (2006, p. 91).

The key characteristic was included in the first version of the set of key characteristics. In the theme interviews it was shown to be relevant and beneficial, and has therefore not been modified.

- Production equipment is easy to use
  - Using production equipment for recurrent daily tasks is easy and does not require learning or use of manuals
  - Easy-to-use equipment enables employees to operate multiple machines

The aim of this key characteristic is to ensure that the use of equipment, especially for daily and recurrent tasks, is fast and simple. Easy-to-use equipment reduces the need for learning and use of manuals, and makes it possible for employees to operate multiple machines and to rotate between work tasks. Ohno (1988, p. 10-11) and Womack and Jones (1996, p. 308) also emphasise the importance of the ability to operate multiple machines, and state that it is essential in creating production units and cells. Thus, the key characteristic can also be linked with the unit structure of the production system discussed in the production system structure decision area. Equipment user interfaces are regarded as an important factor in the implementation and realisation of this key characteristic. If machines and equipment have similar user interfaces and can be used based on the same logic, operating multiple machines is easier and the need for learning is reduced.

In terms of production objectives, the key characteristic is connected to lead time, flexibility, and cost-efficiency. Easy-to-use equipment can be seen to contribute towards a short lead time as delays due, for example, to the need for learning and use of manuals is reduced. The ability and possibility for employees to use multiple machines and to work in several workplaces can be connected with cost-efficiency, since human resource utilisation and work efficiency are improved when compared to systems in which employees are limited to exclusively operating one machine. This ability and possibility can also be connected with product and volume
flexibility, as employees can more easily be allocated to different work stations according to demand and product mix.

The key characteristic was added to the final version of the set of key characteristics on the basis of the second round of interviews. In the interviews it was seen to be important that equipment and their usability supports production operations and enables operating multiple machines.

- Production equipment supports occupational safety and ability to work
  - Production equipment enables ergonomic working positions
  - Production equipment does not cause accidents or reduce ability to work

This key characteristic aims to support and ensure occupational safety and ability to work, which are also discussed in the human resources decision area. In the breakdown points, the key characteristic is divided into two parts. First, it is pointed out that equipment should support ergonomics, for example, enable correct working positions, working heights and reach distances, and avoid placing undue strain on the user (Stranks 2006, p. 226). In addition to occupational safety and ability to work, ergonomic working positions are seen to improve work efficiency. The second breakdown point emphasises designing, controlling and locating equipment in such a way that operators or other employees are not exposed to risk of injury (Stranks 2006, p. 90, 226-231).

In terms of the objectives of production, securing employees' ability to work reduces capacity variation and hence supports process and lead time reliability. Ergonomics and ergonomic working positions also improve work efficiency, resulting in lead time and cost-efficiency improvements. Furthermore, reducing equipment-related hazards reduces accident-related absences, which is linked with and reduces personnel costs, since less reserve employees are required to cover absences. Finally, supporting occupational safety through correct use of appropriate equipment is an important objective in itself.

The key characteristic was included in the final version of the key characteristics. The importance of and need to consider and emphasise occupational safety was highlighted in both rounds of interviews, but after the first round it was not clear how the topic should be presented in the set of key characteristics. After the second round it was decided that occupational safety and ability to work should be divided among and presented in several key characteristics, this being one of those.

- Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices
  - Value-adding work is supported and simplified by appropriate tools and auxiliary devices that enable ergonomic working positions
  - Non-value-adding work such as transportation, moving and handling of parts and materials are simplified and supported with appropriate tools and auxiliary devices

This key characteristic emphasises that value-adding work, as well as non-value-adding operations that cannot be eliminated, should be supported with appropriate tools and auxiliary devices. In other words, tools and auxiliary devices, or a lack of them, should not reduce work efficiency. Examples of auxiliary devices that support value-adding work and ergonomics include adjustable working or assembly stands and tables. Additionally, conveyors and other handling equipment are examples of tools and devices that support the required handling and transportation operations.
In terms of objectives of production, this key characteristic and the aim to make both value-adding work and such non-value-adding work that cannot be eliminated more efficient, are connected with short lead time and cost-efficiency. In addition, tools and auxiliary devices have a central role in ensuring occupational safety and the ergonomics of the workplace.

Ensuring and improving efficiency and reducing delays in production processes are also considered in the production system structure decision area. There, the aim is to create a layout that supports value-adding work and minimises non-value-adding work, such as transportation and handling. Thus, reducing non-value-adding work and supporting and simplifying value-adding work and the remaining non-value-adding work is achieved firstly through layout decisions and then through equipment. A similar logic, and the importance of reducing non-value-adding work and making value-adding work more effective are presented and emphasised for example by Torvinen et al. (2004, p. 82-83) and in literature on lean production (e.g., Ohno 1988; Womack & Jones 1996; Liker 2004).

The key characteristic was added to the final set of key characteristics after the second round of interviews and factory tours, as supporting production processes and their efficiency with tools and auxiliary devices was seen to be relevant and important. Also, during the plant tours good examples of implementing this key characteristic were identified, and these were seen to support and justify its inclusion in the final set of key characteristics.

### 5.1.5. Information and communication

In this decision area, information and communication and related systems are considered from the viewpoint of production and production control. The following key characteristics are presented:

- Information and communication support and enable decision-making
- Information transfer and communication follow systematic and predefined principles and procedures
- Information and communication systems used in the production system are compatible and integrated
- Information and communication systems are reliable and available for use
- Visual information and control systems are used in the production system

In general, the above are intended to ensure the availability of relevant information and a rapid and reliable flow of information, which both support rapid execution of customer orders. From the production perspective, two types of information are highly relevant: information on orders and demand from customers upstream of the production system, and information on the current status of products and production from the production units. Availability of actual demand information reduces the need for forecasting and the risks related to forecast-based production, while information on the current status of production supports production control and early identification and correction of problems.
• Information and communication support and enable decision-making
  o Information and communication enable deciding what, when, where and how to produce
  o Available information can be easily used and modified
  o Excess or inadequate information does not complicate or delay decision-making and use of information
  o Available information is timely and reliable

The key characteristic aims to ensure that information and communication support production processes and operations and enable decision-making in all parts and levels of the production system. Thus, the key characteristic focuses on relevancy and usefulness of information. The first breakdown point requires that communication and available information enable decision-making regarding the scheduling and control of production, for example, what, when and where to produce, at all levels and units of the production system. In addition, information should be in such a form that it can be used and modified easily. Finally, the reliability and timeliness of information, and the provision of sufficient information, while at the same time avoiding information overload are emphasised. The central role of information in decision-making is identified also by Kehoe et al. (1992, p 174-175), who state that to be useful and to support decision-making, information should be relevant, timely, accurate, available, accessible, comprehensive, and in appropriate format. These requirements are in keeping with this key characteristic and its breakdown points. Additionally, similar issues and requirements to those discussed here have been presented, for example, by Ohno (1988, p. 47-48), Muda and Hendry (2003, p. 475) and Torvinen et al. (2004, p. 109-110).

In terms of production objectives, the key characteristic is connected with quality, and lead time reliability. Useful and relevant information supports meeting the requirements of customers and the reliability of production processes. In addition, the key characteristic and the requirements related to information and communication support production control.

The key characteristic was included in the final version of the set of key characteristics based on ideas and opinions presented in the interviews. In the previous version, one key characteristic stated that relevant and useful information should be available to units and members of the production system. In the second round of theme interviews these requirements were agreed on, but more concrete definitions and means for achieving them were requested. The key characteristic was thus divided into two parts, with the above key characteristic focusing on the content of information, and the following key characteristic considering the availability of information. Furthermore, the interviewees emphasised the usability and reliability of information, and that information and communication should enable production-related decision-making, for example regarding scheduling and improving production. The key characteristic and the breakdown points aim to cover and present these aspects.

Similar issues to those presented in this key characteristic, i.e. information and communication to assist achieving reliable output of production units and production processes, were considered in the production processes and management decision area in discussing the processes and procedures between production units (Section 5.1.3.). There it was established that information on orders, demand, production status, workload of production units and their ability to meet the production schedule, and on production problems or disruptions should be made available to all production units.
• Information transfer and communication follow systematic and predefined principles and procedures
  o Procedures and principles of information transfer and communication define when, how, where and in what format information is provided and transferred
  o Information needs and flows within the production system have been identified and defined
  o Systems and methods for communication and information flow have been defined

This key characteristic considers how information is transferred and communicated within the production system and between production units. Hence, it is closely related to processes and procedures between production units, as discussed in Section 5.1.3. Defining the principles and procedures of information transfer and communication aims to make information available and accessible easily and in a predefined manner. The breakdown points suggest identifying and defining the information needs of production units, and the information flows within the production system. The systems and methods of communication and information transfer, as well as the format in which information is transferred, then need to be defined. These are intended to make information easily available and accessible and to support understanding, use and modification of the provided information.

In literature, for example Kehoe et al. (1992) provide support and reasoning for this key characteristic and the issues presented in the breakdown points. They state that “information acquires value only through use and the fundamental information problems consist of determining what information users need, can absorb and utilise, and how to supply them with exactly this information”. Hence, designing an effective information system includes identifying the information needs and information flows within an organisation. (Kehoe et al. 1992, p. 174-176) Thus, the requirements and suggested solutions are quite similar and in keeping with the breakdown points of this key characteristic.

In terms of production objectives, the key characteristic supports lead time reliability and reduces lead time. The availability of relevant and useful information to all production units supports reliable production and timely deliveries both within the production system and to customers. Furthermore, predefined procedures for communicating disruptions and problems in production enable rapid identification and reaction to such occurrences. These should have a positive effect on lead time reliability. With regard to reducing lead time or achieving short lead time, if information is easily available and accessible, delays caused by searching for information can be reduced and removed.

The key characteristic was added after the second round of theme interviews as the original key characteristic covering relevancy, usefulness, and availability of information was divided into two parts. The interviewees argued that the key characteristics should provide a more concrete means of arranging information flow and communication and for ensuring the availability of relevant information. Furthermore, information and communication was seen to have an important role in processes and procedures between production units. Also, the need to define how communication and information transfer are carried out within the production system was pointed out. On the basis of these opinions and observations, the key characteristic was added with the aim of provide more detailed guidance on ensuring the availability of information.

• Information and communication systems used in the production system are compatible and integrated
  o Information can be transferred automatically and seamlessly between information systems within the production system and order-to-delivery process
This key characteristic focuses on the compatibility and integration of information and communication systems within the production system and the order-to-delivery process. It is intended to enable automatic and seamless information flow, which contributes towards the availability of information. Compatibility of information and communication systems also eliminates manual work and the associated possibility of typing and other errors during information transfer. Hence, the key characteristic also supports reliability of information. The need for integrated and compatible information systems, and the importance of information flow and availability of information have been recognised also by Kehoe et al. (1992, p. 173), Suri (1998, p. 338), MIT (2001, p. 70), and Netland et al. (2007, p. 6).

In terms of production objectives, the key characteristic and its effects can be connected with lead time and its reliability, cost-efficiency, and quality. Availability of information and rapid information flow support a short and reliable lead time, for example by eliminating delays caused by missing information or searching for required information. By eliminating or reducing delays and unnecessary non-value-adding work, the key characteristic should also improve cost-efficiency. Furthermore, compatible and integrated information systems can support achieving required quality levels and meeting customer requirements. This results from eliminating the need for manual input and the related risk of typing errors when transferring information, thus ensuring that the correct customer requirements are communicated to production.

The key characteristic was included in the set of key characteristics after the second round of theme interviews. In the earlier version of the set, one key characteristic had focused on rapid and reliable information flow, which was seen to be useful and important, but the need for a more concrete means was identified by the interviewees. Furthermore, integrated and compatible information systems were seen as a useful means of realising rapid and reliable information flow. The key characteristic was therefore accordingly modified to its current format.

- Information and communication systems are reliable and available for use
  - Malfunctions, failures and interruptions in use of information and communication systems do not cause disruptions to information flow or to production processes
  - Maintenance of information and communication systems is systematic and planned

This key characteristic emphasises that information and communication systems must be reliable and available for use when needed. More specifically, it is required that information and communication systems do not cause disruptions to information flow or to the production process. Furthermore, similarly to production equipment, one way of improving and ensuring reliability and availability is seen to be planned maintenance of information and communication systems.

In terms of production objectives, reliability and availability of information and communication systems are seen to support lead time reliability and achieving consistent quality by eliminating or minimising disruptions to the production process. Furthermore, the key characteristic also contributes towards rapid information flow and availability of information, which support short lead time, as established in the discussion and descriptions of the previous key characteristic.

Cochran et al. (2001, p. 381) also emphasise the capability and reliability of information systems, which is related to the ability to provide timely, reliable and relevant information to all parties of a production system, and further to the achievement of predictable output and lead time. The key characteristic is also consistent with the requirement of availability and reliability of equipment and resources, which Liker and Meier (2006, p. 91) present as a prerequisite for smooth and reliable production flow.
The key characteristic was added after the second round of theme interviews. Similarly to the previously discussed key characteristic, it aims to provide a more concrete means of achieving rapid and reliable information flow, which were considered important by the interviewees.

- Visual information and control systems are used in the production system
  - Understanding and observing the production system structure, production schedule and production status are supported by visual control means and systems
  - Means of visual information and control enable the identification and following of correct and standard procedures and support occupational safety

The purpose of visual information and control systems is to provide production transparency, which allows everyone to see and understand every aspect of production and its status at all times. Similar objectives and the importance and advantages of visual information and control systems have been presented by several authors, including Ohno (1988, p. 48-51), Greif (1991), Womack and Jones (1996), Liker (2004), and Torvinen et al. (2004). The visibility of and ability to monitor the production system and the status of production were discussed also in the production system structure decision area, where the focus was on the layout of the production system and production units. Here, means, methods and solutions that support and enable visual information and control are considered. With regard to different information and control systems, the approach adopted and the suggestion presented here are similar to that presented by Torvinen et al. (2004), who state that computers and software systems should be combined with visual aids such as cards, boards and displays to achieve the most successful and effective information systems. In such a case, more stable data and information can be stored in computers, software systems and databases, while more rapidly changing data and information on the shop floor can be presented and controlled with visual methods (Torvinen et al. 2004, p. 109). Similar ideas are presented also by Liker (2004, p. 157-158) and Liker and Meier (2006, p. 208-212). The breakdown points provide more detailed requirements related to visual information and control.

The first breakdown point states that observing and understanding the structure of the production system and production process, for example process phases and production system units, should be supported. Furthermore, observing the production schedule, order of production and status of production, for example with respect to the work load and ability to meet the production schedule, as well as any deviations from the planned and desired state, should be enabled. Means to these ends include marking and clearly indicating the production phases and units, for example with painted borders, colour codes, numbering, and signboards. In addition, other means of visual control, such as pull inventories, kanban cards, and signboards or displays showing the production schedule, can be used to assist in identifying the order and schedule of production and to support meeting the production schedule. Finally, indicating the correct location and amount of parts and materials enables identification of shortages or build-ups of parts and materials at production units. This supports identifying the work load of a production unit and its ability to meet the production schedule. Similar requirements and means for fulfilling them are presented, for example, by Greif (1991, p. 100-105), Muda and Hendry (2003, p. 474), Torvinen et al. (2004, p. 146-147), Liker and Meier (2006, p. 140), and Netland et al. (2007, p. 6).

The second breakdown point emphasises that visual information and control should enable clear visualisation of how a task or a process should be carried out, and whether standard procedures are being followed. This, together with indicating and increasing awareness of hazards and dangers in the work place, for example using colours, posters and warning signs, supports occupational safety. This perspective and similar objectives are presented also by Liker (2004, p. 176) and Stranks (2006, p. 93, 278).
With regard to production objectives, use of visual control and information can be connected to lead time, its reliability and quality. As Liker (2004, p. 152) points out, visual information and control, and availability of information ensure fast execution of operations and processes, and contribute towards a rapid and reliable lead time. The ability through visual information and control systems to identify and to react quickly to any deviations from standard and planned situations and from standard production status contributes towards high and consistent quality and lead time reliability (Liker & Meier 2006, p. 140).

The key characteristic was identified in the initial literature review and presented in the first version of the set of key characteristics. The key characteristic and its objectives were seen to be relevant and useful in both rounds of interviews, and it is therefore included in the final set of key characteristics. The wording was, however, modified slightly to be more general and to also include the aspects other than production status mentioned in the earlier versions.

5.1.6. Human resources

This decision area considers human resource skills and organisation at a relatively general level. The following key characteristics are included in this area:

- Teamwork and team organisation are used in production
- Employees are cross-trained and skills of employees meet the requirements of the work tasks and processes
- Personnel policy and arrangement of working time support operational flexibility and reliable deliveries
- Commitment to work and involvement in improving the production system and production processes are promoted
- Occupational safety and ability to work are emphasised and ensured

The main objective of the decision area is to support and enable continuous production flow and flexibility of production. Additionally, occupational safety and issues related to motivation and involvement are considered.

- Teamwork and team organisation are used in production
  - Employees are organised into teams and one team operates one or more production units of the production system
  - Responsibility for the team and its operations are defined and allocated to a certain team member

This key characteristic and the first breakdown point suggest that employees should be organised into teams that operate the production units of the production system. The key characteristic and its objective are thus consistent with the unit structure of the production system discussed in the production system structure decision area. Team organisation is also emphasised by Suri (1998, p. 95-96) and in literature on lean production (e.g., Ōhno 1988, p. 7-8, 23-25; Liker 2004, p. 184-199). Furthermore, allocating responsibility for the team and its operations, for example with regard to scheduling and ability to meet the production schedule, to a certain member of the team is recommended. This simplifies communication of the production schedule and the status of the team and its operations between the two levels of production management and control discussed in the production processes and management decision area. A similar idea is presented by Karlsson and Åhlström (1996, p. 36-37), Liker (2004), and Liker and Meier (2006). Liker (2004, p. 191-194) suggests that a team should consist of members and a leader, whose responsibilities include meeting the production schedule and quality standards. The requirement for clarifying responsibility was emphasised also by the interviewees during the second round of interviews.
In terms of production objectives, team organisation, and providing teams and employees with the ability, responsibility, and authority to solve problems on the shop floor support flexibility of production, quality of products and operations, and lead time reliability. These aspects have been discussed and presented also by other authors, including Ohno (1988, p. 46), Maskell (1991, p. 199, 286-288), and Liker (2004, p. 191-194).

A key characteristic focusing on teams and teamwork was also presented in the earlier versions of the set of key characteristics, and only small changes have been made to it during the process of developing the final set. In general, the key characteristic and team work were confirmed in the interviews as being beneficial. During the second round of interviews the responsibilities and their allocation to a certain team-member were emphasised, and this is therefore presented in the second breakdown point. Furthermore, the wording has also been changed so that multifunctional teams are not emphasised in the current version. However, the first breakdown point emphasises the ability of a team to operate one or more production units, while the following key characteristic discusses cross-training of employee.

- Employees are cross-trained and skills of employees meet the requirements of the work tasks and processes
  - Employee skills enable correct execution of production tasks and processes
  - Employees are able to perform several tasks and work in several areas and/or operate several machines

The key characteristic focuses on the skills of employees. The first breakdown point emphasises the ability to perform the required tasks and processes in the correct manner, i.e. according to the definitions and so that the required outputs and quality levels are achieved, while the second breakdown point focuses on cross-training and multi-skilled employees who are able to rotate between different work stations and tasks. These aspects are presented also in literature on lean production (e.g., Ohno, 1988; Karlsson & Åhlström, 1996; Womack & Jones 1996; Liker & Meier 2006).

With regard to production objectives, the key characteristic is connected with lead time reliability, quality, and product and volume flexibility. More specifically, the ability and capability to perform tasks and processes correctly support the consistent achievement of required quality levels and lead and delivery times. These effects are emphasised also by Cochran et al. (2001, p. 381-382). Furthermore, cross-trained, multi-skilled employees support flexibility of production (Maskell 1991, p. 15, 199; Karlsson & Åhlström 1996, p. 34; Suri 1998, p. 96, 121; Cochran et al. 2001, p. 382).

This key characteristic has been modified from a previous version which focused on cross-training and multi-skilled employees. In the interviews, cross-training of employees was considered important and relevant to the target companies of this study. However, the need to consider employee skills and ability to perform tasks and processes according to specifications was highlighted during the second round of interviews. The key characteristic was therefore modified to include this aspect.

- Personnel policy and arrangement of working time support operational flexibility and reliable deliveries
  - Flexibility of working hours and ability to work overtime and extra shifts make it possible to adjust personnel capacity according to orders and required production volume
  - Number of employees can be adapted according to changes in production volumes
This key characteristic focuses on flexibility of personnel capacity, i.e. the ability to adjust the personnel capacity according to demand, orders and required production volume. The breakdown points present means for realising and implementing the key characteristic. Flexibility of working hours and ability to work overtime and extra shifts provide the flexibility and ability to adjust capacity according to changes in demand. Furthermore, when bigger changes in production volume are considered, the ability to adjust employee numbers is needed. One means of doing this is through the use of temporary staff.

In terms of production objectives, the key characteristic aims to support volume flexibility and reliability of lead and delivery time. With regard to volume flexibility, the ability to work overtime and extra shifts enables capacity to be increased to meet temporarily higher demand, while flexible working hours and the ability to adjust employee numbers enable adaptation to both higher and lower demand. Flexible working hours, overtime and extra shifts can also be used for production schedule catch-up and, therefore, the key characteristic also contributes towards reliable lead and delivery times. Similar objectives were also discussed and aimed at in the production processes and management decision area. There, developing and defining plans and procedures for responding to production disruptions, problems and delays was emphasised and suggested as a means for ensuring reliable lead time and consistent quality.

The key characteristic was added after the second round of theme interviews. The interviewees emphasised the importance of enabling volume flexibility and ensuring the ability to meet promised delivery times by means of decisions and arrangements related to employee capacity and working time.

- Commitment to work and involvement in improving the production system and production processes are promoted
  - Employee motivation, work commitment, and performance improvement are supported through pay, incentive and award systems
  - Intrinsic characteristics of the work and working environment support employee motivation and commitment
  - A defined and incentivised suggestion or initiative system for employees is in use

This key characteristic focuses on the role, participation and efforts of employees in achieving high level of performance, and in improving the production system and production processes. These aspects have been emphasised also by Maskell (1991, p. 290-293) and in literature on lean production (e.g., Liker 2004; Liker & Meier 2006).

The first two breakdown points present external and internal factors aimed at motivating employees. With regard to external factors, employee motivation and work commitment can be supported by pay, incentive and award systems. These systems should also direct the efforts of employees towards the objectives of production and the company. With regard to internal factors, the characteristics of the work tasks and the work environment can contribute towards better motivation and commitment. Such characteristics include enriching or challenging tasks, job rotation, feedback on employee performance, and possibilities for training and education. In addition, characteristics of the working environment such as ergonomics, available equipment, and safe working conditions can support and improve the motivation and commitment of employees. Some of these intrinsic characteristics, such as ergonomics and occupational safety, are also considered in other key characteristics. The division into internal and external factors and the examples presented here have also been identified by Liker (2004, p. 194-196).

The third breakdown point emphasises the importance of encouraging and supporting employees in improving their own work performance, production processes and the production system. One way of doing this is to define an incentivised initiative or suggestion system that allows and
encourages employees to suggest improvements. Liker and Meier (2006, p. 261) point out that the suggestion system should be simple and clearly defined so that submitting, evaluating, and implementing suggestions is easy. The importance of employee participation and involvement as well as the usefulness of suggestion and incentive systems is also emphasised by Imai (1986, p. 111-114), and Muda and Hendry (2003, p. 475), and in literature on lean production (e.g., MIT 2001, p. 34; Liker 2004, p. 198).

Although direct connections with production objectives are difficult to draw, employee commitment, involvement and motivation are seen to have an important effect on production performance. Committed and motivated employees can be expected to perform closer to the best of their ability and to invest more effort in meeting the objectives of production and the company. This can be linked, for example, with lead time reliability, consistent quality, and work efficiency in terms of lead time and costs. Furthermore, supporting employee participation in improving work performance, production processes and the production system can provide various advantages related to production objectives such as lead time and costs.

The key characteristic was added to the final version of the set of key characteristics based on the opinions presented in the second round of theme interviews. The interviewees regarded the motivation, commitment and efforts of employees to be important in achieving the objectives of production and in improving production processes and the production system. Therefore, a key characteristic focused on supporting and enabling these aspects was formulated and added.

- Occupational safety and ability to work are emphasised and ensured
  - Employees are given training on correct working methods, ergonomic working positions, and occupational safety
  - Occupational safety and ability to work are promoted, e.g., by posters and by documenting and monitoring accidents
  - Efforts are made to seek and remove causes of accidents and reduced ability to work
  - Employees are provided with adequate protective equipment

This key characteristic focuses on emphasising and ensuring occupational safety and ability to work. Means for doing this include education and training related to correct, ergonomic working methods and occupational safety. Furthermore, occupational safety and ability to work can and should be promoted, for example, by posters, notice boards and campaigns. Employees must also be provided with protective equipment such as safety boots, goggles, helmets, hearing protectors and gloves. Similar means and the importance of utilising them have been presented by Alli (2001) and Stranks (2006).

In terms of production objectives, the key characteristic is connected with lead time reliability and production costs. With regard to lead time reliability, the key characteristic aims to ensure that production resources, in this case employees, are available when needed and enable reliable and predictable production processes and deliveries. The importance of availability of required resources such as people, materials and equipment, in achieving a reliable production process and smooth production flow is also emphasised by Cochran et al. (2001, p. 381) and Liker and Meier (2006, p. 91). The key characteristic is also intended to reduce employee absences from work, which in turn reduces production costs as less reserve resources are needed to cover absences. In general, occupational safety is in itself an important requirement and objective in designing and implementing a production system.

The key characteristic was added to the final set of key characteristics, although the importance of and need to consider and emphasise occupational safety was stressed in both rounds of theme interviews. After the first round, however, it was not clear how the topic should be presented in the set of key characteristics. The decision was subsequently taken to include occupational safety...
in more than one decision area, one of these being human resources. In addition, occupational safety and ability to work have been considered and emphasised in the production equipment and production processes and management decision areas. Thus, in keeping with Alli (2001) and Stranks (2006), risks and hazards and employee exposure to them should be eliminated or minimised by designing and implementing production processes and production equipment appropriately, in addition to which education, training and appropriate protection equipment should then be provided to safeguard and promote occupational safety and ability to work.

5.1.7. Production system and process themes

The key characteristics presented in the previous sections are interconnected and combinations of the key characteristics contribute towards creating certain features of the production system and production processes. Here, these features are called production system and process themes. The themes can be used in summarising the assessment results as they enable clarification of the interrelationships between the key characteristics of a well-performing production system. In this section, the following production system and process themes are discussed in more detail:

- Unit structure of a production system
- Clear material flow and production process
- Efficient production processes
- Reliable and controllable production processes
- Availability of production prerequisites
- Late-point differentiation and predefined product variety
- Visibility of and ability to monitor the production system, production process and production status
- Occupational safety and ability to work

The key characteristics of a well-performing production system, which form the basis of the developed TUTKA tool, can be shown to be interconnected. Based on the interconnections, production system and process themes can be identified, and here some themes considered beneficial and relevant to assessing and improving the production systems of the target companies of this study are discussed. For each theme, the key characteristics that comprise it and the expected effects of the theme on the production system, production processes and production objectives are presented.

- Unit structure of a production system
  - Product architecture is modular
  - Levels in product structure simplify the structure of the production system and support production control
  - Production system consists of production units that are responsible for certain parts of a product
  - Teamwork and team organisation are used in production

This theme focuses on the layout and structure of the production system, emphasises the need for a clear unit structure, and incorporates key characteristics from the product architecture, production system structure, and human resources decision areas. With regard to product architecture, the key characteristics focusing on modular product architecture and on the number of levels in the product structure are intended to ensure that products are composed of clearly defined entities, such as modules and subassemblies. This enables designing and organising the production system so that it consists of production units that are responsible for certain parts or subassemblies of a product, which is emphasised by the third key characteristic included in this theme. Finally, organising employees into teams that operate the production units is consistent with and supports realising the unit structure of the production system. Thus, the unit structure of
a production system is enabled by a modular product architecture, and implemented by production system structure and organisation of human resources.

The theme contributes towards a short and reliable lead time. It clarifies the structure of the production system, which simplifies production control and supports lead time reliability. Furthermore, the unit structure of a production system enables a branch-type production process as parts and subassemblies of a product can be produced and assembled in parallel in the production units. This should result in a shorter lead time than a sequential process. The unit structure of a production system and its advantages are emphasised also by Suri (1998, p. 90) and Lapinleimu (2001, p. 96, 98).

- Clear material flow and production process
  - Product architecture is modular
  - Production system consists of production units that are responsible for certain parts of a product
  - Production system structure corresponds to the structure and production process of products

This theme focuses mainly on the layout of a production system and seeks for a clear material flow and production process. It is based on a unit structure of products and the production system, as aimed at by the first and second key characteristics. Furthermore, the third key characteristic requires that the production units are located according to the structure and production process of the products, i.e. that the layout of the production system is product-based. Together, these result in a clearly structured production system, and create a clear and straightforward material flow by eliminating back- and cross-flows in the production system and production process.

With regard to the objectives of production, the theme contributes towards short lead time and cost-efficiency. When compared with a functional or process-based production system layout, the theme reduces delays and non-value-adding work, such as transportation, and hence contributes towards a rapid and cost-efficient production process. Furthermore, reducing lead time usually reduces work-in-progress and can therefore be linked with cost-efficiency (Maskell 1991, p. 124). Also, when compared to a functional or process-based layout, the theme simplifies production control, for example by simplifying and reducing the need for coordination and control between phases of the production process.

- Efficient production process
  - Production system structure corresponds to the structure and production process of products
  - Distances between production units and distances between production equipment are short
  - Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work
  - Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices
  - Information and communication support and enable decision-making
  - Information transfer and communication follow systematic and predefined principles and procedures

Having a production system structure that corresponds to the structure and production process of the products as well as short distances within the production system reduces the amount of delays and non-value-adding work, such as transportation and handling, in the production process. Furthermore, the layout and organisation of workplaces should enable employees to
concentrate on value-adding work by eliminating or minimising the need for unnecessary non-
value-adding operations such as moving, handling and searching for tools, materials, parts, and
products. In addition to production system and workplace layout, the key characteristic
concerning appropriate tools and auxiliary devices supports an efficient production process by
making value-adding operations as well as the remaining non-value-adding operations as
efficient as possible. Finally, the two key characteristics from the information and
communication decision area aim to ensure the availability of relevant and useful information,
which supports production process efficiency by reducing delays caused by searching for
information, or by irrelevant or unavailable information.

The theme focuses on the efficiency of production processes and aims to reduce non-value-
adding work and to make value-adding work more efficient. Thus, in terms of production
objectives, the theme aims to shorten lead time and improve cost-efficiency.

- Reliable and controllable production processes
  - Product structure consists of predefined parts and subassemblies
  - Dissimilar main processes of production are identified and separated from each other
  - Processes of production units are defined
  - Processes and procedures between production units are defined
  - Production system structure corresponds to the structure and production process of
    products
  - Distances between production units and distances between production equipment are
    short
  - Information and communication support and enable decision-making
  - Information transfer and communication follow systematic and predefined principles
    and procedures
  - Production system structure makes it possible to observe the state of and the
    prerequisites for production
  - Visual information and control systems are used in the production system
  - Plans and procedures for responding to production disruptions, problems and delays
    are in place
  - Personnel policy and arrangement of working time support operational flexibility and
    reliable deliveries
  - Responsibility for production control is allocated to production units
  - Production equipment is reliable and available for use

This theme aims to ensure that the production processes are reliable and controllable. Reliability
of production processes concerns the duration and output of the processes, while controllability
of production processes is connected to the amount and level of effort required to control the
production units and production process so that the required outputs are produced according to
the production schedule and delivery times. Thus, good controllability of production processes or
simple production control means that the production schedule can be carried out easily and
without exceptional effort. Similar descriptions of controllability of production processes and
simple production control have been presented also by Lapinleimu et al. (1997, p. 230) and
Torvinen et al. (2004, p. 71).

The key characteristics included in the theme emphasise defined and repeatable processes,
simple production flow, and rapid and effective reaction to and correction of problems and
disruptions in production. Firstly, the focus is on using predefined parts and subassemblies in
products, i.e. limiting the product variety offered to customers, and on separating different
processes of production. These are intended to reduce variation within a process and to increase
the similarity of products produced in a process. This, together with the use of defined processes
within the production system, aims to ensure predictable and reliable production process
operation and outputs and to simplify and support production control. Locating production units according to the structure and production process of the products and in close proximity to each other thus simplifies production flow and production control when compared to a production system with a functional layout. A simpler and more straightforward production flow also supports the reliability of production processes. The content of and systems for information and communication also contribute towards reliable and controllable production. To support and enable production control, information should enable decision-making. Subsequently, predefined procedures aim to ensure that such information is easily available. Use of visual information and communication is also emphasised and is seen to support production control. An observable production system and processes, enabled by visual information systems and production system structure, make it possible to identify problems in production and deviations from defined procedures, the desired production status, or production schedule. These, together with predefined plans and procedures for correcting problems, and working time flexibility are intended to ensure reliable processes and deliveries even if problems or deviations occur. Furthermore, allocating responsibility for production control to production units reduces the need for and amount of control work at the production system level, and is hence connected with the controllability of production processes. Finally, reliability and availability of production equipment are emphasised and seen as key enablers of reliable production process and production flow.

In terms of production objectives, the theme and the key characteristics included in it contribute towards lead time reliability and achieving consistent high quality. Controllability of production can also be connected with costs of production, as the aim is to implement the production schedule and to produce the required outputs without unnecessary work and production control efforts.

- Availability of production prerequisites
  - Product structure consists of predefined parts and subassemblies
  - Processes of production units are defined
  - Processes and procedures between production units are defined
  - Production equipment fits the requirements of the products and processes and the objectives of production
  - Production equipment is reliable and available for use
  - Production equipment supports occupational safety and ability to work
  - Occupational safety and ability to work are emphasised and improved
  - Information and communication support and enable decision-making
  - Information transfer and communication follow systematic and predefined principles and procedures
  - Visual information and control systems are used in the production system
  - Production system structure makes it possible to observe the state of and the prerequisites for production

Production prerequisites are the enablers, such as materials, tools, equipment and employees, required to start up and carry out the processes and operations of a production system or production unit. The availability of production prerequisites aims to ensure that production operations and processes can be started rapidly and completed according to the production schedule. These definitions are based on Lapinleimu (2001, p. 90), who states that rapid and cost-efficient operation of a production system is based on production prerequisites that include all plans or physical equipment needed to carry out an order. Production prerequisites were previously presented and considered in a single key characteristic of a well-performing production system. In the final version, however, the prerequisites and the aim to ensure their availability are divided among various key characteristics.
The key characteristics focus on identifying the production prerequisites, and on ensuring their availability. Firstly, defining the product variety offered to customers in advance, i.e. using predefined parts and subassemblies in the products, makes it easier to identify and define the prerequisites such as processes, materials and tools required to produce the order-specific products. Then, defining the processes both within and between production units in advance aims to ensure that production can be started when an order is received. Defining production processes is also intended to ensure predictable processes and their outputs, and the ability of each production unit to produce and deliver its products according to the production schedule and within the defined lead and delivery time. This should make the required materials available to the production units of the production system when needed. Production equipment is also an important prerequisite, and therefore equipment should be reliable and available to use when needed, suit the production process, and meet the requirements of the products and processes, for example in terms of capacity and accuracy. Two of the key characteristics focus on occupational safety and aim to ensure employee availability and ability to work. Additionally, relevant and useful information is needed in order to start and carry out production processes according to the customer orders and production schedule. Therefore usefulness, relevancy, and availability of information are emphasised by two key characteristics from the information and communication decision area. Finally, the last two key characteristics focus on visual information and control, which enables identification of the availability of production prerequisites such as materials, and reaction to any deviations related to these.

To conclude, the key characteristics and availability of production prerequisites aim to enable a rapid and reliable production process by ensuring that production can be started immediately and carried out as planned. Thus, in terms of production objectives, the theme contributes towards short and reliable lead time and consistent achievement of quality objectives and standards.

- Late-point differentiation and predefined product variety
  - Product structure consists of predefined parts and subassemblies
  - Product platforms are used
  - Product architecture is modular
  - Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point

This theme aims to enable efficient and controllable production of the product variety offered to customers, and combines key characteristics related to product architecture and production processes and management. Firstly, the use of predefined parts and components, i.e. defining and limiting the product variety offered to customers, is emphasised. From the point of view of production, it eliminates or reduces uncertainty concerning the processes and operations that are required to produce the order-specific products. This supports defining and standardising production processes, which contribute towards the reliability of processes and their outputs, and efficiency of production. Modular product architecture and use of product platforms support identification of the standard and order-specific parts of the production process, and limitation of order-specific operations in certain parts of the production process. They also support appropriate positioning of the order penetration point, which aims at combining standardised and cost-efficient processes with more flexible processes throughout the entire production process.

In terms of production objectives, the theme contributes towards cost-efficiency, reliable lead time, and, thirdly, product flexibility, which in this study emphasises the ability to produce a predefined product variety efficiently and reliably. More specifically, when late-point differentiation is used, cost-efficiency can be emphasised in the standard part of the production process. At the same time, order-specific operations are limited to a certain part of the production process, thus simplifying the production process and its control compared to an entirely order-specific production process. This can be linked with reliability of the production process and its
outputs. Furthermore, late-point differentiation and a shorter order-specific production process should result in shorter delivery times to the customer. Similar advantages of late-point differentiation or postponement have been presented, for example, by Feitzinger and Lee (1997) and van Hoek (2001).

- Visibility of and ability to monitor the production system, production process and production status
  - Production system structure corresponds to the structure and production process of products
  - Distances between production units and distances between production equipment are short
  - Production system structure makes it possible to observe the state of and the prerequisites for production
  - Visual information and control systems are used in the production system

This theme emphasises a visual production system and production process, and includes key characteristics from the production system structure and information and communication decision areas. A clear and easily identifiable material flow, enabled by the first two key characteristics, improves the visibility of and ability to monitor the production system and production process. More specifically, monitoring the status of production can be supported by decisions related to production system structure, for example, by defining and marking locations for materials. Furthermore, means of visual information and control such as colour codes, painting, cards, signboards, notice boards and displays can and should be used to improve the visibility and ability to monitor the production process, status, order and schedule.

The theme is intended to improve the availability of information and to support and simplify production control. In terms of production objectives, it can be linked with quality and lead time reliability, since identifying the standard situation and procedures, and deviations from these is enabled.

- Occupational safety and ability to work
  - Production equipment supports occupational safety and ability to work
  - Processes of production units are defined
  - Occupational safety and ability to work are emphasised and improved
  - Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work

Occupational safety and ability to work are mainly considered in the production equipment, production processes and management, and human resources decision areas. Production equipment and related arrangements should ensure that operating the equipment is safe, that working positions are ergonomic, and that employees are not exposed to hazards. Furthermore, production process definitions should describe correct and safe working procedures, and occupational safety should be emphasised and ensured through training and information. Additionally, the layout and organisation of workplaces should enable ergonomic working positions that support ability to work.

The theme aims to ensure availability of employees and their ability to work, which supports a reliable production process and reliable lead time. Ensuring employee ability to work is also connected to the availability of production prerequisites discussed as a separate theme above. Furthermore, if absences can be reduced, the amount of reserve employees needed and, hence, personnel costs can also be reduced. Finally, in the interviews, occupational safety as such was regarded as an important aspect and objective of production system design and operation.
5.1.8. Links with production objectives

In this section, the key characteristics of a well-performing production system are linked with the objectives of production. Similarly to the production system and process themes discussed above, combining the key characteristics on the basis of production objectives is intended to assist in assessing a production system, in summarising the results of an assessment, and in explaining the expected effects of the suggested improvements. In this study, six production objectives are considered:

- **Quality**: the ability of materials, products and operations to conform to specifications and to meet the expectations and requirements of customers.
- **Lead or delivery time**: lead time of production or delivery time of an order to customers, i.e. the time required to produce a product or the time from placing the order to delivery of the product.
- **Reliability of lead or delivery time**: ability to meet the defined lead or delivery time.
- **Volume flexibility**: range of product volume that can be produced profitably, and ability to profitably change the production volume according to demand.
- **Product flexibility**: range of products or product variety that the production system and production processes are able to produce profitably, using controlled and stable production processes. Includes also the ability to change the production schedule and product mix.
- **Cost**: costs and expenditures derived from resources such as labour, equipment and material, used to produce a product.

Below, each of these production objectives and the key characteristics linked with them are discussed in more detail. This section thus describes how the key characteristics of a well-performing production system included in the TUTKA tool are intended to support achieving good performance with regard to the objectives of production.

**Quality**

In terms of quality, the focus is on the ability to consistently produce products according to specifications. As product design is not considered in this study, it is assumed that the customer requirements are understood, and the features, functions and specifications of a product are defined and determined so that the requirements of the customer are met and fulfilled. The key characteristics support consistent, high quality in the four ways presented below.

Firstly, the focus is on defined and repeatable processes and their outputs. The following three key characteristics contribute towards these:

- **Processes of production units are defined**
- **Employees are cross-trained and skills of employees meet the requirements of work tasks and processes**
- **Production equipment fits the requirements of the products and processes and the objectives of production**

Defining production processes and ensuring that the equipment used and the skills of the employees meet the requirements of the products and processes are assumed to enable repeatable processes, and to reduce variation in the processes and their outputs. Thus, the key characteristics are expected to contribute towards uniform quality of the processes and their outputs and to support achieving quality objectives and meeting customer requirements.
Secondly, procedures related to problems and delays in production are emphasised:

- Visual information and control systems are used in the production system
- Plans and procedures for responding to production disruptions, problems and delays are in place

Visual information and control systems support rapid identification of problems and deviations from standards in production. Plans and procedures for responding to and handling such deviations are thus intended to limit and minimise their effect on quality. Furthermore, the processes for identifying and removing the causes of problems and disruptions are expected to reduce the occurrence of problems and disruptions and therefore to contribute towards consistent high quality and lead time reliability.

Thirdly, the production system structure and personnel organisation can support the achievement of consistent and uniform quality. The key characteristics related to this are:

- Production system consists of production units that are responsible for certain parts of a product
- Teamwork and team organisation are used in production
- Production units work in close cooperation

Having a production system with a unit structure and then organising employees into teams to operate the production units serves to clarify responsibility for the quality of products and processes, and therefore supports the achievement of quality objectives. Furthermore, close cooperation between production units, which involves open communication and clear customer-supplier relationships, is expected to assist in identifying and eliminating potential defects and quality problems.

Finally, two key characteristics focusing on information and communication are presented:

- Information and communication support and enable decision-making
- Information and communication systems used in the production system are compatible and integrated

These aim to ensure usefulness and relevancy as well as reliability of information, which are seen to support production according to product specifications and customer requirements.

**Lead or delivery time**

The aim is to achieve a short lead time by reducing delays and non-value-adding work from the production process. The key characteristics connected with lead time are located in the production system structure, production equipment, and information and communication decision areas. Here, they are presented and discussed in four sets.

The key characteristics related to the layout of the production system aim to create a clear and straightforward material flow and an efficient production process.

- Production system structure corresponds to the structure and production process of products
- Distances between production units and distances between production equipment are short
- Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work
A product-based layout and short distances between production units result in clear material flow and aim to eliminate or reduce non-value-adding work such as transportation and handling between production units. Furthermore, the layout and organisation of workplaces should also reduce non-value-adding work and support value-adding work.

Furthermore, equipment, especially with regard to capacity and set-up times, is seen to have an effect on lead time:

- Production equipment fits the requirements of the products and processes and the objectives of production
- Changeover and set-up times of equipment are short

These two key characteristics are intended to ensure that equipment supports rapid production according to demand and orders and enables production in small batches. This contributes towards short lead time.

Furthermore, the number of levels in the product structure, which is related to the number of phases in the production process, is seen to have an effect on lead time. The key characteristics focusing on this aspect are:

- Levels in product structure simplify the structure of the production system and support production control
- Production equipment enables integration and reduction of production phases

The aim of the key characteristics is to reduce the number of levels in the product structure and the number of phases in the production process. This is seen to support short lead time, as reducing the number of phases in the process reduces non-value-adding time caused, for example, by transportation and waiting between production phases.

Finally, information and communication are seen to enable a rapid production process. Hence, two key characteristics from that decision area are included:

- Information and communication support and enable decision-making
- Information transfer and communication follow systematic and predefined principles and procedures

These two key characteristics aim to ensure availability of useful information within the production system. This supports rapid execution of orders and reduces delays caused by missing information or by searching for information.

**Reliability of lead or delivery time**

The key characteristics connected to reliability of lead or delivery time aim to reduce variation in processes and their outputs. These are grouped into four sets.

The first set of key characteristics focuses on defined and predictable processes:

- Processes of production units are defined
- Processes and procedures between production units are defined
- Production equipment is reliable and available for use
Predefined production processes and reliable and available equipment support predictable, reliable and repeatable execution of production processes. They therefore contribute towards reliable lead time.

Reducing variation and uncertainty within the production system and production processes are then emphasised by the following two key characteristics:

- Product structure consists of predefined parts and subassemblies
- Dissimilar main processes of production are identified and separated from each other

Limiting and defining the product variety offered to customers in advance and separating different production processes both serve to reduce variation and uncertainty concerning products and their functions and features produced in a given production process. This reduces variation in the required tasks, operations, and processes, which should in turn reduce variation in the duration of processes and in lead and delivery time.

Furthermore, the aim is to ensure that the required lead and delivery times can be met even if problems or disruptions occur in production. The following key characteristics focus on this:

- Visual information and control systems are used in the production system
- Production system structure makes it possible to observe the state of and the prerequisites for production
- Plans and procedures for responding to production disruptions, problems and delays are in place
- Personnel policy and arrangement of working time support operational flexibility and reliable deliveries

Visual information and communication, and visibility of the production system and production processes enable rapid identification of and reaction to problems, disruptions and delays. In addition, plans and procedures for responding to such events and for handling production during them should be in place to ensure a reliable lead time even if problems occur. Finally, the personnel policy and working time arrangements should enable schedule catch-up and achievement of the promised lead time, for example, through use of overtime or extra shifts.

Finally, the importance of information and communication in achieving lead time reliability is addressed:

- Information and communication support and enable decision-making
- Information transfer and communication follow systematic and predefined principles and procedures
- Information and communication systems are reliable and available for use

The key characteristics focus on availability and reliability of information, which support executing processes in a predefined way. This should improve predictability and lead time reliability.
Volume flexibility

Volume flexibility, i.e. the ability to change production volume and to produce different production volumes profitably, is related mainly to the ability to adjust equipment and employee capacities. The key characteristics that contribute towards this are:

- Production equipment fits the requirements of the products and processes and the objectives of production
- Personnel policy and arrangement of working time support operational flexibility and reliable deliveries

With regard to equipment characteristics, equipment should fit the needs of production and enable profitable production of the required production volumes. Furthermore, the ability to use overtime, extra shifts and temporary staff enable production capacity and output adjustment according to demand.

Product flexibility

With regard to product flexibility, the aim is not to achieve maximal flexibility, but to enable efficient and controllable production of the product variety offered to customers. The key characteristics that are seen to support such flexibility are grouped into two sets:

Firstly, decisions related to product architecture and production processes and management can enable efficient and controllable production of the product variety offered to customers. The key characteristics related to this are:

- Product structure consists of predefined parts and subassemblies
- Product architecture is modular
- Product platforms are used
- Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point

In terms of product architecture, defining and limiting the product variety in advance reduces and limits variation between products and orders. This makes it possible to define and standardise production processes and to identify prerequisites of production, such as equipment and materials, that are needed to produce order-specific products. Furthermore, use of product platforms and modular product architecture support both configuring and producing an order-specific product. They also enable the identification of standard and order-specific parts of the production process as well as late-point differentiation, i.e. creating the order-specific features and functions of a product during the latest possible phases of the production process. These support controlled and predictable production of the product variety offered to customers, and simplify production control.

Equipment and employee skills characteristics are also important in realising product flexibility:

- Production equipment fits the requirements of the products and processes and the objectives of production
- Changeover and set-up times of equipment are short
- Employees are cross-trained and skills of employees meet the requirements of work tasks and processes

Equipment that meets the requirements of the products and has short changeover and set-up times enables production in small batches according to demand and orders, as well as rapid
changes to the product mix. Furthermore, cross-trained and multi-skilled employees support efficient and controlled production of the product variety offered to customers.

Cost
The key characteristics support cost-efficiency in three ways: through standardisation and reducing the number of parts and components, by supporting the efficiency of production processes, and by enabling production in small batches according to order and demand.

Firstly, the key characteristics related to product architecture and structure are presented:

- Product architecture is modular
- Product platforms are used
- Product structure consists of predefined parts and subassemblies

Use of product platforms, modular architecture, and predefined parts and subassemblies supports standardisation and reducing the number of parts and components used in production. This can provide economies of scale and improve cost-efficiency of production. Furthermore, Torvinen et al. (2004, p. 74) point out that each part used in a product requires numerous tasks, such as design, scheduling, production, testing, and assembly. In addition to this, each part demands a certain level of inventory (Torvinen et al. 2004, p. 74). Hence, reducing the number of parts and components used in production has an effect on the processes and costs of production.

Next, the efficiency of production processes is emphasised and aimed at by the following key characteristics:

- Production system structure corresponds to the structure and production process of products
- Distances between production units and distances between production equipment are short
- Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work
- Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices
- Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point

The aim is to enable rapid and efficient production process by eliminating or minimising delays and non-value-adding operations by means of the production system and workplace layout. Additionally, value-adding work is supported by workplace organisation and appropriate tools and auxiliary devices. Improving and supporting the efficiency of production processes and reducing delays and non-value-adding work are assumed to improve cost-efficiency. Furthermore, late-point differentiation is seen to support and enable cost-efficiency improvement, especially in the standard part of the production process.

Finally, the equipment characteristics and the ability to produce products in small batches according to order are emphasised:

- Production equipment fits the requirements of the products and processes and the objectives of production
- Changeover and set-up times of equipment are short
Equipment that meets the requirements of the processes and the products and has short changeover and set-up times enables the production of parts and products in small batches according to order and demand. This reduces work in progress and related costs, and supports process efficiency by reducing waiting caused by batch production.

5.2. Assessment scale

The assessment scale included in the TUTKA tool is used in assessing a production system and in presenting the results of an assessment. The assessment scale focuses on the correspondence between the characteristics of the assessed production system and the key characteristics of a well-performing production system, or, in other words, on the realisation of the key characteristics in the assessed system. It also considers adaptability of the assessed production system. The scale was developed on the basis of the maturity models (Section 4.4.) and consists of the following four levels:

- **Level 1: No correspondence.** The characteristics of the assessed production system do not correspond with the key characteristic of a well-performing production system considered. In other words, the key characteristic is not realised in the assessed production system.

- **Level 2: Partial correspondence.** Parts of the assessed production system correspond with the key characteristic of a well-performing production system, i.e. i) the key characteristic is realised in some parts of the assessed production system, or ii) the key characteristic is partly realised in the assessed production system, i.e. some but not all of the breakdown points of the key characteristic are realised.

- **Level 3: Full correspondence.** The characteristics of the assessed production system correspond with the key characteristic of a well-performing production system, i.e. the key characteristic is realised in the production system.

- **Level 4: Adaptability.** The characteristics of the assessed production system correspond with the key characteristic and the correspondence can be maintained even if the product variety and/or production volume change. In other words, the key characteristic and its implementation allow the system to accommodate or adapt to changes in production volume and product variety.

The first three levels of the assessment scale are concerned with assessing the production system at the present moment and in the current operational environment. The breakdown points and definitions of each key characteristic correspond to level 3 of the assessment scale. Hence, level 3 is achieved if the production system characteristics correspond with the key characteristics of a well-performing production system considered, i.e. if the key characteristic and its breakdown points are realised in the assessed production system. The fourth level of the assessment scale considers the adaptability of the production system, i.e. the ability of the production system to accommodate changes, or the ability to adapt the production system to fit the changes and new requirements in the medium term. The changes and new requirements considered are limited to production volume and product variety or product mix. This perspective is not assessed for all of the key characteristics, but only for those that are seen to have direct effect on the adaptability of a production system. With regard to production flexibility, the fourth level and the adaptability of a production system can be connected with tactical flexibility of production, which Beach et al. (2000, p. 49) define as the ability to operate at varying rates, to handle a variety of parts of known basic design, and to accept random, minor changes. In addition, short-term operational flexibility is covered by the product and volume flexibility production objectives, which are addressed by the key characteristics.
The developed four-level assessment scale enables identification of a production system’s strengths and improvement potential. Key characteristics of well-performing production system ranked highest on the scale, i.e. level 3 or 4, indicate the production system’s strengths. Key characteristics ranked at levels 1 and 2 indicate improvement potential related to realisation of the characteristics. In such cases improvement can be gained by modifying the production system so that the key characteristics are implemented and realised. Additionally, key characteristics ranked at level 3 but not level 4 indicate improvement potential related to the adaptability of the production system, i.e. its ability to accommodate changes in production volume or product mix.

5.3. Production system assessment methods and measures

As discussed in Section 4.5., the production system assessment is based mainly on questions related to the key characteristics of a well performing production system and their realisation in the assessed production system. The questionnaire used in the assessment is presented in full in Appendix 4 and therefore the questions are presented and discussed here only at a general level. In addition to the questionnaire, quantitative measures and other sources of information can be used in the assessment process.

5.3.1. Assessment questionnaire

Assessment questions have been developed for each of the key characteristic of a well-performing production system included in the TUTKA tool, and the questions are grouped into three sets. The first set presents one question or claim concerning the realisation of a key characteristic at the general level. Then, the second set complements this with more detailed questions and claims based on the breakdown points and descriptions of the key characteristics. These two sets of questions and claims are connected to levels 1 to 3 on the assessment scale, and enable either a more general level or more detailed assessment of the realisation of a key characteristic. Furthermore, a third set of questions and claims addresses the adaptability of the production system and its ability to accommodate changes in production volume and product variety. These questions were developed only for those key characteristics that were seen to have an effect on adaptability of a production system. The three sets of questions and claims and their linkages with the assessment levels are summarised in Figure 33.

![Figure 33. The question sets and assessment levels](image-url)
To further clarify the assessment questions and claims, two examples are presented. Table 10 presents the questions and claims used in assessing the key characteristic “Product architecture is modular” included in the product architecture decision area (Section 5.1.1.).

**Table 10. Questions and claims for assessing modularity of product architecture**

<table>
<thead>
<tr>
<th><strong>Product architecture is modular</strong></th>
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<tbody>
<tr>
<td><strong>Set 1: General assessment of the key characteristic:</strong> Products consist of building blocks (modules) that have specified interfaces</td>
</tr>
<tr>
<td><strong>Set 2: Detailed assessment of the key characteristic:</strong> The interfaces of the modules enable interchangeability, i.e. changing a module or its functions or features in such a way that the change does not affect other modules of the product</td>
</tr>
<tr>
<td><strong>Building blocks (modules) of a product can be tested separately before assembling the product</strong></td>
</tr>
<tr>
<td><strong>Set 3: Adaptability of the production system:</strong> Modular product architecture and specified interfaces of modules enable introducing and adding new functions and features to current modules</td>
</tr>
<tr>
<td><strong>Modular product architecture and specified interfaces of modules enable adding new modules to the product</strong></td>
</tr>
<tr>
<td><strong>Current modules can be used in new products</strong></td>
</tr>
</tbody>
</table>

In this case, the breakdown points of the key characteristic are used as claims that enable consideration and assessment of modularity of the company’s products. In terms of adaptability and ability to meet changing customer requirements, the focus is on new products and new features of products, i.e. changes to product variety. In this regard, modularity can enable the creation and realisation of new features and functions in a certain module or modules, thus limiting the effects of changes to a certain part of the product. The specified interfaces can also make it possible to introduce new features and functions by designing and including a new module in a current product. Finally, a wider variety of products, functions and features can be offered to customers if the current modules can be used in new products, for example by combining them with a new product platform.

As a further example, Table 11 presents the questions and claims related to the key characteristic “Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work” included in the production system structure decision area (Section 5.1.2.).

**Table 11. Questions and claims focusing on the layout and organisation of workplaces**

<table>
<thead>
<tr>
<th><strong>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Set 1: General assessment of the key characteristic:</strong> Required equipment, materials and tools are located in workplaces so that non-value-adding work is minimised and value-adding work is supported</td>
</tr>
<tr>
<td><strong>Set 2: Detailed assessment of the key characteristic:</strong> Workplaces contain only necessary and required materials, tools and equipment Tools and materials are located according to their use Locations of material and tools enable ergonomic working positions and working at correct height Locations of material and tools enable working without exerting undue force or stretch Need to move, lift or rotate materials, parts or products before or during work task is minimised Operators’ or employees’ need to move during work task is minimised (e.g., possible to work in one place, eliminating need to pick up materials)</td>
</tr>
<tr>
<td><strong>Set 3: Adaptability of the production system:</strong> New tools and materials can be located in workplaces according to their use Ergonomic working positions can be maintained if new tools and materials are added to workplaces</td>
</tr>
</tbody>
</table>

Here, the questions and claims included in Set 2 are more detailed than the breakdown points of the key characteristic, and were developed on the basis of the definitions of the key characteristic.
and examples of its implementation. With regard to adaptability of the production system, a situation in which new tools and materials must be added to a workplace to enable production of new products, higher product variety, or higher production volume is considered. Thus, the questions and claims in Set 3 focus on the ability to maintain a layout and organisation that supports value-adding-work in a case where new tools and materials are added to the workplace.

These examples are intended to demonstrate the questions and claims that are used to assess the realisation of a key characteristic. Some key characteristics are assessed based on their breakdown points, while others are assessed based on more detailed questions and claims. Furthermore, as the examples indicate, in terms of adaptability the main idea is to consider the effects of changes in product variety or production volume on a certain key characteristic. More specifically, either the ability of a key characteristic and its implementation to support making the required changes is evaluated, or the ability to maintain the correspondence between the production system and the key characteristic even if product variety or production volume changes is evaluated.

5.3.2. Performance measures and additional sources of information

The performance measures and other sources of information included in the TUTKA tool complement the assessment questions and provide additional information for production system assessment. The measurement data and other information can also be used to clarify or evaluate the responses of the company’s personnel to the assessment questions and claims. Furthermore, the data and information are beneficial when presenting the assessment results, since they increase the level of detail and provide examples related to the current situation and improvement potential. With regard to collecting measurement data and other information, use of data and information that is readily available in the company is suggested. Generating and collecting the data and information during the assessment process is also possible, although this will increase the time and effort involved in the assessment.

The performance measures included in the TUTKA tool focus mainly on the production equipment and human resources decision areas. With regard to production equipment, the following measures of performance are considered to provide useful information for the assessment process:

- Potential process capability index ($C_p$), which is the ratio of specification width over the process spread, or process capability index ($C_{pk}$) (for equations see e.g. Ramakrishnan et al. 2001; Kotz & Johnson 1993)
- Changeover and set-up times of equipment
- Mean time between failures (MTBF)
- Mean down time (MDT), which can be further divided into
  - Mean waiting time (MWT), i.e. time before repair is started and
  - Mean time to repair (MTTR)

In the assessment process, these measures and the data derived from them can be linked to three key characteristics related to production equipment. The measures of process capability, $C_p$ and $C_{pk}$, provide data and information for considering the first key characteristic: “Production equipment fits the requirements of the products and processes and the objectives of production”. Furthermore, the changeover and set-up times can be measured to evaluate and consider the need to shorten them, which is emphasised in the second key characteristic of the decision area. Finally, mean time between failures as well as mean down time and its parts are related to the fourth key characteristic: “Production equipment is reliable and available for use”.

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Performance measures and measurement data related to the human resources decision area include:

- Time since last occupational accident
- Number of days missed due to occupational accidents
- Number of occupational accidents or near misses during a given time period e.g., month or year
- Number of initiatives or suggestions from employees in a given time period
- Number or share of initiatives and suggestions that have been implemented

These measures and the data provided by them are linked to two key characteristics, and both their current values and their trends over a given time period provide useful information for the assessment. The first three measures consider occupational safety and are hence connected to the last key characteristic of the decision area: “Occupational safety and ability to work are emphasised and ensured”. The remaining two are indicators of commitment to work and involvement in improvement, which are presented in the fourth key characteristic: “Commitment to work and involvement in improving production system and production processes are promoted”.

In addition to performance measures and measurement information, various descriptions and definitions can provide useful information for the assessment process. The most important of these are considered to be:

- Description or documentation of the product structure
- Map or description of production process and order-to-delivery process
- Layout picture of the production system
- Matrices or descriptions of skills
- Organisation chart of production

The information provided by these can be linked to various decision areas, such as product architecture, production system structure, production processes and management, and human resources. The description of the product structure supports consideration and assessment of the characteristics of the product architecture, such as the modularity of the product structure, the use of product platforms, and the number and usefulness of product structure levels. The process descriptions and maps enable consideration of production processes and management, particularly key characteristics that emphasise defined processes both within and between production units and the separation of different production processes. Furthermore, the description of the order-to-delivery process indicates whether the product variety offered to customers is defined and limited in advance, which is discussed and assessed in the product architecture decision area. The production system structure can be considered and evaluated using the production system layout picture. Combining the layout picture with the descriptions or maps of the process enables identification and visualisation of the material flow. These information sources can hence be connected to the key characteristics of the production system structure that emphasise the unit structure of a production system, product-based layout, and short distances within the production system. The identified sources also provide information related to human resources decision area. Skill matrices enable comparison of skills with the requirements of the processes and products, and consideration of the ability of employees to engage in job rotation. These aspects are presented in the second key characteristic of the decision area. Furthermore, the organisation of employees, for example the use of team organisation as emphasised in the first key characteristic, can be examined with the help of a production organisation chart.
The performance measures, measurement data and sources of information presented above can be used in the production system assessment process to complement the information collected with the questionnaire. However, as mentioned in Section 4.5., the list is not exhaustive, but includes some typically used performance measures and sources of information.

5.4. Summary

This chapter presented the results of this study, i.e. the TUTKA production system assessment tool and its parts: the set of key characteristics of a well-performing production system, the assessment scale, and the assessment methods.

First part of the chapter (Section 5.1.) presented the key characteristics of a well-performing production system, which provide the basis for the TUTKA tool. The tool includes 33 key characteristics that are grouped into six decision areas. Each key characteristic was described and reasoned in detail, and the linkages to production system and process themes and to production objectives were discussed.

Subsequently, the assessment methods and assessment scale included in the TUTKA tool were presented. The assessment methods and scale focus on the realisation of the key characteristics of a well-performing production system in the assessed production system, and also include a perspective on the adaptability of the system. The four-level assessment scale enables the identification of strengths as well as improvement potential of the assessed system. The primary assessment method is the questionnaire that presents questions grouped into three sets. Additionally, performance measurement data and other sources of information such as descriptions of products, processes and the production system can be used in the assessment process.
6. Use of the TUTKA production system assessment tool

This chapter discusses the use of the TUTKA tool in assessing production systems. The assessment process is based on the set of key characteristics of a well-performing production system, which provides a reference against which a production system and its characteristics can be compared. The adopted assessment approach thus shares similarities with benchmarking and some of the assessment and improvement tools, models and frameworks reviewed, for example the SHEN model and the SCMAT tool.

In the following sections, the process of assessing a production system using the TUTKA tool is described, and the ability to tailor the assessment process to specific company needs is discussed. Finally, the results of pilot cases in which the TUTKA tool has been used are presented.

6.1. General assessment process

The assessment process is based on the developed set of key characteristics of a well-performing production system and focuses on the correspondence between the key characteristics and the characteristics of the assessed production system. The majority of the information used in the assessment is collected by means of a questionnaire and an assessment discussion, although supplementary information from other sources can also be used. The assessment results are presented on a four-level assessment scale, and the system’s strengths as well as improvement potential are identified. The set of key characteristics of a well-performing production system, and the assessment scale and methods are presented in Chapter 5 and in Appendix 4.

The assessment process can be divided into three phases (Figure 34), and is intended to be facilitated by the author or a person familiar with the TUTKA tool and the assessment process.

<table>
<thead>
<tr>
<th>Phase 1: Assessment discussion and information collection</th>
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<tbody>
<tr>
<td>- Questionnaire-based assessment of the production system</td>
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<tr>
<td>- Collection of additional information, e.g. performance measurement data and process maps</td>
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</table>

<table>
<thead>
<tr>
<th>Phase 2: Analysis and summary of information, preparation of results</th>
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<tbody>
<tr>
<td>- Strengths and improvement potential of the assessed production system identified and clarified using the collected information and the set of key characteristics of a well-performing production system</td>
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<table>
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<tr>
<th>Phase 3: Presentation of assessment results to the company</th>
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<tbody>
<tr>
<td>- The results of the assessment process, i.e. the strengths and improvement potential of the assessed production system, are presented and discussed with the company</td>
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</table>

Figure 34. The three phases of the assessment process

In the first phase of the assessment process, an assessment discussion is conducted with company personnel and supplementary data and information for the assessment is collected. In the assessment discussion, the realisation or implementation of each of the key characteristics of a
well-performing production system is considered and evaluated with the help of a questionnaire. However, if the respondents argue that a key characteristic is not applicable or relevant, it is not considered or assessed. The assessment questions are grouped into three sets (Section 5.3.1.). The first two sets present a general question as well as more detailed questions related to the realisation of a key characteristic in the production system in the current operational environment. On the assessment scale, these questions correspond to levels 1 to 3. The third set of questions focuses on the adaptability of the production system and corresponds to level 4 on the assessment scale. These questions are assessed for those key characteristics that, on the basis of the earlier questions, are realised and implemented in the production system. The questions are answered by personnel of the company who are able to provide the required information related to the production system and production processes. These typically include production managers or production engineers. Hence, the production system assessment is based largely on the knowledge and opinions of the participants. In order to support and simplify the assessment, the discussion is facilitated by the researcher or other person who can provide additional information and examples related to the key characteristics and to the questions and claims. Additionally, information such as performance measurement data and definitions and descriptions of products, processes and the production system can be collected in the first phase of the assessment process. This information is intended to complement the information collected by the questionnaire and to support the analysis and assessment of the current state of the production system. The additional information can also support and improve the objectivity of the assessment by enabling evaluation of the responses to the questions and assessment of the realisation of the key characteristics in the production system. The assessment process is intended to be relatively quick, therefore use of readily available information is suggested, rather than collecting the information during the process and by the facilitator.

The second phase of the assessment process, analysis and summary of information and preparation of results, aims to identify and clarify the strengths of the assessed production system and the potential and means for improving the system. The phase is carried out by the facilitator and is based on the results of the assessment discussion, information collected from other sources, and the structure and content of the TUTKA tool. Based on the adopted improvement and assessment approach, the differences between the characteristics of the assessed production system and the set of key characteristics of a well-performing production system indicate the potential for improvement. Hence, those key characteristics that are not realised in the assessed production system, i.e. are ranked at levels 1 and 2 on the assessment scale, indicate potential for improving the production system. Additionally, those key characteristics that have reached level 3 but not level 4 indicate improvement potential that is related to the ability to accommodate changes in production volume or product mix, or the ability to adapt the production system according to such changes. With regard to the key characteristics that indicate improvement potential, the company is suggested to consider and evaluate whether the characteristics of their production system should be modified or improved in order to improve the production system and production performance. On the other hand, the key characteristics that are ranked at the highest level for the given key characteristic, i.e. are either realised in the current operational environment (level 3) or enable and support adaptability of the production system (level 4), are seen as strengths of the production system.

The collected information and the hierarchy of the set of key characteristics of a well-performing production system (see Section 5.1.) enable clarification and elaboration of the identified strengths and improvement potential of the production system, as well as suggestions for means for improvement. The issues discussed during the assessment process and the information collected from other sources provide concrete examples that enable clarification and reasoning regarding the strengths and improvement potential of the production system. With regard to the structure and hierarchy of the set of key characteristics, the breakdown points and the detailed definitions and descriptions enable connection of the strengths and improvement potential related
to a key characteristic with production objectives, and identification of ideas and means for improvement. Additionally, the strengths or improvement potential can be combined into production system and process themes (Section 5.1.7.) and connected with production objectives (Section 5.1.8.). Hence, the assessment results can be clarified and explained. Connecting the assessment results with production objectives can also help in prioritising the potential and means for improvement.

In the third phase of the assessment process, the results are presented and provided to the company in a meeting. An overview of the assessment results is presented using a radar chart, and then the results, i.e. the strengths, improvement potential and means for improvement, and their connections with the themes and performance of the production system and processes, are presented and described in more detail. Additionally, a document presenting the assessment results for each key characteristic of a well-performing production system on the four-level assessment scale, and the notes made by the facilitator during the assessment discussion is provided to the participants.

The assessment process described here requires two meetings with the company and can be carried out within a short time frame. The first meeting takes place during the first phase of the process when the required information is collected, and the second during the third phase when the results are presented. Based on experiences from the six pilot assessment cases, the first meeting takes from two to four hours, and the presentation and discussion of the results typically lasts roughly two hours. Hence, the time required from the company personnel participating in the assessment process is around eight hours or one working day depending on the time taken to prepare for the discussion and to collect additional information, such as performance measurement data or process maps. The time required for analysing and summarising the information and preparing the results was not measured in detail, but the quickest pilot cases were carried out in two days, which provides a rough guideline for the amount of time and effort required for this phase.

The TUTKA tool provides a quick assessment that gives an overview of the current state of the production system. The tool and the assessment results thus provide a starting point for the production system and production performance improvement process. After the assessment, more detailed evaluation of the identified improvement potential as well as evaluation and planning related to available options and means for improvement are required before plans and efforts towards improvement can be determined and initiated.

### 6.2. Tailored assessment processes

The typical or suggested process for assessing a production system using the TUTKA tool can be modified and tailored according to the needs of the participating company. The questionnaire used in the assessment and the structure of the set of key characteristics of a well-performing production system enable selection of the aspects covered and the level of detail of the assessment. From the perspective of the participants, the choices made have an effect on the time and effort required for the first phase of the assessment process, i.e. the assessment discussion and collecting information for the assessment. Furthermore, instead of a facilitated process, the assessment can be carried out as a self-assessment by the company. In this section, the ways in which the assessment process can be modified, and the effects on the process and its results are explained.

The three sets of questions included in the assessment questionnaire (Section 5.3.1.) enable selection of the level of detail at which the realisation of a key characteristic is assessed, and determination of whether the adaptability of the production system is to be assessed. The first set
of questions enables a quick and general-level assessment of the realisation of a key characteristic, and the second set enables consideration of the aspect in more detail. The adaptability of the production system is then covered by the third set of questions. The different assessment processes enabled by these three sets of questions vary in terms of the level of detail and duration of the assessment discussion, and the type and level of detail of the results achieved. The following figure presents different options for using the questionnaire in the assessment discussion and shows their correspondence with the assessment scale levels (Figure 35).

![Figure 35. Three sets of questions enabling tailoring of the assessment process according to the needs of the company](image)

The solid arrows represent the suggested assessment process that utilises all three sets of questions, while the dotted arrows indicate modified processes that are created by combining the three sets of questions in different ways. The suggested process is the most detailed and time-consuming of the assessment discussion options, but provides the most detailed assessment. At the other extreme, a quick and general-level assessment of the realisation of the key characteristics can be carried out using only the first set of questions. Another option is to combine the first and second set of questions so that the more detailed questions are used for those key characteristics that, on the basis of the general-level question, are not fully realised in the production system. This process provides more detailed information than the quickest version, but enables a simpler and quicker assessment discussion than the suggested process in which the second set of questions is used for all of the key characteristics. The remaining assessment process variations are provided by the third set of questions. For each of the options discussed, the third set of questions, i.e. the perspective on adaptability of the production system, can be either included in or excluded from the assessment process. The three question sets thus enable the first phase of the assessment process to be modified.

The first phase of the assessment process and the amount of work required in collecting information for the assessment can also be adjusted by the way of collecting and use of additional information for the assessment. To enable a relatively quick assessment, it was suggested in the previous Section (6.1.) that additional sources of information such as process maps, layout pictures and product structure descriptions are used if they are readily available. However, generating and collecting such information material as part of the assessment process is also possible. The advantage of generating and collecting additional information and material for the assessment is that it enables a more detailed assessment process that can provide more concrete results and potential and means for improvement. On the other hand, compared to using only readily available information, more effort and time is needed in the first phase of the assessment process.

Another way to tailor the assessment process is to modify the scope of the assessment by considering only some of the decision areas or only some of the key characteristics included in the TUTKA tool. As an example, assessment of the production equipment decision area may not be relevant for companies operating on the basis of an assemble-to-order approach, and thus this
decision area and the key characteristics included in it can be omitted from the assessment. Similarly, other key characteristics that are not seen to be relevant or applicable to the company need not be considered in the assessment process. Additionally, the linkages between each key characteristic and the six objectives of production indicated in the final set of key characteristics of a well-performing production system (Table 9, Section 5.1.) can be used to modify the scope of assessment. The linkages enable the identification and assessment of the key characteristics that are relevant in terms of the objectives of the participating company. A company may, for example based on performance measurement or customer feedback, have identified that production performance related to a certain production objective, such as lead time, should be improved. In such a case, the linkages between the key characteristic and the production objectives enable identification of those key characteristics that are expected to have a positive effect on the selected and emphasised objective of production. The assessment process can then be simplified by considering only those key characteristics. Hence, the scope of assessment, and also the amount of work required in the assessment process, can be modified by assessing only certain decision areas and key characteristics, which can be selected in different ways.

Furthermore, the focus of the assessment can also be modified. The assessment typically focuses on the production system of a single company, which may consist of one or more factories (Section 1.2.). However, instead of the entire production system of a company, only a certain part of the system, for example, one factory or a part of a factory such as an assembly unit can be considered in the assessment process. On the other hand, as pointed out earlier in connection with the key characteristics of the production system structure and production processes and management decision areas, some key characteristics can also be considered at the level of a production network, which also includes the company’s suppliers (Sections 5.1.2 and 5.1.3.). Hence, the TUTKA tool also enables broadening or limiting of the assessment focus.

Finally, the assessment process can be carried out in different ways, as a self-assessment or facilitated process, and by one or more groups. Firstly, although the assessment is intended to be facilitated, a self-assessment by the target company is also possible. In self-assessment, the company assesses the realisation of the key characteristics using the questionnaire and additional information, and summarises the results with the help of the information provided in this study. However, compared to the facilitated process, the self-assessment approach includes potential drawbacks. For example, the questions and claims used in the assessment may require explanation in order to ensure that they are correctly understood. Furthermore, a facilitator who has a thorough knowledge of the set of key characteristics can elaborate on the assessment results and provide additional information related to the results and the identified improvement potential. Thus, the self-assessment may not be as useful and concrete as a facilitated assessment process. In addition to the possibility of carrying out a self-assessment or facilitated assessment, the first phase of the assessment process, i.e. the assessment discussion, can be carried out with a single group in a single meeting, or with several groups for which separate meetings are arranged. A group can consist of one or more people who are able to provide the required information. As an example, one group might include a production manager or managers, while a second group consists of production engineer or engineers. Separate assessment discussions are then carried out with or by these groups. Comparing the results of these two assessments can highlight differences between the opinions and points of view of these two groups, which can inspire discussion and raise questions on the current state of the production system as well as its improvement potential and needs.

Thus, the TUTKA tool enables various assessment processes. The differences of the processes are mainly related to the first phase of the assessment process, i.e. how the assessment discussion and collection of additional information are carried out, and which aspects are covered in the assessment. Hence, the different assessment processes vary in terms of time and effort required, and the type and level of detail of results achieved.
6.3. Case-examples of using the TUTKA production system assessment tool

The TUTKA tool and the production system assessment process were tested in six pilot cases during last part of year 2008 and beginning of year 2009. These cases aimed to demonstrate the applicability and usefulness of the TUTKA tool and assessment process in practice. The pilot cases also involved collecting participant feedback on the developed production system assessment tool, assessment process and results using a questionnaire. The purpose of the feedback was to enable evaluation of the results of this study (Chapter 7).

In this section, the pilot cases in which the TUTKA tool has been used are reported and the results of the assessment, i.e. the identified strengths and improvement potential of each production system, are summarised. Some of the pilot companies wished to remain anonymous and required that the cases be reported in such a way that the assessment results cannot be linked to the company. The pilot cases are therefore reported so that the general characteristics of the pilot companies are first presented and then the assessment processes together with the results are reported in a different order in separate sections.

6.3.1. General characteristics of the companies and assessment

The six assessment cases were carried out in five companies. The aim was to select companies that belong to the target group of this study, i.e. meet the criteria and definitions presented in Section 1.3. This selection and criteria can be justified by the aim of demonstrating and enabling evaluation of the applicability and usefulness of the TUTKA tool and the assessment process to the target companies of the study. However, in three of the six pilot cases, the pilot company operated mainly on the basis of the engineer-to-order approach and therefore did not completely fulfil the target company description. Figure 36 presents the production approaches of the six cases.

![Figure 36. Production approaches of the case companies](image)

The five companies participating in the pilot cases can be described in terms of business area, type of products and production volume as follows. One of the companies produced loaders that can be used, for example, in agriculture, construction, property maintenance and landscaping. The production volume of the company was around 3,500 products per year. Another company was a producer of forest machines and the product portfolio contained harvesters and forwarders. The company produced approximately 150 machines per year. In addition, the production system of a company designing and producing special vehicles, mainly ambulances, from various automobile brands was assessed. The production volume of this company was approximately 200 vehicles per year. A supplier of cargo handling equipment to ports and terminals also participated in the pilot cases. Two separate production systems of the company were assessed, one for straddle carriers used in container handling and another for terminal tractors used for trailer handing at ports and terminals. The production volumes of these production systems were approximately 200 and 500 products per year, respectively. Finally, one of the pilot companies was supplier of machines and technology for the mining and construction industries. The production volume of the assessed production system was between 500 and 1,000 products per year.
In each pilot case the assessment process was carried out as described in Section 6.1. In the first meeting with the pilot company participants the assessment discussion was carried out and additional information was collected. In the assessment discussion the realisation and implementation of the set of key characteristics in the production system was assessed by means of the questionnaire and the four-level assessment scale, and the discussion was facilitated by the researcher. During the first meeting, available information to assist the assessment, such as process and product descriptions and layout pictures, was also collected. The duration of the first meeting was between two to four hours. Then, in the second phase of the assessment process, the collected information was analysed and summarised and the results were prepared by the researcher. Following this, the results and findings of the assessment process were presented to the company representatives in a separate meeting lasting from one and half to two hours. At the end of this session the participants were asked to fill in a feedback questionnaire regarding the TUTKA tool, the assessment process, and the results and findings. In two of the six pilot cases the second meeting, i.e. the presentation of the results, was held on the next day following the assessment discussion, while in rest of the pilot cases there were a couple of days between the two meetings. In addition to the meeting in which the results of the assessment were presented, the pilot companies were provided with a document in which the assessment of each key characteristic together with notes on the discussion concerning the key characteristic was presented. Also, the materials used in the results meeting to present and summarise the results and observations of the assessment, i.e. the strengths and improvement potential of the production system, were sent to the company.

6.3.2. Case A

In this pilot case, a production system consisting of a factory producing one of the main subassemblies of the company’s product and a part production facility that serves the subassembly plant was assessed. The company and the production system operated in make-to-order mode as the products were configured but not designed based on an order. All six decision areas were assessed in this pilot case. Three persons, an Industrial Engineering Manager and two Manufacturing Managers, were involved in the assessment process. In addition to the assessment discussion, a layout of the subassembly factory provided information for the assessment process. The score given using the four-level scale for each key characteristic of a well-performing production system is presented in Table 12.
<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristic</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product architecture</td>
<td>Product architecture is modular</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>3</td>
</tr>
<tr>
<td>Production system structure</td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>2</td>
</tr>
<tr>
<td>Production processes and management</td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>4</td>
</tr>
<tr>
<td>Production equipment</td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>2</td>
</tr>
<tr>
<td>Information and communication</td>
<td>Information and communication support and enable decision-making</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>2</td>
</tr>
<tr>
<td>Human resources</td>
<td>Teamwork and team organisation are used in production</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and improved</td>
<td>3</td>
</tr>
</tbody>
</table>
The following chart provides an overview of the results of the assessment (Figure 37). The category labels indicate the decision area (product architecture PA, production system structure PSS, production processes and management PP, production equipment PE, information and communication IC, and human resources HR) and the number of key characteristics in each area.

Figure 37. Overview of Case A assessment results

Regarding the above table and figure, it should be noted that in the assessment process, level four is not assessed for all key characteristics. Therefore, the key characteristics ranked at level three or four are seen as strengths of the production system, while key characteristics ranked at levels two and one indicate improvement potential.

Strengths of the production system

As Table 12 and Figure 37 show, several decision areas, i.e. product architecture, production processes and management, production equipment, information and communication, and human resources, include key characteristics ranked at the highest levels of the assessment scale. These key characteristics were seen as the strengths of the assessed production system.

With regard to human resources, the assessment indicated that the personnel are multi-skilled and their skills meet the requirements of the products and processes. In terms of production objectives, these characteristics contribute towards high quality of products and processes and support flexibility in terms of product variety. Furthermore, the employee skills and the human resource arrangements and policies in place were seen to enable the adjustment of personnel capacity according to demand. This ensures volume flexibility and lead and delivery time reliability. It was also found that the involvement and participation of employees in their work and in its improvement was promoted and supported. This is expected to support production system and production processes improvements. Finally, the assessment shows that occupational safety and employee ability to work are promoted.

In the production equipment decision area, the equipment of the production system was seen to meet the requirements and objectives of production and to enable reliable part production in small batches. These characteristics are connected to reliable production processes and, in terms of production objectives, to achieving consistent high quality and cost-efficiency.
Regarding product architecture and structure, the assessment indicated that key characteristics related to modular product architecture and use of predefined parts and subassemblies were realised and implemented. These should simplify the specification or configuration of order-specific products. Furthermore, limiting the product variety by using only predefined parts and subassemblies in products contributes towards efficient production processes. Hence, these strengths can be connected to lead time and costs as well as product flexibility. Furthermore, they assist production control and purchasing by enabling identification of the main entities of the product.

Additionally, based on the responses, in the area of production processes and management, the main processes of production were identified and separated and plans and procedures for responding to disruptions and delays in production were in place. Realisation of these key characteristics support and ensure a reliable production process and contribute towards lead time reliability. Furthermore, it was concluded that responsibility for scheduling and controlling production was allocated to production units. This should simplify production control and improve production controllability. Finally, cooperation between production units, for example in improving the production system and processes, was seen to be supported.

Potential and means for improving the production system

On the basis of the assessment, improvement potential was found mainly in the production system structure decision area. In addition, some key characteristics in the production processes and management, production equipment, information and communication, and product architecture decision areas indicated potential for improvement.

In the production system structure decision area, the most important improvement potential was related to two production system and process themes: the unit structure of the production system and straightforward material flow (Section 5.1.7.) In addition to the assessment discussion, the layout picture of the subassembly plant was used in the assessment process and in identifying these improvement needs. The descriptions of the themes and key characteristics indicate that the potential improvements involve firstly identifying the production units that are responsible for certain subassemblies or entities of the product, and then arranging these units according to the structure and production process of products so that subsequent units are in proximity to each other. The assessment also indicated that modular structure of products was well implemented. Implementing the suggested improvements would clarify the structure of the production system, simplify production control and reduce delays in the production process. Considering the objectives of production, these can be linked with reducing lead time, improving its reliability and reducing costs of production.

Furthermore, the responses indicated that monitoring of the production system, the status of production, and the availability of production prerequisites such as required materials, could be made easier. Based on the assessment results and the description of this production system and process theme related to visibility and monitoring of the production system and processes (Section 5.1.7.), the means for improvement were related to production system structure and information and communication. With regard to production system structure, the means of improvement included creating a unit structure and straightforward material flow, which was discussed already above. Then, regarding information and communication, improvements would involve clearly indicating the production units, for example by painting, using colour codes and signboards, and defining and clearly indicating the locations for both the incoming and outgoing materials of each production unit. Furthermore, production boards or displays that show the production order and current status of production would support monitoring of the production
schedule and status of the production processes. Developing a more visual production system and production process should support and simplify production control. In terms of production objectives, these improvements contribute towards lead time reliability and achieving required quality by enabling rapid identification of and reaction to deviations from the normal status or procedures.

Another improvement theme was the elimination of non-value-adding work and the promotion of value-adding work at production units and workplaces. This was related to the decision areas and key characteristics of production system structure and production equipment. With regard to the layout and organisation of workplaces, 5S principles, such as removing unnecessary items and positioning the remaining items according to their use and so that they enable ergonomic working positions, could improve the layout of the assessed production system. In addition to this, value-adding work as well as required handling, transportation etc. could be supported by auxiliary devices, as discussed in connection with the production equipment decision area. These improvements are expected to contribute towards reduced lead time and lower production costs.

With regard to production processes and management, the need to define processes at a more detailed level both within and between production units was identified. The assessment discussion revealed that production processes, procedures and tasks were defined at the product level but not at the subassembly level. More specific definitions of processes and procedures were suggested in order to improve and ensure the reliability of production processes. This can be linked with the improvement potential related to production system structure, namely the need to create production units, as discussed above. If production units that are responsible for certain entities or subassemblies of the product are created, processes and procedures must be defined at the same level of detail. With regard to production objectives, the more detailed definitions of processes and procedures could contribute towards consistent quality and lead time reliability.

In the decision areas of product architecture and production processes and management, the assessment revealed improvement potential related to the use of product platforms and to the location and use of the order penetration point. These are related to identifying order-specific and standard parts of the product and production process and utilising these in simplifying production control. It was noted that the order penetration point cannot be clearly positioned and identified because some order-specific features affect the product and production process in earlier phases than others. If the order penetration point could be clearly positioned and standard and order-specific parts of the production process identified, production control would become easier. Furthermore, it was noticed that production control could be simplified by using simpler control methods, such as stock-based control and replenishment instead of order-based control in the standard part of the production processes upstream from the order penetration point.

Finally, in the information and communication decision area, the assessment showed that information and communication systems in different functions, such as sales and production, as well as in assembly and part production factories were not integrated and compatible, but manual work was required in transferring data and information between the functions and factories. Thus, the company was suggested to evaluate whether the number of different information and communication systems could be reduced by using the same system in different parts of the production system, or whether the interfaces between the systems could be modified to enable automatic information exchange. Improving the integration and compatibility of information systems should reduce the need for manual input and the related information transfer error potential. Thus, the improvements could improve and ensure the availability and reliability of information, which supports rapid and reliable production processes.
6.3.3. Case B

The pilot company focused mainly on product assembly, although it also conducted sheet metal cutting, trimming and welding in-house. Its mode of operation was classified as make-to-order, although the majority of part production was done by suppliers. Furthermore, the products were configured, not designed, based on an order. In this case, all six decision areas were assessed. A Production Manager and a Production Engineer participated in the assessment process, and the assessment discussion was carried out in two meetings so that the participants were interviewed separately. The aim of this was to enable comparison between the opinions and responses of the two participants. Table 13 presents the results of the two assessments carried out in the company on the scale from 1 to 4. Score A and Score B indicate the scores given by the Production Manager and the Production Engineer respectively. One of the key characteristics was not considered to be applicable and hence was not assessed. In Table 13 this is indicated by “-“ in the score column.
Table 13. Production system assessment results for Case B

<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristic</th>
<th>ScoreA</th>
<th>ScoreB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product architecture</strong></td>
<td>Product architecture is modular</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Production system structure</strong></td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Production processes and management</strong></td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><strong>Production equipment</strong></td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Information and communication</strong></td>
<td>Information and communication support and enable decision-making</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Human resources</strong></td>
<td>Teamwork and team organisation are used in production</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and improved</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 38 gives an overview of the results of the assessment process. It presents the two scores, A and B, given for each key characteristic of a well-performing production system. Score A and Score B represent the scores given by Production Manager and the Production Engineer.
respectively. The key characteristic that was not assessed is given a zero score. The category
tables indicate the decision area (product architecture PA, production system structure PSS, production processes and management PP, production equipment PE, information and communication IC and human resources HR) as well as the number of key characteristics in each area.

Figure 38. Overview of Case B assessment results

The strengths, i.e. the key characteristics assessed to levels 3 or 4, as well as the improvement potential, i.e. the key characteristics at levels 1 and 2, can be identified from the table and figure above. Again, it should be noted that level four is not assessed for all key characteristics in the assessment process.

In general, the results of the two assessments are quite similar and the respondents seem to agree with regard to the strengths and improvement potential of the production system. Improvement potential was identified in the decision areas of information and communication and human resources, whereas product architecture, production system structure, and production processes and management were identified as the production system’s strengths.

Strengths of the production system

On the basis of the assessment, the greatest strengths and advantages of the production system were the logical design and implementation of the production system and the compatibility between the decisions made in the different areas of production system design and improvement. With regard to production system and process themes (Section 5.1.7.), the strengths can be summarised as an efficient and reliable production process, late-point differentiation and predefined product variety, and a clear material flow and production process.

Firstly, regarding the efficiency and reliability of the production process, assessment of the product architecture decision area showed that the product variety offered to customers was clearly defined and limited, i.e. products could be configured and produced from predefined parts and subassemblies. Furthermore, a modular architecture and use of product platforms simplified the configuration process and enabled limiting the effects of changes and new features of products to certain parts of the product. These characteristics reduce variation between products and within production processes and hence provide a good basis for designing and
implementing efficient and reliable production processes. In terms of production objectives, reliability and efficiency of processes can be connected with consistent quality, lead time and its reliability, and cost-efficiency.

In the production processes and management decision area, the order penetration point (OPP) was found to be appropriately positioned and well controlled. Related to this, the use of product platforms and modular product architecture were seen to enable late-point differentiation and appropriate positioning of the OPP. With regard to production processes, efficiency and standardisation of production processes upstream of the OPP was emphasised, while production processes downstream of the OPP were more flexible and enabled creating order-specific functions and features in products. These characteristics should result in efficient and controlled production of the defined product variety, which contributes towards good performance in terms of lead time, its reliability, costs, and production flexibility.

The advantages of product architecture, especially modularity, had also been utilised in designing and implementing the production system structure that was seen to enable a clear and simple material flow. Based on the assessment, the production system consisted of production units responsible for certain subassemblies or entities of products and these units were located according to the structure and production process of the products. Furthermore, employees were organised into teams that operated the production units. Hence, the unit structure of the production system was also implemented in the human resources decision area.

Based on the above discussion, the decisions and characteristics related to product architecture, production system structure and production processes and management were clearly connected and consistent. The decisions made in these three areas were seen to enable reliable and efficient production of the product variety offered to customers.

Further strengths that were identified in the assessment included production equipment that meet the requirements of products and production and also enable production in small batches. These characteristics can be connected to quality, cost-efficiency and lead time. Team organisation, multi-skilled employees, and personnel policies and working time arrangements were also identified as strengths that contribute towards flexibility in terms of product variety and production volume.

**Potential and means for improving the production system**

Improvement potential was related to three production system and process themes, as well as certain individual key characteristics from the information and communication and human resources decision areas.

The first theme of improvement was ensuring reliable and predictable production processes by eliminating or minimising disruptions and problems and their causes in production. This potential for improvement was connected to three key characteristics that consider dissimilar processes of production, plans and procedures for responding to disruptions and problems, and procedures of information and communication. Figure 38 and Table 13 show that the respondents scored two of these key characteristics differently (characteristics PP1 and PP4), but when the results of the assessment were discussed, they both agreed on the need to improve these characteristics of the production system. Ideas and means for improvement were then identified based on the key characteristics, their descriptions and breakdown points, and the assessment discussion. Regarding production processes, creating separate production processes for spare parts and assembled parts or defining clear and strict procedures and guidelines for these two categories if they are processed in the same process and with same resources were suggested. The aim is to simplify production control and to ensure reliable production and deliveries for
both assembled and spare parts. Regarding the other two key characteristics, the assessment discussions revealed that a systematic way of informing about disruptions and problems in production, as well as a defined and systematic procedure for identifying and removing their causes were lacking. Improving these issues and developing more systematic procedures would involve specifying responsibilities and procedures for solving problems and identifying and eliminating their root causes, and creating standard communication paths for informing about production problems. Such procedures would help to reduce or eliminate disruptions and problems in production as well as their causes. In terms of production objectives, the improved reliability of production processes should contribute towards reliable lead time and consistent, high quality.

The second theme for improvement focused on improving ergonomics. In terms of key characteristics of a well-performing production system, this was related to layout and organisation of workplaces and to production equipment (PSS 5 and PE 6 in Figure 38). The aim of improvement would be better and more ergonomic working positions, and reducing or eliminating the need for employees to exert undue force or stretch when carrying out their work tasks. The key characteristics suggest that this could be achieved by improving the design and layout of workplaces and by equipping workplaces with better tools. The improvements are expected to improve and ensure the ability to work and also to enable more efficient work and production processes, which should result in shorter lead time and lower production costs.

The third improvement theme addressed the need for more detailed definition of the processes and procedures employed when implementing changes in production and the production system, for example when introducing new products. In discussing and assessing the first and second key characteristics of the information and communication decision area, it was identified that procedures for informing production about changes in the product mix and product variety were insufficient, and therefore relevant and reliable information was not necessarily available to production control and to the production units when needed. Thus, the need was identified to improve the processes and procedures between sales and marketing, product design, and production, in order to ensure the availability of relevant and reliable information also in the event of changes in the production volume of the product mix. The improvements should contribute towards and ensure high and consistent product quality and lead time reliability also when changes are made in production.

Furthermore, with regard to information and communication, the assessment showed that compatibility and integration of the information systems used in sales and in production could and should be improved. Orders arrived via email or fax and had to be manually entered into the information systems used in production. Based on the product architecture assessment, it was recognised that the clearly defined and limited product variety offered to customers provided a good basis for improving this aspect. It was suggested that a specified order form should be developed as this would allow automatic configuration of the order-specific product. Then, if the systems used in sales and production were integrated and compatible, order information could be transferred automatically to production, for example for purposes of production scheduling and control. Furthermore, it was noticed that two separate information systems were used for scheduling and controlling production, and that transferring information between these systems required manual input. It was suggested, firstly, to consider whether two systems are needed, or whether one system could be used for both tasks. If both systems are needed, the interfaces should be improved to enable automatic transfer of information. The suggested improvements to information and communication systems would reduce the amount of manual work involved in entering orders and in the scheduling and control of production. The potential for reduction was quite substantial due to the relatively high annual production volume of the case company. In terms of production objectives, the reduction or elimination of manual work can be connected with cost-efficiency and with delivery and lead time performance. Furthermore, the availability
and reliability of information should also be improved as potential errors related to manual transfer of information are reduced. This should have a positive effect on quality and lead time reliability.

Finally, improvement potential was also identified in the human resources decision area, as promoting commitment to work and involvement in the improvement process were given low score. It was concluded that pay and incentive systems could better promote employee commitment and an incentivised suggestion scheme could encourage employees to improve their work performance as well as contribute to improvement of production processes and the production system. These improvements could support the achievement of higher levels of production performance. Furthermore, it was established that, although accidents and related absences from work were not a major issue for the company, occupational safety and ability to work could be better promoted, for example through training and information.

6.3.4. Case C

The case company focused on final assembly of products and operated on an assemble-to-order basis. The products offered and produced for customers were configured but not designed based on an order. The company had no in-house part production. Suppliers produced the required parts and also assembled and delivered some subassemblies to the final assembly. Thus, the production equipment decision area was not considered in this pilot case. The assessment process was carried out with the CEO of the company. A production system layout picture and descriptions of the order-to-delivery and production processes and the structure of the products provided additional information for the assessment. The results of the assessment are presented in Table 14. The key characteristics that were not considered applicable and therefore were not assessed are marked with “-“.
<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristic</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product architecture</td>
<td>Product architecture is modular</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>2</td>
</tr>
<tr>
<td>Production system structure</td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>2</td>
</tr>
<tr>
<td>Production processes and management</td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>4</td>
</tr>
<tr>
<td>Production equipment</td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>2</td>
</tr>
<tr>
<td>Information and communication</td>
<td>Information and communication support and enable decision-making</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>2</td>
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<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>2</td>
</tr>
<tr>
<td>Human resources</td>
<td>Teamwork and team organisation are used in production</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and improved</td>
<td>2</td>
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</tbody>
</table>
The following chart provides an overview of the results of the assessment (Figure 39). The score (from 1 to 4) given for each assessed key characteristic of a well-performing production system is presented. Key characteristics that were not assessed are scored zero. The category labels indicate the decision area (product architecture PA, production system structure PSS, production processes and management PP, production equipment PE, information and communication IC and human resources HR) and the number of key characteristics in each area.

![Graph showing assessment results]

**Figure 39. Overview of Case C assessment results**

Table 14 and Figure 39 show that strengths and improvement potential were identified in each of the decision areas considered. Also in this case, level four was not assessed for all key characteristics.

**Strengths of the production system**

Although the identified strengths were related to characteristics in a number of different decision areas, they can be summarised under four improvement themes. Regarding product architecture, an important strength and advantage from the point of view of production was found to be the use of predefined parts and subassemblies in the products, meaning that the product variety offered to customers was limited and predefined. However, some orders and products required order-specific features and product design, but, as suggested in the first key characteristic of production processes and management, these were produced in separate process than the products configured from the predefined parts and subassemblies. These characteristics and procedures reduce variation in the “main production process” in which the configured products are produced, and support defining and standardising production processes and improving their efficiency. With regard to production objectives, this is expected to have a positive effect on costs as well as length and reliability of lead time. In addition to the assessment discussion, the process descriptions for order-delivery and production processes provided useful information for assessing these key characteristics and for identifying this strength of the production system.

As another strength of the production system, the assessment indicated that a clear and delay-free material flow and production process, which is one of the production system and process themes discussed in Section 5.1.7., was well implemented and realised. This was related to the production system structure characteristics. Although some improvement potential related to the
production system layout could be identified, the researcher’s opinion was that the unit structure, product-based layout and short distances were relatively well realised in the production system. These result in a clear and simple production system structure and material flow, and reduce delays in the production process caused, for example, by transportation and moving products between production units. As a result, production control is simplified and short lead time is supported. These strengths were identified and verified by considering the layout picture of the production system and the description of the production processes.

Furthermore, the characteristics of the production processes and management and information and communication decision areas indicated that procedures between production units were defined and that communication and cooperation between the units were effective. These are seen to ensure or support reliable and efficient production processes. In terms of production objectives, efficiency can be connected with costs and lead time, while reliability of processes contributes towards quality and lead time reliability.

Finally, related to the human resources decision area, employees were cross-trained and multi-skilled, and rotation of employees in different jobs and tasks aimed to ensure their ability to work in different production units. With regard to production objectives, this supports both product and volume flexibility. Additionally, personnel policies and working time arrangements were seen to enable balancing of capacity with demand. This flexibility of human resources and capacity enables responsiveness to changes in the product mix and production volume and also supports lead time reliability.

**Potential and means for improving the production system**

As with the production system strengths presented above, the potential for production system improvement was also indicated by several key characteristics, and these can be grouped under certain themes and the decision areas. The first improvement theme was creating a more visual and observable production system and production processes. The aim is to enable monitoring of the status of the production process and rapid identification of deviations from defined procedures and progress, which simplify production control and support consistent, high quality and lead time reliability. The means for improvement were related to production system layout and means and methods of visual information and communication. It was suggested that the locations for materials, parts and tools should be defined more clearly and specifically. With regard to information and communication, the defined locations should then be clearly indicated, for example, with colour codes. Furthermore, various means of visual information and control, such as pull inventories, kanban cards and boards or displays showing the production schedule, could be used to support monitoring of the production status, for example the order of production and ability to meet the production schedule.

Potential for improvement was also indentified with regard to supporting and enhancing the efficiency of value-adding work. This improvement potential and the means for realising it were related to workplace layout and the availability of auxiliary tools and equipment. The identified improvement measures included improving the organisation and layout of workplaces by removing unnecessary materials and tools and by locating the remaining items so that they are easy to use and enable ergonomic working positions. In addition, ergonomics could be improved and processes and tasks made more efficient by investing in auxiliary devices such as assembly and working tables and stands. In terms of production objectives, these improvements and work efficiency could contribute towards reducing lead time and production costs.

Additionally, the assessment process revealed relevant improvement opportunities in the production processes and management decision area. It was identified that variation existed in the procedures and outputs of the production units, and creating more detailed definitions for
processes and procedures of the units was suggested as a means of improving the situation. As the related key characteristic and its breakdown points and definitions indicate, this entails more detailed definition of the inputs, outputs, activities, correct work procedures, and duration of processes. Furthermore, a need was identified to develop better defined and more systematic procedures for responding to disruptions and problems in production and for identifying and removing their causes. With regard to production objectives, these improvements should have a positive effect on the quality of products and operations as well as on lead time reliability.

With regard to human resources, the conclusion of the assessment was that commitment to work, involvement in improving production processes and the production system, as well as occupational safety and ability to work should be better promoted. Improving and supporting employee commitment and motivation to work towards the objectives of production and the company would include developing pay, incentive and award systems that are linked with employee performance and with the objectives set for employees and production. Furthermore, an incentivised suggestion system could enable and encourage employees to participate in improving their own work as well as the production processes and production system. Thus, the suggested improvements are intended to support the achievement of the objectives of production and the company and to encourage improvement of the production system and production processes. Also related to the area of human resources, it was recognised that although the rate of accidents and related absences from work were low, occupational safety and ability to work could be better promoted. As the breakdown points and description of the related key characteristic suggest, the means for this include education and provision of more information related to occupational safety and correct working procedures and methods.

Potential for improvement in the information and communication decision area was provided by compatibility and integration of information systems. For example, customer orders could not be automatically transferred from sales systems to the information systems used by production and production control. This could be improved and manual input and the related risk of human error eliminated by improving the information system interfaces. Automatic transfer and flow of information would improve the reliability and availability of information and, in terms of production objectives, this could have a positive effect on quality and lead time reliability. The improvement should also have an effect on work efficiency as non-value-adding manual work in information transfer would be reduced or eliminated. This aspect is connected with cost-efficiency.

It was also noted that information and communication systems and procedures could simplify and provide better support for configuring order-specific products. If marketing and sales personnel were provided with a specified order form with which orders could be made, the well-designed product architecture and clearly defined and limited product variety could be utilised to automatically configure each order-specific product. Then, if the interfaces between information and communication systems were improved, the required information for processing the order and producing the product could be automatically transferred to the relevant parties of the production system and company. Thus, the specified order form, automatic configuration process and compatible information systems could simplify the order-delivery process and reduce delivery time.

Potential for improvement was also identified in the product architecture decision area. Regarding the key characteristic and breakdown points related to modular product architecture, it was pointed out that due to hydraulics and electricity, the modules were partly integrated, i.e. features of a module had an effect on other modules. Furthermore, the company was not able to test the modules separately before final assembly, which would simplify final testing and also ensure that subassemblies delivered to final assembly meet the requirements and function as they are intended. Hence, the modularity of products could be improved. For example, enabling
separate testing of modules could shorten lead time and have a positive effect on quality as possible errors could be identified earlier. Then, in terms of product platform and positioning of the order penetration point, the assessment indicated that the position of the order penetration point varied between products and orders and that some parts and subassemblies produced by suppliers were order-specific. These issues have an effect on lead and delivery time and present challenges with respect to production control as well as the reliability of lead and delivery times.

Finally, with respect to the production system structure, the two key characteristics related to production unit location were ranked at level two, and the respondent’s opinion was that material flow could be further simplified and delays in the production process reduced by improving the production system layout. The researcher’s opinion, however, was that these key characteristics were already well implemented in the system, although some further improvement in this area was achievable by implementing the already planned layout changes.

6.3.5. Case D

In Case D, the company focused on final assembly of the product and did not produce parts for its products. The company operated on the basis of the engineer-to-order approach as each product required order-specific design prior to purchasing and assembly. Due to the company’s focus on assembly, the production equipment decision area was not considered in the assessment. The assessment discussion was conducted with the Production Director of the company. Additionally, a layout picture, description of the production process, and pictures and diagrams of the products and their structure were used as supplementary sources of information in the assessment process. Table 15 presents the results of the assessment. The key characteristics that were not considered to be applicable and therefore were not assessed are marked with “-“.
Table 15. Production system assessment results for Case D

<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristic</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product architecture</strong></td>
<td>Product architecture is modular</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>3</td>
</tr>
<tr>
<td><strong>Production system structure</strong></td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>1</td>
</tr>
<tr>
<td><strong>Production processes and management</strong></td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>3</td>
</tr>
<tr>
<td><strong>Production equipment</strong></td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>-</td>
</tr>
<tr>
<td><strong>Information and communication</strong></td>
<td>Information and communication support and enable decision-making</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>2</td>
</tr>
<tr>
<td><strong>Human resources</strong></td>
<td>Teamwork and team organisation are used in production</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and improved</td>
<td>2</td>
</tr>
</tbody>
</table>

The following figure (Figure 40) presents an overview of the results of the assessment. The chart presents the scores given for each key characteristic considered in the assessment. Those not considered are scored zero. The category labels indicate the decision area (product architecture
PA, production system structure PSS, production processes and management PP, production equipment PE, information and communication IC and human resources HR) and the number of key characteristics in each area.

**Figure 40. Overview of Case D assessment results**

The above table and figure enable identification of the strengths of the production system, i.e. the key characteristics ranked at levels 3 or 4, as well as the improvement potential, i.e. the key characteristics ranked at levels 1 and 2. Level four was not assessed for all key characteristics. As an overview, strengths and improvement potential can be identified in each of the decision areas included in the assessment.

**Strengths of the production system**

With regard to product architecture, the conclusion was that modular architecture was well implemented and well designed, and that the modules and their interfaces limited the effects of customer orders and possible changes to orders to certain parts of a product. Also, the characteristics concerning the use of predefined parts and the number of levels in the product structure were seen to be implemented sufficiently.

In the production system structure decision area, the layouts of the production system, production units and workplaces were seen to support and enable monitoring of the phases of the production system as well as the status and order of production. This supports and simplifies production control and also assists in consistently achieving the required quality and a reliable lead time by enabling the identification of and reaction to deviations from the desired schedule and production status.

With regard to the production processes and management decision area, the conclusion of the assessment discussion was that processes within and between production units and cooperation between units enabled product and volume flexibility. Additionally, the ability and responsibility of production units to decide the order and schedule of production was seen to support flexibility of production processes. Due to the engineer-to-order approach and low similarity between products, flexibility of production processes was regarded important. The processes and
procedures of the production units, cooperation between units and the flexibility of production were also seen to enable and ensure meeting the promised delivery times.

In the information and communication decision area, the identified strengths included usefulness of information, i.e. information enabled decision-making related to production, and integration and compatibility as well as reliability and availability of information systems. These characteristics contribute towards availability and reliability of information and enable rapid information flow. Hence, they support the production processes and, in terms of objectives of production, achieving short and reliable lead time and consistent quality level.

Finally, in the human resources decision area, team organisation and employee skills were seen to enable production according to specifications. This can be connected to supporting and ensuring good product quality. Furthermore, multi-skilled employees were seen to enable allocating employees to different tasks and teams according to orders and required product features, thus supporting product flexibility.

**Potential and means for improving the production system**

With regard to the structure and layout of the production system, the most important improvement potential was related to creating a clear and delay-free material flow and production process. This is also one of the production system and process themes (Section 5.1.7.). In identifying this potential and means for improvement, the layout picture and the description of the production process were useful as they enabled consideration of the structure of the production system and identification of the material flow through the system. The key characteristics related to this theme indicate that implementing the improvements would involve first clarifying the unit structure of the production process, for example by creating production or assembly units for the subassemblies of the product. Then, these production and assembly units should be located according to the structure and production process of the products. Finally, sequential production units should be in close proximity to each other. These changes would simplify and support production control and shorten production lead time by reducing delays.

Also related to the production system structure, the assessment showed that the arrangement and layout of workplaces could be improved to better support value-adding work. Means for improvement include applying 5S principles, such as removing unnecessary items, and locating the required items according to their use and such that ergonomic working positions are enabled. It was also pointed out that non-value-adding work could be reduced by eliminating the need for assembly staff to collect required parts and materials from stock. In terms of production objectives, reducing non-value-adding work and making value-adding work more efficient by rearranging inventory operations and by improving the layout of workplaces should improve the efficiency of production and reduce lead time and costs.

Another important area of improvement identified was human resources. Here the key issue was a lack of capacity flexibility, i.e. ability to adjust capacity according to demand and customer requirements. The issues raised during the assessment discussion and the related key characteristics and their descriptions indicated that the means for improving this aspect are connected to availability of and ability to use temporary staff. In addition to this, working time arrangements, such as the ability to use extra shifts and overtime work, should be considered and modified. Difficulties in using overtime and extra shifts were also identified when discussing the plans and procedures for handling disruptions and delays in production (production processes and management decision area). The importance of improving capacity flexibility is emphasised in the engineer-to-order approach, in which customer requirements and orders have a great influence on the features and functions of a product as well as on the production processes and
required production capacity. Thus, the suggested improvements could have a positive effect on reliability of lead and delivery time as well as on product and volume flexibility.

Further potential for improvement in the human resources decision area was identified in improving pay, incentive and award schemes. These could better promote and support commitment to work, as well as participation in improving work performance, production processes and the entire production system. Better commitment and involvement in improvement could bring advantages related to all objectives of production. Finally, a need to improve and emphasise occupational safety and ability to work was identified. As the related key characteristic and its breakdown points indicate, means for doing this include training and providing more information related to these topics.

In the information and communication decision area, improvement potential related to two key characteristics was identified. In assessing the second key characteristic of the decision area, it was noted that procedures for communicating changes to a customer order efficiently to all relevant parties should be improved. This aspect is related to reliability of information and, in terms of production objectives, it can be connected to quality, i.e. the ability of products to meet the requirements of customers. The other potential improvement was related to monitoring the status of and prerequisites for production. Improving and supporting this would require indicating production units and defined locations for materials more clearly, for example with colour codes and signs. The improvement would also include the use of production boards or displays that indicate the production schedule and order. These changes could support and simplify production control and could also improve lead time reliability by enabling rapid identification of deviations from the production schedule.

**Observations and discussion related to the pilot case and its results**

The pilot case indicated that the engineer-to-order approach has an effect on the usefulness and applicability of the TUTKA tool. In the pilot company, the functions and features of a product varied significantly between orders and flexibility was needed in production. Therefore, some of the key characteristics included in the TUTKA tool that focus on and emphasise defined and efficient processes and procedures were not considered applicable, beneficial or important. Also in general, in ETO approach production flexibility is more important than in make- or assemble-to-order approaches, in which products of a more similar nature are produced. Furthermore, during the discussion it was established that the main problems and challenges of the company’s operations were related to discussing and clarifying customer requirements in time and avoiding late changes to these requirements in order to allow enough time for production to complete the order and meet the promised delivery time. Thus, the most important area of improvement seemed to be the sales-customer interface, which is not included in the scope of this study or the TUTKA tool.

**6.3.6. Case E**

The company and the assessed production system focused on assembly of the end product and certain sub-assemblies, while suppliers were responsible for part production and also for assembling certain sub-assemblies of the product. However, the production approach of the company was classified as engineer-to-order as most of the orders required order-specific product design. Due to the focus on assembly, the decision area and the key characteristics focusing on production equipment were not assessed. The assessment was carried out with the Plant Manager and Production Development Engineer. The results of the assessment are presented in Table 16. The key characteristics that were not assessed are marked with “-“.
<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristic</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product architecture</strong></td>
<td>Product architecture is modular</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>1</td>
</tr>
<tr>
<td><strong>Production system structure</strong></td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>2</td>
</tr>
<tr>
<td><strong>Production processes and management</strong></td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>3</td>
</tr>
<tr>
<td><strong>Production equipment</strong></td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>-</td>
</tr>
<tr>
<td><strong>Information and communication</strong></td>
<td>Information and communication support and enable decision-making</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>2</td>
</tr>
<tr>
<td><strong>Human resources</strong></td>
<td>Teamwork and team organisation are used in production</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and improved</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 41 provides an overview of the results of the assessment process. The chart presents the score on the four-level scale given for each of the assessed key characteristics. The key characteristics that were not assessed are scored zero. The category labels indicate the decision
area (product architecture PA, production system structure PSS, production processes and management PP, production equipment PE, information and communication IC and human resources HR) and the number of key characteristics in each area.

![Figure 41. Overview of Case E assessment results](image)

Level four was not assessed for all key characteristics, therefore the key characteristics ranked at level three or four were seen as strengths of the production system, while key characteristics ranked at levels two and one indicated improvement potential.

**Strengths of the production system**

Based on the assessment, two decision areas, human resources and production processes and management, were seen as the strengths of the assessed production system. In addition to these, strengths were identified from key characteristics belonging to the production system structure and information and communication decision areas.

With regard to the characteristics and organisation of human resources, employees were seen to be skilled, committed to work and involved in improvement. These aspects can be expected to ensure consistent quality of products and processes and to support improvement of the production system and processes. Furthermore, multi-skilled employees, personnel policy and working time arrangements were found to support product and volume flexibility and to ensure lead time reliability.

In the production processes and management decision area, processes were defined and plans and procedures for responding to disruptions and delays were in place. In terms of production objectives, these characteristics are expected to improve and ensure lead time reliability. Additionally, responsibility for production control was allocated to production units, which should simplify production control.

Furthermore, although some improvement potential related to product-based layout and distances between production units was identified, the structure of the production system was found to be relatively well designed. The layout was seen to enable a relatively simple and straightforward
material flow, which contributes towards simple production control and a short production lead time by reducing delays in the production process.

**Potential and means for improving the production system**

The main potential for improvement was found in the decision areas of product architecture, production system structure, and information and communication. The suggested improvements were also related to the production approach of the case company.

With regard to product architecture, the greatest potential for improvement was related to three key characteristics: modular product architecture, use of product platforms, and use of predefined parts and subassemblies. In terms of the production system and process themes (Section 5.1.7.), the improvement potential was related to late-point differentiation, predefined product variety, and efficient production processes. Specifying and limiting the product variety offered to customers and the use of predefined parts in products would allow the company to configure, instead of design, the order-specific products from predefined parts and subassemblies. Then, realising or improving the modular product architecture would involve defining and developing more standard interfaces for the modules. Alternatively, it was suggested that product platforms, i.e. product entities that are not dependent on the customer order, should be identified or developed. As discussed in Section 5.1.1., modular product architecture and use of product platforms simplify and support configuring and producing an order-specific product. The use of product platforms also provides better control of the order penetration point and supports combining efficient and more flexible processes in the production process, which were identified as improvement potential in the production processes and management decision area. The suggested improvements should shorten the delivery time to customer by removing the need for order-specific product design and by simplifying defining and configuring the order-specific product. The improvement ideas also support developing efficient and reliable production processes, which contributes towards shorter and more reliable production lead time and lower production costs.

The improvement means suggested above were related also to the production approach. The case company operated on an engineer-to-order basis, and the suggested improvement means involved limiting the product variety and moving towards a make-to-order or assemble-to-order approach. From the production point of view this strategic decision would be beneficial because it supports designing, implementing and operating efficient and reliable production processes.

Also related to product architecture and structure, it was noted that the levels in the product structure did not support identification of subassemblies of the product as well as they could, and therefore presented potential for improvement. The aim of improvement would be to modify the presentation of the product structure so that subassemblies can be identified and utilised in production control and purchasing. Hence, the aim is to simplify and support these tasks, for example by making it possible to carry them out at subassembly level rather than at part level.

With regard to production system structure and information and control, it was noticed that monitoring of the production system and of the state of and prerequisites for production could be better supported. Improving this aspect, that is also one of the production system and process themes, would involve clearly marking and indicating the production units, the phases of the production process and the positions for materials in each production unit. Furthermore, production control could be supported and production schedule and order of production monitoring could be enabled by using production boards or displays that present the production schedule and status of each order. In terms of production objectives, a more visual production system, production process and production control could improve quality and lead time reliability by making it possible to quickly identify and react to problems and deviations from the defined status, the defined procedures, and the production schedule.
Finally, it was noticed that information and communication systems were not fully integrated and compatible, and manual input was required in transferring information between sales, product design and production. Thus, there was a need to improve the interfaces between the systems to enable automatic information transfer. With this, the error potential of manual information transfer would be avoided and the availability of information could be improved. In terms of production objectives, these improvements can be connected with quality and lead time of production.

6.3.7. Case F

This pilot company and the assessed production system focused on final assembly of the product and the company did not conduct part production. Therefore, from the production equipment decision area only the last key characteristic was considered relevant and was assessed. The company’s production approach was labelled as engineer-to-order, as nearly all of the orders required product design prior to purchasing and assembly. Two persons from the company participated in the assessment process, the Plant Manager and a Production Development Engineer. In addition to the assessment discussion, layout pictures of the facilities were used in the assessment. The results of the assessment are presented in Table 17. The key characteristics not assessed are marked with “-“.
Table 17. Production system assessment results for Case F

<table>
<thead>
<tr>
<th>Decision area</th>
<th>Key characteristic</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product architecture</td>
<td>Product architecture is modular</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Product platforms are used</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Product structure consists of predefined parts and subassemblies</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Levels in product structure simplify the structure of the production system and support production control</td>
<td>2</td>
</tr>
<tr>
<td>Production system structure</td>
<td>Production system consists of production units that are responsible for certain parts of a product</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Production system structure corresponds to the structure and production process of products</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Distances between production units and distances between production equipment are short</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Production system structure makes it possible to observe the state of and the prerequisites for production</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work</td>
<td>4</td>
</tr>
<tr>
<td>Production processes and management</td>
<td>Dissimilar main processes of production are identified and separated from each other</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes of production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Processes and procedures between production units are defined</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Plans and procedures for responding to production disruptions, problems and delays are in place</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Responsibility for production control is allocated to production units</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Close cooperation between production units is supported and enabled</td>
<td>4</td>
</tr>
<tr>
<td>Production equipment</td>
<td>Production equipment fits the requirements of the products and processes and the objectives of production</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Changeover and set-up times of equipment are short</td>
<td>-</td>
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<tr>
<td></td>
<td>Production equipment enables integration and reduction of production phases</td>
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<tr>
<td></td>
<td>Production equipment is reliable and available for use</td>
<td>-</td>
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<tr>
<td></td>
<td>Production equipment is easy to use</td>
<td>-</td>
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<tr>
<td></td>
<td>Production equipment supports occupational safety and ability to work</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices</td>
<td>3</td>
</tr>
<tr>
<td>Information and communication</td>
<td>Information and communication support and enable decision-making</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Information transfer and communication follow systematic and predefined principles and procedures</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems used in the production system are compatible and integrated</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Information and communication systems are reliable and available for use</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Visual information and control systems are used in the production system</td>
<td>4</td>
</tr>
<tr>
<td>Human resources</td>
<td>Teamwork and team organisation are used in production</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Employees are cross-trained and skills of employees meet the requirements of work tasks and processes</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Personnel policy and arrangement of working time support operational flexibility and reliable deliveries</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Commitment to work and involvement in improving production system and production processes are promoted</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Occupational safety and ability to work are emphasised and improved</td>
<td>3</td>
</tr>
</tbody>
</table>

The following figure (Figure 42) presents an overview of the assessment results. It shows the score from one to four given for each key characteristic that was assessed. Those not assessed are scored zero. The category labels indicate the decision area (product architecture PA, production
system structure PSS, production processes and management PP, production equipment PE, information and communication IC and human resources HR) and the number of key characteristics in each area.

![Figure 42. Overview of Case F assessment results](image)

Table 17 and Figure 42 enable identification of the strengths of the production system (the key characteristics ranked at levels 3 or 4) as well as the improvement potential (i.e. the key characteristics ranked at levels 1 and 2). Level four was not assessed for all key characteristics.

As the above figure and table show, the participants of the pilot case considered the production system to be well-suited to the requirements of production processes and products. In the assessment discussion, the production system structure was seen to enable a clear and controllable production process and material flow, and the characteristics of production processes and management were argued to enable reliable production. Furthermore, information and communication as well as human resources were seen to correspond to product and production process requirements and to support and enable reliable operations. In terms of production objectives, efficient production is connected with lead time and costs, while reliable processes contribute towards consistent quality and reliable lead time. On the other hand, improvement potential was identified from only a few key characteristics belonging to the decision areas of product architecture, production system structure, production processes and management, and information and communication.

**Potential and means for improving the production system**

The greatest improvement potential was related to the characteristics of product architecture and production processes and management, and was connected with two production system and process themes: limiting the product variety offered to customers, and efficient and reliable production processes. With regard to product architecture, limiting the variety of the products offered to customers by using only predefined parts and subassemblies in the products, and improving the modular structure of the product would be useful and beneficial for the production processes and management. As mentioned, the company operated based on an engineer-to-order approach and all orders included functions and features that required order-specific product design, which increases the delivery time. Furthermore, order-specific features and functions of products reduce similarity between products, which makes it difficult to define and standardise
the production processes and to identify and utilise the standard part of the product and production process. These aspects were noticed in assessing the fifth key characteristic in the production processes and management decision area that focuses on combining cost-efficient and flexible processes in production system. The suggested improvement, i.e. limiting the product variety offered to customers, would enable configuring rather than designing the order-specific product. This would shorten the delivery time by eliminating the need for order-specific product design. Furthermore, variation between orders and within the production processes would be reduced, which would support defining and standardising production processes and improving their efficiency. This could contribute towards a shorter and more reliable lead time and towards cost-efficiency of production. The suggested improvements are related to strategic decisions and choices and would involve moving from the engineer-to-order approach towards make-to-order or assemble-to-order, and making changes not only in production but also in sales and product design.

Also related to product architecture, it was noticed that the modular product architecture and especially the interfaces between modules could be improved. The interfaces were not standardised well enough and therefore the different modules of the product were interdependent, i.e. features of or changes to one module also affected other product modules. Thus, if the interfaces were better standardised, the order-specific functions and features would be easier to produce and the effect of changes to an order could be limited to a certain part of the product and the production process.

Improvement potential was also identified in the production system structure decision area. The assessment discussion and the layout picture showed that distances between production units were relatively long, i.e. the units could be located closer to each other. This would reduce delays caused by transportation of parts and subassemblies in the production process. Shorter distances between the production units would also reduce the need for using buffer stocks between units, and would support identification of and reaction to problems and disruptions in adjacent production units. Thus, the improvement could reduce the lead time of the production process, simplify production control, and have a positive effect on quality and lead time reliability.

Further improvements were suggested in the decision area of information and communication. The compatibility and integration of information and communication systems were considered insufficient, and manual input was required in transferring data and information between sales, product design and production. Thus, improving the interfaces between the systems to enable automatic information transfer was suggested. This would improve the availability and reliability of information and could also have a positive effect on production process efficiency as well as on quality and lead time reliability.

Finally, as the researcher was aware that the pilot company was planning to change the final assembly from the cellular layout to a line layout, the required changes and improvements were considered with the help of the TUTKA tool. The main conclusion of the exercise was that the level of detail and accuracy of design and implementation of the production system and production processes should be increased. As prerequisites for creating an efficient assembly line, limiting the product variety offered to customers and improving the modularity of the product architecture by dividing the product into smaller and better defined building blocks were recommended. Furthermore, the production system should be divided into smaller production units in order to create assembly stations along the assembly line as well as subassembly units to serve the assembly line. Then, the production processes for these smaller production units as well as the processes and procedures between the production units need to be defined at a more detailed level than currently.
Observations and discussion related to the pilot case and its results

In this pilot case, the TUTKA tool and the assessment process did not reveal many areas or production system characteristics providing potential for improvement. This is argued to be partly due to the production approach of the company and the characteristics of the products produced. As mentioned, the company operated on an engineer-to-order basis, i.e. each order required product design, and the annual production volume was relatively low. As a result, the company’s operations were mainly project-based. The production system was organised into a cellular layout and there were production cells for subassembly and final assembly. As is typical for a cellular layout, the flexibility in terms of product variety was high and the capacity of each cell could be adjusted by the number of employees. Thus, the layout and organisation were well-suited to the project-based production that requires high product and volume flexibility. Based on the discussion with the pilot case participants, the company’s main challenges seemed to be in sales and product design and their cooperation, for example in clearly defining customer requirements and designing product features that meet these requirements, rather than in improving the production system and efficiency of production. Thus, as the areas or functions of sales and product design were not considered in this study, the TUTKA tool and the production system assessment process were not able to identify these improvement needs.

The pilot case also indicates that the TUTKA tool and the key characteristics of a well-performing production system included in it are better suited to make-to-order or assemble-to-order production where efficiency of production rather than flexibility is emphasised more than in project-based engineer-to-order production. These ideas regarding the effect of the type of operation on the results and usefulness of the assessment were also presented and discussed in the case company, and the participants were in agreement with them.

6.4. Summary

This chapter focused on the use of the developed TUTKA tool in assessing the current state of production systems. Firstly, the production system assessment process was described, and the pilot cases in which the tool was used were then presented.

The production system assessment process using the TUTKA tool is intended to be facilitated and carried out together with selected company personnel. The assessment process can be divided into three phases. In the first phase, the information used in the assessment is collected by means of an assessment discussion and additional sources of information. Then, the information is analysed and summarised and the results are prepared by the facilitator. Next, the results, i.e. the strengths and improvement potential of the production system, are presented to the company. The assessment process and, in particular, the amount of work required in collecting information, can be modified to meet the needs of the participating company. This is enabled by the structure of the questionnaire and the set of key characteristics, which make it possible to choose the appropriate level of detail as well as the aspects to be considered in the assessment. Furthermore, the use of additional information in the assessment and the means of collecting this information also have a bearing on the first phase of the assessment process.

The TUTKA tool and the production system assessment process described have been used in the six pilot cases reported in this chapter. The results of the pilot cases demonstrate that the strengths of a production system as well as its potential and means for improvement can be identified with the TUTKA tool. It was also shown that the breakdown points and descriptions of the key characteristics enable identifying and presenting means and ideas for improvement. The identified strengths and improvement potential can also be combined into themes, and the effects of the suggested improvements on the production objectives can be presented. The pilot cases also showed that the assessment process requires two meetings and approximately 8 hours of input from the participants. Hence, it can be concluded that the TUTKA tool and the assessment process enable a rapid assessment that provides an overview of the current status of a production system.
7. Evaluation of the study and its results

This chapter presents an evaluation of the study and its results in two parts. Firstly, the focus is on evaluation of the results, i.e. the developed TUTKA production system assessment tool and its parts, using criteria developed based on literature. The ability of the TUTKA tool to meet and fulfil the evaluation criteria is considered based on the results of the assessment cases and feedback received. Then, in the second part, the entire study is evaluated and considered. The aim is to demonstrate and justify that the study has been successful and carried out properly, and that its results are beneficial to practitioners and academics in the field of production and production systems.

7.1. Evaluation of the TUTKA production system assessment tool

This section presents the criteria, methods and information used for evaluating and justifying the TUTKA tool. Firstly, the criteria and methods suggested in literature for evaluating the results of a research project based on the design science and constructive research approaches, i.e. the approaches applied in this study, are presented. Based on this, the criteria, methods and information used in evaluating the results of the study are expounded and discussed.

7.1.1. Criteria and methods suggested in literature

In design science, the novelty and utility of the results, for example, the artefact developed, are emphasised in evaluating the results of a research project and in justifying the success and contribution of the project (e.g., March & Smith 1995; Hevner et al. 2004; Järvinen 2007). For example, Järvinen (2007, p. 1392-1394) emphasises the novelty of results and the ability to meet the requirements and targets set for the research project and its results. He also suggests comparing the developed artefact or tool and its usefulness or performance with available tools and solutions reported in literature. For this purpose, a goal function that combines all of the different expectations and requirements of the stakeholders of a research project can be used, and it is assumed that all of the values of the factors included in the function can be measured or estimated. (Järvinen 2007, p. 1392-1394) To evaluate and demonstrate the contribution and success of a research project, Järvinen (2007, p. 1394) also presents the following four classes of design research results:

1. The totally new artefact or innovation
2. The value of the goal function associated with the new artefact or innovation is better than the value of the best earlier innovation
3. The value of the goal function associated with the new artefact or innovation is equal to the value of the best earlier innovation
4. The project failed

A researcher should show that the contribution of a research project is either a new artefact or innovation, or that the artefact provides higher goal function value than the available artefacts (Järvinen 2007, p. 1394). Hence, a research project is considered successful if it can be classified within the first or second class presented above. Also in the field of design science, Hevner et al. (2004, p. 82) state that the aim of a research project is to create an innovative or novel artefact that is purposeful and yields utility for a specified problem domain. Examples of novel or innovative results of a design research project are artefacts that solve a heretofore unsolved problem, or that solve a known problem in a more effective or efficient manner than the available solutions and artefacts (Hevner et al. 2004, p. 82-83). Hevner et al. (2004, p. 85) also point out that the business environment and the problem domain establish the requirements upon
which the artefact is evaluated, and for example utility, quality, efficacy, functionality, consistency, accuracy, reliability and usability can be included in the criteria. To summarise, according to Järvinen (2007) and Hevner et al. (2004) the success of a design research project can be justified by demonstrating that a novel artefact or innovation has been developed, or that the new artefact is better than the available ones. On the other hand, March and Smith (1995, p. 258) focus on comparison with available tools rather than on the novelty of results. They emphasise that progress is made when the results of a research study perform better, for example, are more efficient than the available tools, artefacts or products (March & Smith 1995, p. 258).

With regard to the constructive approach, Kasanen et al. (1993) present both criteria and tests for evaluating the results of a research project. Similarly to the authors in the field of design science, Kasanen et al. (1993, p. 253) emphasise the practical usefulness of the results. More specifically, relevancy, simplicity, and ease of operation or use are seen as the key criteria for evaluating the results of constructive research (Kasanen et al. 1993, p. 253, 258). In addition to these, three market tests are presented (Kasanen et al. 1993, p. 253):

- Weak market test: has any manager responsible for the financial results of his or her business unit been willing to apply the construction in question in his or her actual decision-making?
- Semi-strong market test: has the construction become widely adopted by companies?
- Strong market test: have the business units applying the construction systematically produced better financial results than those that are not using it?

The market tests are based on the concepts of innovation diffusion and viewing the construction resulting from a research project as a product that competes in the market of solutions and ideas. With regard to selecting and using the tests, even the weak market test is relatively strict and difficult to pass, and the semi-strong or strong market tests often require a substantial amount of data and relatively long-term monitoring of the situation and development of the construction in the market. (Kasanen et al. 1993, p. 253)

In addition to requirements and criteria for evaluation, various methods for testing and evaluating the results of a research project are available. For example Hevner et al. (2004, p. 86) categorise these into observational, analytical, experimental, testing, and descriptive evaluation methods. More specifically, case and field studies enable observation of the use of an artefact in the business environment, while analytical methods include static, dynamic and architecture analysis as well as optimisation. Experimental methods consist of controlled experiments and simulations, and testing involves functional and structural tests. Descriptive methods cover constructing scenarios or using information from available artefacts and previous research in order to demonstrate the utility of the developed artefact. (Hevner et al. 2004, p. 86)

### 7.1.2. Criteria and test used

The criteria and test for evaluating the TUTKA tool were generated on the basis of suggestions and ideas discussed in the previous section. In doing this, the suggestion that the methods and metrics used in evaluation should be matched with the results of a research project, i.e. the developed artefact, presented by Hevner et al. (2004, p. 86-87) and March and Smith (1995, p. 258), was followed. The criteria and the test used in the evaluation are:

- Novelty
- Usefulness
- Ease of use
- Reliability
- Validity
- Weak market test
For the purposes of this study and evaluating its results, the above criteria are defined as follows. Novelty focuses on the difference and dissimilarity of the TUTKA tool from the available tools for assessing and improving production. It also includes the novelty to the potential users of the tool, for example, whether they have used similar tools or not. Hence, the aspect of novelty is also related to the ability of this study and its results to provide a new contribution to the field of production, production systems and their improvement. Usefulness of the TUTKA tool is related to the ability of the tool to assist in assessing the current status of a production system, which involves identifying the strengths and potential and means for improvement. Also the usefulness of the assessment results in improving production systems is considered. Reliability focuses on the repeatability of measurement, while validity considers the measure’s or instrument’s ability to measure what it is intended to measure (Andersen & Fagerhaug 2001, p. 14-15). Reliability and validity are defined in more detail in Sections 7.5. and 7.6.

The use of these criteria can be explained and justified based on literature. Firstly, novelty and usefulness are emphasised in literature on design science (March & Smith 1995; Hevner et al. 2004; Järvinen 2007) and in the constructive research approach (Kasanen et al. 1993). The novelty and usefulness of results are also addressed by the two classes of successful research projects presented by Järvinen (2007, see Section 7.1.1.). Usefulness and ease-of-use are also connected to the requirements and objectives set for the TUTKA tool at the beginning of this study (Section 1.1.). Finally, reliability and validity are emphasised and presented as basic requirements in the field of performance measurement (e.g., Andersen & Fagerhaug 2001, p. 14-15). Although the focus of this study is not on performance measurement, these criteria are considered relevant and important also in the context of assessing production systems.

In evaluating and justifying the results of this study, the aim is to show that the TUTKA tool fulfils the developed criteria. However, evaluation and comparison with a goal function suggested by Järvinen (2007) are not used, because the evaluation criteria are difficult to measure quantitatively and information on the available tools with regard to the criteria is not available and cannot be easily generated.

In addition to the criteria presented, one of the tests suggested by Kasanen et al. (1993), the weak market test, is also used in evaluating and justifying the results of this study. The test was chosen because it provides a relatively strict test and because the semi-strong and strong market tests are considered, for a number of reasons, to be difficult to implement and use. For instance, as Kasanen et al. (1993, p. 253) point out, the semi-strong and strong market tests require observing the use and effects of the developed construct for quite a long period, which was not appropriate due to the schedule of this study. Furthermore, using the strong market test would require, in addition to assessing a production system and identifying its improvement potential with the TUTKA tool, the suggested improvements to be implemented by the company. This presents certain problems. Firstly, this study is limited to the initial stages of the improvement process (see Section 1.2.) and therefore implementing the changes is not within the scope of the study. Furthermore, the suggested production system changes and improvements are likely to require relatively large investments and substantial input in terms of time and effort. Therefore, finding companies that are prepared to not only test the TUTKA tool but also to implement the suggested changes for the purposes of evaluating the tool could be difficult. Finally, even if the suggested changes and improvements could be made to an assessed production system, identifying measures or indicators for evaluating the effects of the assessment and the related improvements to the performance of the production system would be challenging. For example, the financial results of a company, suggested by Kasanen et al. (1993) as a criterion for evaluation and comparison, are dependent on various factors such as productivity and efficiency of production, demand, market prices, and expenditure on material, equipment and employees. Thus, clarifying the effects of using the TUTKA tool by comparing the financial results of
companies that have and have not used the tool, or by comparing the financial performance before and after the assessment would be difficult. Hence, of the tests suggested by Kasanen et al. (1993), the weak market test was seen to be the most appropriate and applicable for this study.

7.1.3. Methods and information

Evaluation of the results of this study is based on comparing the TUTKA tool with available tools and models for assessing and improving production, and on using the developed tool in pilot cases. In addition, feedback collected from potential users of the TUTKA tool provided information for the evaluation.

Comparison of the TUTKA tool with available tools and methods for assessing and improving production and production systems is based on the review presented in Chapter 3. It focuses on certain characteristics of the assessment and improvement tools and models, and the aim is to identify and point out similarities and differences between the TUTKA tool and the other available tools and models. In terms of the evaluation criteria (Section 7.1.2.), the comparison is mainly related to the novelty of the developed assessment tool. Comparing the developed tool or solution with available ones is suggested in literature on design science (e.g., Järvinen 2007; March & Smith 1995), and with regard to the evaluation methods presented by Hevner et al. (2004, p. 86), it corresponds to descriptive evaluation of the results of a research project.

The six pilot cases (Section 6.3.) in which the TUTKA tool has been used are also utilised in evaluating and justifying the results of this study. The pilot cases were intended to demonstrate in practice the applicability and usefulness of the tool in assessing production systems. The importance of this is indicated by Kasanen et al. (1993, p. 246), who include “demonstrate that the solution works” as one of the phases of the constructive research process. Also Järvinen (2007, p. 1394) states his preference for proof by demonstration rather than proof by design in evaluating and justifying the results of a research project.

Additionally, information that assists in considering the ability of the TUTKA tool to fulfil the selected criteria was collected from its potential users. Firstly, feedback on the developed production system assessment tool, the assessment process, and assessment results was collected from the participants of the pilot cases by means of a questionnaire consisting of multiple-choice and open-ended questions. Then, the tool and its use were presented to three consultants working in the field of production and production systems (Section 4.6.). Their opinions on the TUTKA tool and the production system assessment process were collected using a questionnaire consisting of five open ended questions. Finally, feedback and comments received from the reviewers of conference papers in which the TUTKA tool, its parts, and its use have been presented are also used in evaluating the results of this study. The questions presented to and feedback provided by the pilot cases participants are presented in Appendices 5 and 6, while the questions and feedback of the consultants are presented in Appendices 7 and 8. Finally, the review reports of conference articles are presented in Appendix 9. However, the multiple-choice questions and the responses provided by the ten participants of the pilot cases are presented and summarised below.
The questions or claims used were:

1. The assessment approach (evaluating and assessing the characteristics of the production system) is well-suited for assessing the current state of the production system.
2. The results and observations of the assessment process provide a correct and realistic view of the current state and the improvement potential of the production system.
3. The assessment process and its results highlighted useful improvement potential and ideas for improving the production system.
4. I could recommend the production system assessment process and assessment tool to other companies belonging to the target group of this study.

The response options were: 1) disagree, 2) partly disagree, 3) partly agree and 4) agree.

Table 18. Summary of feedback from assessment participants

<table>
<thead>
<tr>
<th>Question no.</th>
<th>Answer option</th>
<th>Mode</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 1 5 4</td>
<td>3</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>0 0 8 2</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>0 1 5 4</td>
<td>3</td>
<td>3.3</td>
</tr>
<tr>
<td>4</td>
<td>0 1 4 5</td>
<td>4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table 18 presents the number of response options chosen per question and the mode of the responses for each question. In addition, the average of the responses for each question is also calculated and presented as it is considered a useful indicator, even though the appropriateness of calculating and using averages with this type of scale may be open to question (see e.g., Baumard & Ibert 2001 and KvantiMOTV). Table 18 and the feedback presented in the appendices are referred to in the following sections, and hence are not interpreted and discussed in more detail here.

7.2. Novelty of the TUTKA production system assessment tool

In this section, the novelty of the TUTKA tool is considered from three perspectives. Firstly, the developed production system assessment tool is compared to the available assessment and improvement tools and models reviewed in Chapter 3. Then, the perspective of the potential users of the TUTKA tool is considered based on the feedback collected from the participants of the assessment cases and the consultants. Finally, the novelty of the tool is discussed based on the review reports of conference articles. In general, the aim is to justify that the study provides a new contribution to the field of production, production systems and their improvement.
7.2.1. Available assessment and improvement tools and models

The comparison between the TUTKA tool and the available tools and models for assessing and improving production aimed to demonstrate the novelty of the TUTKA tool and its difference from available tools and models. The following aspects and characteristics were covered:

- **Scope and focus of assessment**: The parts of a supply chain or an order-delivery process and the processes or functions of a company that are covered and focused on by the assessment
- **Target companies**: The type of companies or industries for which the tool is developed
- **Theoretical background**: The theoretical background and framework based on which the tool or model has been developed
- **Basis of the assessment and methods used**: What provides the basis for assessment? What kind of methods are included in the tool and used in the assessment process?

The comparison is summarised in the following table (Table 19). The TUTKA tool and its characteristics are summarised on the first row of the table. For each of the reviewed assessment and improvement tools and models, the results of the comparison with the TUTKA tool and a summary of the characteristics or aspects of the tool or model are presented. The comparison of the scope and focus of assessment indicates whether the tool or model considered adopts a broader, similar or narrower scope than the TUTKA tool and this study. Furthermore, the differences in or similarity of focus of the assessment are also presented. Subsequently, the difference or similarity of the target companies and the theoretical backgrounds of the tools compared are presented. Finally, the last cell indicates whether the tool or model considered includes a narrower, similar or broader set of assessment methods than the TUTKA tool. As an example, the SHEN model adopts a broader scope and focus of assessment, is developed for a different company type, is based on a different theoretical background, and includes a narrower set of assessment methods when compared to the TUTKA tool.
<table>
<thead>
<tr>
<th>Tool or model</th>
<th>Scope and focus of assessment</th>
<th>Target companies</th>
<th>Theoretical background</th>
<th>Basis of the assessment and methods used</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUTKA tool</td>
<td>Main focus on production system. Some aspects of product architecture and production processes also considered. Limited to one company and to the production function.</td>
<td>Finnish mechanical engineering companies operating a MTO or ATO approach, mainly in the business-to-business market.</td>
<td>Production strategy, lean production, agile manufacturing and mass customization.</td>
<td>33 key characteristics of a well-performing production system. Realisation assessed by means of questions and a four-level assessment scale. Assessment can be complemented with additional information e.g., performance measurement data, product descriptions and process maps.</td>
</tr>
<tr>
<td>SHEN model</td>
<td>Broader. Covers the supply chain and order delivery process as well as various functions of a company, e.g., production, product design and marketing.</td>
<td>Different. Small- to medium-sized, traditional make-to-order companies (corresponds to engineer-to-order approach using the definitions adopted for this study).</td>
<td>Different. World class manufacturing.</td>
<td>Narrower set of assessment methods. 12 principles from world class manufacturing and make-to-order literature, each consisting of five steps. Current practice and performance is assessed and the level achieved is determined for each principle.</td>
</tr>
<tr>
<td>PPA method</td>
<td>Broader scope and different focus, i.e. more emphasis on production processes and performance. Main focus on utilisation of labour and machines and on shop-floor production operations and processes. Covers also productivity at corporate level and skills and ability to run and develop production.</td>
<td>Different. Applicable generally to Swedish production companies. International version under development.</td>
<td>Different. Productivity and productivity assessment.</td>
<td>Similar or even broader set of assessment methods. Standardised assessment process divided into four levels. Includes observation, interviews, use of available documentation and performance data as well as a work sampling study.</td>
</tr>
<tr>
<td>LESAT tool</td>
<td>Broader. Covers an enterprise, e.g., a company or a supply chain. Considers transformation, leadership and lifecycle processes as well as enabling infrastructure.</td>
<td>Different. Initially developed for the aerospace industry, but applicable to a wide variety of industries.</td>
<td>Different. Lean production.</td>
<td>Narrower set of assessment methods. 54 best practices. Current capability determined by means of Capability Maturity Matrices that present five levels of maturity. Definitions of the five maturity levels and examples of the practice considered assist in the assessment.</td>
</tr>
<tr>
<td>Baldrige Award and Criteria</td>
<td>Broader. Covers all factors that define an organisation, its operations and results.</td>
<td>Different. Applicable to all industries and all types of companies.</td>
<td>Different. Theoretical background is not clearly stated. The Criteria are at the leading edge of validated management practices.</td>
<td>Narrower set of assessment methods. Approximately 100 questions divided into seven categories. Guidelines for scoring are also presented.</td>
</tr>
<tr>
<td>Framework</td>
<td>Scope/Scope</td>
<td>Focus/Industry/Company Type</td>
<td>Literature/Tools/Assessment Methods</td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>PSD framework</td>
<td>Broader.</td>
<td>Different. Discrete-part, repetitive production systems. Target company type or industry sector not specified.</td>
<td>Different. Lean production, production system design literature. Slightly narrower set of assessment methods. Functional requirements and physical solutions related to the areas covered. Assessment carried out with a questionnaire and a six-level maturity model. Performance metrics and measures related to functional requirements and physical solutions also presented.</td>
<td></td>
</tr>
<tr>
<td>MSDD model</td>
<td>Slightly broader scope, different focus. Design and organisation of a production system, production processes.</td>
<td>Different. Medium to high volume repetitive production. Applicable to a wide variety of production systems in different environments.</td>
<td>Different. Lean production, literature on production systems and production strategy. Slightly narrower set of assessment methods. Functional requirements and design parameters assessed using questions and measures related to these.</td>
<td></td>
</tr>
<tr>
<td>SCOR model</td>
<td>Broader. Supply chain from supplier’s supplier to customer’s customer.</td>
<td>Different. Cross-industry model, not limited to certain industry or company type.</td>
<td>Similar or even broader set of assessment methods. Five management processes considered at three levels of detail. Contains process descriptions, management practices and performance measures that enable supply chain modelling and analysis.</td>
<td></td>
</tr>
<tr>
<td>EFQM model</td>
<td>Broader. Organisation viewed from a broad perspective including strategy, leadership, resources, processes and results.</td>
<td>Different. Applicable to a wide variety of organisations in public as well as private sector.</td>
<td>Similar or even broader set of assessment methods. The model consists of nine criteria, RADAR logic that provides a scoring framework and assists in learning and improvement and Fundamental Concepts of Excellence that underpin the model. Results as well as practices of an organisation are assessed.</td>
<td></td>
</tr>
<tr>
<td>ABO framework</td>
<td>Broader scope and different focus. Covers the order-delivery process and focuses on operations of the process.</td>
<td>Different. Focuses on companies producing physical products, company type or industry sector not specified in more detail.</td>
<td>Narrower set of assessment methods. Presents an approach and tools for modelling, analysing and measuring the process. These assist in identifying development actions to optimise the order-delivery process.</td>
<td></td>
</tr>
<tr>
<td>Model for Assessing Changes Towards Lean Production</td>
<td>Similar scope, different focus. Covers the production function of a company, especially the work organisation. Focuses on production processes and the change process of implementing lean production.</td>
<td>Different. Company type or industry sector for which the tool is developed not specified.</td>
<td>Narrower set of assessment methods. Nine principles of lean production and measurable determinants for these. The determinants present both quantitative measures and breakdown points of a principle.</td>
<td></td>
</tr>
</tbody>
</table>
The novelty of the TUTKA tool compared with the available tools and models can be further clarified and explained based on the aspects included in the comparison and Table 19. The aim is to point out and highlight the differences between the developed tool and the available tools.

The scope and focus of assessment and the target companies for which a tool or model is developed demonstrate the novelty of the TUTKA tool and its difference from available assessment tools and models. Figure 43 summarises these aspects at a general level and shows that the TUTKA tool adopts a narrow focus and scope and is intended for a clearly defined industry sector and company type.

Figure 43 shows that for all but one of the reviewed tools and models, the target group is broader than in this study. The SCMAT test, LESAT tool, Baldrige criteria, SCOR model, EFQM model and the Model for Assessing Changes Towards Lean Production (MACL) are either intended to be applicable to a wide variety of companies and industries or the target group is not defined or limited. The ABO framework and PPA method are developed for production companies and, in addition to this definition, the developers of the PSD framework and MSDD model state that these are best applicable to repetitive, discrete-part production. The conclusion thus is that, in terms of the target group, the TUTKA tool is novel and differs from all of the tools and models discussed because it is developed for a specific industry sector and company type. The only other tool for which a target group is clearly specified is the SHEN model. However, in this case the target companies are different, even though both the SHEN model and the TUTKA tool are intended for companies operating based on the make-to-order approach. In developing the SHEN model, Muda and Hendry (2002a; 2002b; 2003) used the traditional definition of make-to-order, which states that products are designed and produced based on an order. In contrast, the definition of the make-to-order approach used in this study requires that the products are designed prior to order and then configured and produced based on the order. Thus, using the definitions adopted in this study, the target companies of the SHEN model operate on the basis of an engineer-to-order approach and such companies are not considered in this study. Hence, also compared to the SHEN model, the TUTKA tool is novel and different in terms of the target company types and production approach considered.

Figure 43. Comparison between the TUTKA tool and the available tools and models based on focus and scope and target company or industry type

Figure 43 shows that for all but one of the reviewed tools and models, the target group is broader than in this study. The SCMAT test, LESAT tool, Baldrige criteria, SCOR model, EFQM model and the Model for Assessing Changes Towards Lean Production (MACL) are either intended to be applicable to a wide variety of companies and industries or the target group is not defined or limited. The ABO framework and PPA method are developed for production companies and, in addition to this definition, the developers of the PSD framework and MSDD model state that these are best applicable to repetitive, discrete-part production. The conclusion thus is that, in terms of the target group, the TUTKA tool is novel and differs from all of the tools and models discussed because it is developed for a specific industry sector and company type. The only other tool for which a target group is clearly specified is the SHEN model. However, in this case the target companies are different, even though both the SHEN model and the TUTKA tool are intended for companies operating based on the make-to-order approach. In developing the SHEN model, Muda and Hendry (2002a; 2002b; 2003) used the traditional definition of make-to-order, which states that products are designed and produced based on an order. In contrast, the definition of the make-to-order approach used in this study requires that the products are designed prior to order and then configured and produced based on the order. Thus, using the definitions adopted in this study, the target companies of the SHEN model operate on the basis of an engineer-to-order approach and such companies are not considered in this study. Hence, also compared to the SHEN model, the TUTKA tool is novel and different in terms of the target company types and production approach considered.
With regard to scope and focus of assessment, the novelty and difference of the TUTKA tool is based on its limited scope and focus and on placing its main emphasis on the production system. As Figure 43 shows, many of the assessment and improvement tools and models considered here adopt a broad scope and focus. The SCMAT test, the SCOR model, the LESAT tool, the Baldrige criteria and the EFQM model consider the entire enterprise or supply chain. Hence, these tools and models clearly differ from the TUTKA tool in terms of scope and focus of assessment and improvement. The remaining tools and models presented in Figure 43 focus on production or cover it as a part of the order-delivery process or supply chain. The following figure aims to clarify the novelty and difference of the TUTKA tool compared to these (Figure 44). The PPA method, the MSDD model, the PSD framework and the Model for Assessing Changes Towards Lean Production (MACL) cover both the production system and production processes. The PPA method also includes more general corporate level aspects and the PSD framework also considers product design. Thus, these four tools and frameworks adopt a broader scope than this study and the TUTKA tool. Furthermore, the PPA method emphasises performance and utilisation of labour and machines and focuses mainly on the production processes rather than the design and organisation of the production system emphasised in this study. The MSDD tool does not consider product architecture but, on the other hand, puts more emphasis on production processes and assesses them in much more detail than the TUTKA tool. Thus, the scope of the MSDD tool is slightly different than in this study and the focus is more on the production processes than the design and organisation of a production system. In addition to its broader scope, the Model for Assessing Changes Towards Lean Production has a clearly different focus to the TUTKA tool, since it emphasises production processes, their characteristics, and the effects of implementing lean production on the production processes. Finally, the ABO framework and the SHEN model have a broader scope and different focus to this study as they cover the order-delivery process or supply chain and emphasise processes rather than the production system.

Figure 44. Comparison of scope and focus of available assessment and improvement tools and models

The above figures (Figure 43 and 44) and discussion show that the TUTKA tool is novel and differs from the available assessment tools and methods by adopting a narrower scope and focus and by emphasising the production system. In addition to its novelty, the tool’s limited and narrow focus and scope provide certain advantages in production system assessment. Compared to tools and models that consider production and the production system as part of a broader assessment, an assessment that focuses mainly on the production system can be carried out with less effort and in a shorter time. On the other hand, if the same amount of time and effort is invested as with other tools and models, the more limited scope and focus will enable a more detailed assessment and can hence provide more practical and useful results.
The TUTKA tool differs from the available tools and models also in terms of its theoretical background and framework. The dominant theoretical background or paradigm of the reviewed tools and models is lean production, which is used in the LESAT tool, PSD framework, MSDD model, and the Model for Assessing Changes Towards Lean Production. With regard to these, the TUTKA tool is based on a broader theoretical background that combines lean production, agile manufacturing, mass customization, and production strategy. The effects of considering mass customization and agile manufacturing in addition to lean production can be seen, for example, in greater emphasis on product architecture and structure, and in the ideas on late-point differentiation (Sections 5.1.1. and 5.1.3.). Furthermore, the SHEN model is based on a different production paradigm or approach than this study, while the PPA method and the ABO framework adopt a different focus of improvement and hence utilise a different theoretical background and literature than the TUTKA tool. Finally, the theoretical backgrounds to the Baldrige Award, the SCOR model and the EFQM model are not clearly described, and the development of these tools and models has mainly been based on the opinions and perspectives of the development groups and organisations. While the lack of a clear definition of their theoretical basis makes comparison complicated and to some extent unreliable, the TUTKA tool is nevertheless seen to be different and distinct also from these tools and models.

Finally, with regard to the fourth aspect considered, most of the reviewed assessment and improvement tools and models include a narrower set of assessment methods than the TUTKA tool. The assessment methods and sources of information included in the TUTKA tool can be categorised into three groups. Firstly, the questions and claims related to the key characteristics are the main assessment method. This is followed, secondly, by additional sources of information covering performance measures or performance measurement data. The final group includes documentation and descriptions on processes, products, and organisation. In contrast, the SHEN model, the SCMAT test, the LESAT tool, the Model for Assessing Changes Towards Lean Production and the Baldrige Criteria are based on principles or best practices and questions or measures related to these, but do not incorporate additional assessment methods or sources of information such as performance measures, process maps, or process and product documents. Furthermore, the ABO framework lacks best practices and focuses on modelling and measuring the operations of the order-delivery process. The PSD framework and the MSDD tool present practices or principles, i.e. functional requirements, physical solutions or design parameters, and questions and performance metrics related to these, but do not suggest the use of process maps or product documentation. The TUTKA tool is thus argued to include and utilise a broader set of assessment methods and sources of information than these tools and models. On the other hand, the SCOR model, the EFQM model and the PPA method utilise a similar or even broader set of methods and sources of information. Hence, this aspect of the comparison does not present a clear difference with these models and tools.

Based on the comparison, the TUTKA tool differs from the available assessment and improvement tools and models mainly in terms of the scope and focus of assessment and the target companies. Further differences with the majority of the available tools and models result from the theoretical background and the assessment methods and sources of information utilised in the assessment. The main conclusion is that none of the reviewed tools is similar to the TUTKA tool in terms of all of the aspects considered and compared here. Thus, the comparison shows the novelty of the results of this study in the context of assessing and improving production.

7.2.2. Perspective of potential users

The novelty of the TUTKA tool from the practical, i.e. potential users’, perspective is considered and justified using the feedback collected. Both the consultants (Appendix 8, Question 5) and the
participants of the assessment cases (Appendix 6, Question 3) were asked to compare the TUTKA tool with available assessment and improvement tools and models.

The feedback and responses received demonstrate the novelty of the TUTKA tool and its difference with the available assessment and improvement tools and models. The differences pointed out are quite similar to those identified based on the comparison to available assessment and improvement tools and models (Section 7.2.1.). With regard to the novelty of the developed tool, two respondents from case company E stated that their company had not used any other similar or as comprehensive assessment tools as the TUTKA tool. In discussing the differences between the TUTKA tool and the other available tools and models, the focus, target companies and level of detail of the TUTKA tool were mentioned. The focus of the developed assessment tool on production system rather than production processes was mentioned by one of the consultants and one of the participants in pilot case B as being a differentiating factor from other available tools and models. Furthermore, one of the consultants mentioned that the clear definition of the target companies of the study, and focusing on companies important to Finnish exports and on a production approach typical to Finnish companies differentiate the TUTKA tool from other assessment and improvement tools and models. The TUTKA tool was also compared to and contrasted with performance measurement, and the main difference was that the developed assessment tool provides more detailed information related to the potential and means for improvement and adopts a broader perspective on performance and improvement than performance measures (respondents from cases A, B, C and E, Appendix 6).

7.2.3. Feedback from conference articles

The review reports of conference articles that presented the assessment tool, its parts, and its use further evidence and support for the novelty of the TUTKA tool. In the reviews, the contributions and the originality or novelty of results have been evaluated, and both practical and theoretical or academic perspectives have been considered.

The review reports indicate the novelty of the TUTKA tool, the key characteristics of a well-performing production system, and the assessment scale. More specifically, two reviewers of an article that presented the TUTKA tool and the production system assessment process (Koho 2008a) agreed on the contributions and originality of the results (Appendix 9). In another article (Koho & Torvinen 2007a) the main focus was on the set of key characteristics of a well-performing production system, but the assessment tool was also presented at a general level. The evaluation of this paper, made by two reviewers, indicates the originality and novelty of the study and its results (Appendix 9). The developed assessment scale was also introduced in one conference article (Koho & Torvinen 2007b) and the reviewer agreed that the paper presents a new contribution (Appendix 9).

7.3. Usefulness of the TUTKA production system assessment tool

This section focuses on the usefulness of the TUTKA tool, which as mentioned in Section 7.1.2., is defined as the ability to assist in assessing a production system and to identify useful potential and means for improvement. Additionally, the usefulness and relevancy of the key characteristics of a well-performing production system and the assessment scale included in the TUTKA tool are discussed. The evaluation and justification of usefulness is based on the six pilot cases in which the developed assessment tool was used, and on the feedback received from the case participants and the consultants.

The assessment cases and their results, discussed in Section 6.3., demonstrate that the TUTKA tool can be successfully used in assessing a production system. In each assessment case both the
strengths and improvement potential of the production system were identified. Furthermore, initial ideas and means for improvement were suggested to the companies. Thus, the pilot cases and their results show the applicability and usefulness of the developed tool in practice.

The feedback from the participants of the assessment cases further indicates and supports the usefulness of the results of this study. Nine of the ten participants agreed or partly agreed on the usefulness and applicability of the TUTKA tool for assessing a production system and on the usefulness of the assessment results (Appendix 6, Section 7.1.3., multiple-choice questions 1 and 3). Furthermore, the majority of the participants were willing to recommend the developed assessment tool to other companies (Appendix 6, Section 7.1.3., multiple-choice question 4), which is seen as an indicator of its usefulness in production system assessment. For each of these questions focusing on the usefulness of the TUTKA tool and the assessment results, one “partly disagree” response was given. Regarding the first of these, the response was given by case company D. As discussed in Section 6.3.5, this company operated an engineer-to-order approach, and its improvement efforts were directed towards clearly defining customer requirements prior to commencing production and ensuring required flexibility of production, rather than towards improving efficiency and controllability of production emphasised by the TUTKA tool. Thus, the characteristics of the engineer-to-order approach, rather than any deficiencies of the TUTKA tool, are seen to limit and reduce the usefulness of the tool and the assessment results in this case. This is indicated also by the first open ended question, to which the respondent states that lack of knowledge about the products (which the author assumes relates to problems in defining customer requirements and changes to these requirements) makes production system assessment difficult (Appendix 6). In Question 3, the “partly disagree” response was given by case company F. The reason for the response was not explained by the respondent, but the assessment discussion indicated that the respondent was satisfied with the current production system and did not recognise any urgent need for improvement or changes. Presumably for this reason the improvement potential and means identified by the assessment were not regarded highly in terms of usefulness. With regard to the fourth question, the reason for partly disagreeing was not explained by the respondent and the author is not able to further clarify the issue.

The responses of the consultants and the participants of the assessment cases to the open ended questions also support the usefulness of the TUTKA tool, the production system assessment process, and its results (Appendices 6 and 8, Questions 1 and 2). The consultants regarded the TUTKA tool and the assessment process as able to provide an overview of the production system and to identify its improvement potential. Similarly, several participants of the assessment cases stated that the TUTKA tool and the assessment process are useful and applicable for assessing the current state of a production system and for identifying its improvement potential. Their responses also show that the assessment process and its results are useful in improving a production system. For example, one participant stated that “The assessment tool is well-suited and applicable for quick assessment of a production system and it covers the most important areas that have an effect on production.”. It was also stated that “[the results and the process] Were useful. Results can be used, although they didn’t highlight anything new, they show dependencies and relationships between issues and assist in prioritising objects and needs for improvement.” and that “Backs up conceptions and opinions, and provided some good reminders related to the product architecture and structure. Certainly useable.”. Thus, in general, the results of this study were seen to be useful by the case participants and the consultants. However, the assessment case participants mentioned that there is a need for further analysis and efforts before actual improvements and changes can be determined and started. They also stated that the results of the assessment were not surprising, i.e. the identified improvement potential was for the most part already known and recognised by the company prior to the assessment. Regarding these comments, this study is limited to the initial phases of the improvement process, namely assessing the current state and identifying improvement potential, and planning and execution of
improvements are not included in the scope and focus of this study (Section 1.2.). Further efforts and analysis based on the results of the assessment are therefore needed before improvement plans and projects can be clearly defined and initiated. Furthermore, the assessment process and its results are mainly based on the assessment discussion with the members of a company. Consequently, since the assessment results are based mainly on the information and responses provided by the respondents, the results may not always provide the company and the participants with wholly new information. However, the assessment and the questionnaire can cover aspects and characteristics of a production system that have not been considered by the company. The assessment can also bring up issues that have been noticed, but are not currently focused on by the company. Hence the TUTKA tool and the production system assessment process have the potential to introduce new and unconsidered insights, issues and aspects of improvement. Furthermore, even if the assessment results were more or less known, the TUTKA tool and the assessment process provide a comprehensive overview of the production system, and the descriptions of the key characteristics and their linkages to production system themes and production objectives can provide useful insights and information related to the strengths and improvement potential of a production system. These perspectives and advantages were presented also in the feedback provided by the participants of the assessment cases (see Appendix 6, Question 2, e.g., companies A, B and C).

In addition to the developed production system assessment tool, the usefulness of the set of key characteristics of a well-performing production system and the assessment scale included in the tool are considered. The usefulness of the set of key characteristics to the target companies of this study and in identifying the improvement potential of a production system are justified based on the development process and the results of the six pilot cases. The usefulness of the assessment scale and its four levels in assessing and presenting the current status of a production system is then discussed based on the results of the assessment cases.

The relevancy and usefulness of the set of key characteristics of a well-performing production system to the companies considered in this study were emphasised and aimed at during the development process (Section 4.3.). In addition to literature reviews, the development process involved evaluating the set of key characteristics in theme interviews, and modifying them based on the feedback and comments received and information collected by observing production systems. The iterative development process aimed to ensure that the key characteristics of a well-performing production system included in the TUTKA tool are useful and relevant to the target companies of this study.

With regard to the results of the six pilot cases, a key characteristic of a well-performing production system can be considered useful if improvement potential related to it has been identified. A review of the results of the pilot cases reveals that 29 of the 33 key characteristics indicated improvement potential for at least one of the case companies. Improvement potential was related to both implementing the key characteristic in the production system, i.e. the key characteristic was ranked at level 1 or 2, and to the adaptability of the production system to changes in product variety and production volume, i.e. the key characteristic was ranked at level 3 but did not reach level 4. On the other hand, four key characteristics were ranked to the highest level of the assessment scale in all cases and hence no improvement potential was identified. However, three of these belong to the production equipment decision area and were considered only in two cases. Therefore, it is argued that further cases and evidence are required in order to properly evaluate the usefulness and relevance of these three key characteristics. Only the key characteristic considering reliability and availability of information and communication systems was ranked at the highest level in all six pilot cases. Although, the results of the cases do not provide support for the usefulness of this key characteristic, it can be justified based on the objectives of the key characteristic and the comments presented during the development process. The key characteristic aims to ensure rapid and reliable information flow and availability of
relevant information in the production system. These were regarded as important objectives, and the need to identify means for achieving them was presented in the theme interviews (Section 5.1.5.). Hence, considering the key characteristic in assessing and improving production systems is argued to be important. This conclusion is supported also by Cochran et al. (2001, p. 381) who highlight the importance of capable and reliable information systems in minimising production disruptions and in achieving predictable and reliable production processes, outputs and lead time. However, the results of the pilot cases indicate that there may be a need to modify this key characteristic and this must be considered based on the results of and observations made during subsequent assessment cases.

Finally, the developed assessment scale can be evaluated on the basis of the assessment cases. The results of the cases show that all four levels of the assessment scale were used, and that improvement potential related to both the realisation of the key characteristics and the adaptability of the production system was identified. This demonstrates the usefulness and applicability of the developed assessment scale and its four levels in assessing production systems and in identifying improvement potential.

Thus, the six pilot cases demonstrated that the TUTKA tool can be used in assessing production systems, and that it enables identification of the strengths of a production system, and its potential and means for improvement. The feedback received indicated that the tool, the assessment process and the assessment results are useful for the potential users of the TUTKA tool. Finally, the review of the results of the assessment cases provided support for the usefulness and applicability of the key characteristics of a well-performing production system and the assessment scale in identifying improvement potential. Hence, the results of this study fulfil the usefulness criterion.

7.4. Ease of using the TUTKA production system assessment tool

The ease of use aspect or criterion relates to the time and effort required for assessing a production system using the TUTKA tool. As described in Section 6.1., the assessment process consists of three phases and requires two meetings with participants from the company. In the pilot cases, the first meeting, in which the assessment discussion was carried out and additional information for the assessment was provided to the researcher, typically lasted from two to four hours. The collected information was then analysed and the results were prepared by the researcher. The results were subsequently presented and discussed in the second meeting lasting between one and half to two hours. Thus, the total time input required of the participants for the meetings and for preparation equals roughly one working day and, at quickest, the entire assessment process was carried out in two days. This demonstrates that the assessment process can be carried out relatively quickly and that it requires relatively minimal effort from the participants. The TUTKA tool is thus considered relatively easy to use.

The feedback received from the consultants and participants of the pilot cases also indicates that the TUTKA tool is easy to use (Appendices 6 and 8). For example, one of the pilot case participants stated that “The tool developed by the research project is suitably quick and light/lean in terms of structure.”, while another mentioned that “The results and benefits provided by the assessment tool are very good compared to the time and effort used.”.
7.5. Reliability of the TUTKA production system assessment tool and assessment results

Considering and evaluating the reliability of the TUTKA tool and the results of the production system assessment process are based on the definitions and guidelines presented in literature. In quantitative measurement, in particular, reliability is concerned with the consistency and stability of measures, repeatability of measurement, and the consistency of results of separate measurements. Reliability also has an inverse relation with random error, which can be caused, for example, by the characteristics of the measurement system or the circumstances of measurement. (Bryman & Bell 2003; Drucker-Godard et al. 2001, p. 200-202) With regard to assessing or evaluating the reliability of a measurement instrument, Drucker-Godard et al. (2001, p. 205) emphasise the need to demonstrate that the instrument enables obtaining reliable results and measurements. More specifically, the focus should be on whether the results of separate measurements of a given object or phenomenon using the same measurement instrument are as similar as possible. Calculating correlations between duplicated or reproduced measurements is suggested as a way to evaluate and demonstrate this. (Drucker-Godard et al. 2001, p. 204-205) In considering and evaluating the reliability of the TUTKA tool and the assessment results, the main focus is on explaining and demonstrating how the structure of the tool and the assessment process contribute towards and ensure the reliability of the assessment results. Furthermore, the pilot case B is used to assess and justify the aspect in more detail.

The facilitated assessment process and the assessment methods included in the TUTKA tool are argued to improve and ensure the reliability of the results of production system assessment. The facilitated assessment process enables respondents to be provided with detailed explanations of the questions and the key characteristics used in the assessment, which ensures that the questions are understood and interpreted correctly. Furthermore, if additional information, such as performance measurement data and descriptions of products and processes, is used, the responses to the questions can be compared with information from other sources and, if necessary, unclear issues can be discussed in more detail in order to determine the actual situation. Thus, the assessment process and the different sources of information improve and ensure the reliability of the assessment results.

The reliability of the TUTKA tool and the assessment results are demonstrated by the results of case B, in which the production system was assessed in separate sessions with two separate participants (Section 6.3.3.). Thus, a duplicate assessment with the same measurement instrument was carried out and the results can be used to assess the reliability of the instrument. The results of these two assessments were highly similar with 27 of the 32 key characteristics ranked at the same level of the assessment scale by both respondents, and the remaining five characteristics ranked at subsequent levels, i.e. with a difference of one level on the assessment scale. Also, the difference in response averages, 2.85 and 2.76, was small. In addition, Pearson’s correlation coefficient can be used as an indicator of the strength of relationship between two variables. According to this method, the closer to 1 the coefficient is, the stronger the relationship between the variables is (Bryman & Bell 2003). Applying this to case B, a coefficient value of 1 would indicate that the responses of the two respondents are identical. The correlation coefficient for the two sets of responses is 0.93, indicating a high degree of similarity between the responses. Thus, the similarity of the results and the correlation coefficient demonstrate the reliability of the TUTKA tool and the results provided by it. However, regarding the reliability of assessment results and the approach used for evaluating it, differences between the responses of different persons from the same company are not necessarily caused by the assessment tool or the assessment process, but can result from differences in perspective, understanding and knowledge between the respondents. Thus, even greater differences in the results of separate assessment processes would not necessarily indicate poor reliability of the assessment tool and process.
7.6. Validity of the TUTKA production system assessment tool and assessment results

In general, validity is seen as the ability of a measure or measurement instrument to measure what it is intended to measure, and the ability to deliver correct and accurate measurement and results of the object studied (Drucker-Godard et al. 2001, p. 205; Bryman & Bell 2003). Validity is also affected by non-random measurement error, which refers to the systematic biasing effect on the measured phenomenon produced by the measurement instrument. Thus, to be valid, the measurement instrument, measures or indicators used must ensure that accurate and relevant information on the object or phenomenon studied is obtained. (Drucker-Godard et al. 2001, p. 203, 206) In this case, validity is related to the ability of the TUTKA tool and the included assessment methods to evaluate the realisation of the key characteristics of a well-performing production system, which provide the basis for the production system assessment and for the identification of strengths and improvement potential of a production system. Furthermore, to be valid, the TUTKA tool and the assessment process must provide an accurate and realistic view of the current status and improvement potential of a production system.

In evaluating and demonstrating validity, the researcher is required to explain and demonstrate that the developed tool or instrument enables valid measurements and results to be obtained (Drucker-Godard et al. 2001, p. 204-205). Additionally, Bryman and Bell (2003) suggest using face validity, i.e. the opinions of persons with experience and expertise in the field, in evaluating and establishing the validity of a new measure. In this case, the validity of the TUTKA tool is discussed and demonstrated on the basis of the selected assessment approach and the process of developing the assessment methods, and on the basis of feedback received from the participants of the pilot cases.

The assessment approach adopted in this study is argued to contribute towards the validity of the assessment results. Production system assessment is based primarily on questions that focus directly on the key characteristics and their realisation in the production system. Therefore, the validity of the TUTKA tool in terms of ability to measure what it is intended to measure is considered good. The use of a questionnaire in the assessment process is argued to result in better validity than the use of measures or indicators related to the realisation of a given key characteristic. The problems inherent to using such measures and indicators were discussed in Section 4.5. The key challenge of such an approach with respect to validity relates to the difficulty in identifying measures and indicators that are directly related to the key characteristic considered, and whose results are not affected by other factors.

In developing the assessment methods, the face validity approach suggested by Bryman and Bell (2003) was implemented in order to improve and ensure the validity of the assessment methods. Prior to the pilot cases, the assessment methods, i.e. the questionnaire and the additional sources of information, were presented to three persons with extensive expertise and experience in production and production systems and their assessment and improvement. The assessment methods were then modified based on the discussion and feedback in order to improve their validity and applicability.

The feedback received from the participants of the pilot cases also indicates the validity of the TUTKA tool and the results of the production system assessment process. As Table 18 (Section 7.1.3., Question 2) shows, all respondents agreed or partly agreed that the assessment process and its results provided a correct and realistic view of the production system and its improvement potential. This demonstrates that the TUTKA tool and the production system assessment process are able to provide correct and exact results, which, as discussed at the beginning of this section, is a key aspect of validity.
To conclude, the chosen assessment approach and methods were selected and the opinions of experts were used in order to ensure the validity of the TUTKA tool and the production system assessment process. Feedback received demonstrates that the assessment process provides valid results, i.e. an accurate and realistic overview of the current status of the production system. Thus, the TUTKA tool and the results of the assessment process are seen to meet the validity criterion.

7.7. Weak market test

Finally, the weak market test presented by Kasanen et al. (1993) is used to evaluate and justify the results of this study. The test focuses on the willingness of managers with responsibility for the financial results of a company or business unit to use the developed construction in decision-making (Kasanen et al. 1993, p. 253).

The ability of the TUTKA tool to pass the test is considered and demonstrated based on the feedback received from the consultants and the participants of the pilot cases. The consultants were presented with a question regarding their willingness to use the developed assessment tool. The question was derived directly from the definition and criterion of the weak market test (see Section 7.1.1.; Kasanen et al. 1993, p. 253). Two of the three consultants were willing to use the TUTKA tool in their company and to recommend its use to their customers, especially in cases where an overall view of the current status of the production system and its improvement potential is needed at the beginning of an improvement project. The third consultant mentioned that the developed tool could be used in assisting the analysis of the current status of a production system (Appendix 8, Question 4). For the pilot case participants, the questions related to the weak market test were phrased differently than for the consultants. The reason for this is that the TUTKA tool is not intended to be used continuously in the company, but during the initial phase of a production system improvement project, or as a periodical check to monitor and evaluate the progress and improvements made. Thus, as the assessment had already been carried out, asking whether the participants were willing to use the tool in their company and in decision-making was not considered important or relevant. Rather, the questions focused on the assessment results and the willingness or ability to use them in improving the production system (Appendix 5, open-ended question 2). Also as part of the weak market test, the willingness to recommend using the TUTKA tool to other companies belonging to the target group in this study was queried (Appendix 5, multiple-choice question 4). The responses show that the participants are able and willing to use the results of the assessments in improving production systems, for example in prioritising improvement needs, in layout planning, or in evaluating and improving the product architecture (Appendix 6). Furthermore, all but one of the respondents were willing to recommend the use of the tool to other companies (Appendix 6, Section 7.1.3.).

The willingness of the consultants to use the TUTKA tool and to recommend it to their customers, and the ability of the pilot case participants to use the assessment results, and their willingness to recommend the developed tool to other companies are seen to indicate the ability of the TUTKA tool to pass the weak market test. According to Kasanen et al. (1993, p. 253), the ability to pass the test validates and justifies the success and usefulness of the study and its results.

7.8. Evaluation of the study

In this section, the study and the process of developing the TUTKA tool are considered and evaluated. Firstly, the criteria presented in literature for evaluating research projects are reviewed and the study is then examined based on the selected criteria.
In contrast to quantitative research, where reliability and validity are typically used, in qualitative research there is a lack of consensus regarding the criteria for evaluating a research project. In the context of quantitative research, reliability is concerned with repeatability of the research and its results, and validity covers the precision of the results, the integrity of the conclusions generated from the research process, and the ability to generalise from the results. With regard to evaluating a qualitative research study, different approaches have been proposed, for example, applying the same criteria as in quantitative research, modifying their interpretation, and developing alternative criteria. (Eskola & Suoranta 1998, p. 211; Drucker-Godard et al. 2001, p. 200; Bryman & Bell 2003; Saaranen-Kauppinen & Puusniekka 2006)

For example, Saaranen-Kauppinen and Puusniekka (2006) and LeCompte and Goetz (1982, cited in Bryman & Bell 2003) provide modified definitions of reliability and validity criteria. According to Saaranen-Kauppinen and Puusniekka (2006), validity considers whether the research process is carried out properly and thoroughly, and whether the results and conclusions can be considered to be correct. Validity can also be understood as credibility, for example how well the results of the research project correspond with the object or phenomenon studied, or how well the constructs generated by the researcher correspond to those of the subjects or participants (Saaranen-Kauppinen & Puusniekka 2006). Reliability covers the reliability of the method used, the stability of the measurements or observations over time, and the consistency of the results achieved with different methods (Kirk & Miller 1986, p. 41-42; Saaranen-Kauppinen & Puusniekka 2006). LeCompte and Goetz (1982) divide reliability and validity into external and internal. External reliability refers to the ability to replicate a study while, in a situation where there is more than one observer, internal reliability is related to whether observers agree about the observations and results of the research process. External validity refers to the ability to generalise the results and findings in different contexts, while internal validity considers the match between the researchers’ observations and the theoretical ideas they develop. (LeCompte & Goetz 1982; Bryman & Bell 2003) Thus, the perspectives on and definitions of reliability presented by LeCompte and Goetz (1982) and Saaranen-Kauppinen and Puusniekka (2006) are quite similar, although with regard to validity, LeCompte and Goetz focus on generalisation while Saaranen-Kauppinen and Puusniekka place greater emphasis on how the research process is carried out and reported.

Lincoln and Guba (1985) propose using alternative criteria, trustworthiness and authenticity, for evaluating qualitative research. Trustworthiness is further divided into credibility, transferability, dependability, and confirmability, which correspond with internal validity, external validity, reliability, and objectivity. Credibility is concerned with whether the research project is carried out according to good practice and whether the results or reconstructions are credible to its subjects and participants. Transferability is related to the ability to generalise and apply the results in different contexts, while dependability considers the repeatability of the research project, and the stability of the results or findings and methods used. Finally, confirmability requires that the results and findings are determined by the subjects and conditions of the research project, rather than by the motivations, interests or perspectives of the researcher. (Lincoln & Guba 1985; Girod-Séville & Perret 2001, p. 25-26) Compared to the definitions presented by Saaranen-Kauppinen and Puusniekka (2006), credibility is similar to validity, and dependability covers similar aspects to reliability.

Based on the above discussion and definitions, validity and reliability are used in evaluating this study. With regard to validity or credibility, the focus is on whether the study is carried out thoroughly and according to good practice. External validity or the ability to generalise the results are considered and discussed separately in Chapter 8. Evaluation of reliability focuses on external reliability, i.e. the ability to replicate the study. More detailed definitions for the criteria used are presented in the following sections. With regard to evaluating a research project,
Drucker-Godard et al. (2001, p. 200) state that in qualitative research the main emphasis is on ensuring and improving the ability of the research and its results to meet the evaluation criteria during the project and when decisions are made, rather than testing and assessing the process and the results against the criteria. Thus, in the discussion below, the phases of the study, the decisions made during them, and their effects and relationships with the selected criteria are considered.

7.8.1. Validity

In evaluating and considering the validity of the study and its results, the focus is on how the study was conducted, i.e. whether it was carried out thoroughly and following good practices, and on the credibility of the results. Thus, the definitions of validity and credibility presented by Saaranen-Kauppinen and Puusniekka (2006) and Lincoln and Guba (1985) are adopted. In evaluating the study, both developing the TUTKA tool and identifying and developing the set of key characteristics of a well-performing production system are considered. Evaluation of the validity or credibility of the results focuses mainly on the set of key characteristics of a well-performing production system. With regard to that, the correspondence between the developed set of key characteristics and the perspectives and opinions of the participants of the study, i.e. whether the opinions and perspectives of the interviewees have been presented correctly in the set of key characteristics, is considered. The reason for emphasising the set of key characteristics and their development process is that they form the central basis for the study and the TUTKA tool. The means for improving and ensuring the validity and credibility of the study and its results include the use of respondent validation, collecting information from different sources, and presenting the progress and results in conferences.

In respondent validation, the researcher provides the participants of the study with a summary of his/her conclusions and findings in order to ensure that the conclusions and results are correct and correspond to the perspectives of the participants (Bryman & Bell 2003). In developing the set of key characteristics of a well-performing production system, respondent validation was used in two ways. Firstly, after each interview a summary of the notes of the interview made by the researcher was sent to the participants. This aimed to ensure that all relevant aspects and issues were noticed, and that the perspectives and opinions presented by the interviewees were understood and interpreted correctly. In some cases, clarifications and corrections were provided by the interviewees. Additionally, after each round of interviews, each participant was provided with a document summarising the conclusions regarding the usefulness and applicability of the set of key characteristics and the modifications made to them on the basis of the interviews. This enabled the participants to verify the conclusions and modifications made by the researcher. Hence, the validity of this study and its results, i.e. correspondence between the developed set of key characteristics and the perspectives and opinions of the participants, were improved and ensured using respondent validation.

Triangulation, i.e. the use of more than one source of data, is another method for improving and ensuring the validity and credibility of a research project and its results (Yin 1994, p. 33, 91-93; Bryman & Bell 2003). This method was applied in identifying and developing the set of key characteristics of a well-performing production system and in evaluating the TUTKA tool. In developing and modifying the key characteristics, in addition to interviews, information was collected from literature and by observing production systems. Thus, information derived from different sources was compared and summarised in developing the key characteristics. This is seen to improve the validity and credibility of the results when compared to using information from only one source, such as literature or interviews. Furthermore, the evaluation and justification of the TUTKA tool was based on the results and observations of the pilot cases in which the tool was used, feedback collected from the case participants and consultants, and on comments received from reviewers of conference articles. These sources of information enabled
evaluation of the TUTKA tool from different perspectives and are seen to improve the credibility of the conclusions presented.

Furthermore, the progress and results of this study have been presented in conference articles and presentations (see Sections 1.6. and 4.3.2.). This enabled academic evaluation and commenting on the progress, methods and results of the study during its course. This continuous and systematic reporting was intended and is argued to improve and ensure the validity and credibility of the study and its results.

Finally, the study has been thoroughly conducted based on good practices, and has been reported in detail in order to enable monitoring of its progress, reviewing of the decisions made, and evaluation of its validity and credibility. Firstly, the research approaches were selected and reasoned by presenting available approaches and considering their applicability and usefulness for this study and its objectives. Furthermore, the sources of information and methods used in collecting information were selected based on the research setting and objectives of the study, and were reasoned by considering the alternative options as well as their effects on the study and its results. Additionally, the methods and principles of analysing and using the collected information were explained. The phases and progress of developing the set of key characteristics of a well-performing production system were also presented, the final set of key characteristics was described in detail, and each key characteristic was reasoned based on literature, interviews and observation. These aimed and are seen to ensure the validity and credibility of the study and its results.

7.8.2. Reliability

This discussion on reliability covers the ability to replicate the study and considers whether similar results, i.e. the TUTKA tool and its three parts, would be achieved if the study was repeated by another researcher. In addition, the stability of the results over time is considered. Thus, the aspects presented in the definition of reliability by Saaranen-Kauppinen and Puusniekka (2006), and the similar aspects included in the definitions of external reliability (Bryman & Bell 2003) and dependability (Lincoln & Guba 1985; Girod-Séville & Perret 2001, p. 26) are covered.

Detailed documentation of a research project is suggested, for example, by Yin (1994, p. 36-37), Girod-Séville and Perret (2001, p. 210-211), and Bryman and Bell (2003) as a way to improve and ensure reliability and repeatability of a research project. In Chapter 4, an overview of the phases and progress of the study was presented and the process of developing the TUTKA tool and its three parts, the set of key characteristics of a well-performing production system, the assessment scale and the assessment methods, was described in more detail. The documentation and description of the study and its progress included the research approach, the sources of and methods used in collecting information, and the principles and guidelines of analysing and using information. Thus, it is argued that the study and the process of developing the TUTKA tool have been explained to a sufficient level of detail to enable replicating the study and to ensure its reliability.

However, the study and the development of the TUTKA tool involved creativity, judgement and conclusions by the researcher, which present challenges regarding the repeatability of the study and the ability to achieve similar results. The phases of the research process involving creativity, judgement and the drawing of conclusions, such as developing and modifying the key characteristics of a well-performing production system based on information collected from literature, interviews and observations, are difficult to explain and describe fully and in detail. Furthermore, as creativity and judgement are required, it is possible or even likely that the results and outcomes will be different if the project is replicated by another researcher. This, however, is
seen to be typical of research that applies and follows decision science, constructive research or conceptual research approaches. For example, in decision science, the phase of developing and constructing a new artefact or tool typically involves innovation and creativity (Hevner et al. 2004, p. 76, 88; Vaishnavi & Kuechler 2004; Järvinen 2008, p. 6-7). Furthermore, innovation and solution construction are core elements of the constructive research approach, and involve creativity (Kasanen et al. 1993, p. 246-247; Lukka 2001, p. 4-5). Similarly, conceptual research also involves both creativity and drawing conclusions based on internal and external analysis (Näsi 1980, p. 13). Finally, Saaranen-Kauppinen and Puusniekka (2006) state that in evaluating research projects it must be accepted that research and its results are always constructed by the researcher based on a specific context and certain information, and they therefore represent only one perspective on the studied topic. Hence, the identified challenges related to reliability and repeatability of this study are seen to be typical and acceptable.

Another aspect of reliability, the stability of the results, is typically challenging for qualitative research, because the circumstances and settings of research change over time (Bryman & Bell 2003; Saaranen-Kauppinen & Puusniekka 2006). The practice and theory of production and production systems are in a state of continuous advancement due, for example, to the need to meet new challenges, requirements and production objectives. At the same time, the essential practices and characteristics of production systems and production processes, as well as the opinions and perspectives of the production professionals regarding them, change. Hence, it can be assumed that if the process of developing the TUTKA tool and the set of key characteristics of a well-performing production system are repeated after a reasonably long period (e.g., 10 years), the information collected from literature, interviews and plant tours, and the results of the process will be different. This also indicates a need to regularly review and update the TUTKA tool and the set of key characteristics. However, based on the results of the pilot cases and the feedback received from the participants and consultants, the TUTKA tool and the key characteristics can be expected to remain useful and applicable for a good number of years.

### 7.9. Summary

In this chapter, the study and its results were evaluated in order to justify the success and usefulness of the study and the TUTKA tool. In evaluating the tool, the main emphasis was on novelty and usefulness, which have been suggested and emphasised both in design science (Hevner et al. 2004; Järvinen 2007) and constructive research (Kasanen et al. 1993). According to Järvinen (2007, p. 1394), a design research project is successful if a totally new artefact or innovation is developed, or if the new artefact or innovation provides better value than its predecessors. With regard to this study, the combination of novelty and usefulness were seen to correspond to these two classes of successful design research. The ease of use, validity and reliability of the TUTKA tool and its assessment results, as well as the weak market test presented by Kasanen et al. (1993) were also examined. Finally, an evaluation of the entire study focused on validity and reliability, which were explained and defined based on relevant literature.

The discussion presented, the results of the six pilot cases, and the feedback received demonstrated the ability of the TUTKA tool to fulfil the evaluation criteria and to pass the weak market test. In terms of novelty, comparison with available tools for assessing and improving production showed that the TUTKA tool is different to and distinct from the available tools, and hence novel. Additionally, the feedback received from the consultants, the pilot case participants, and conference articles demonstrated the novelty of the developed tool and clarified its differentiation from available tools and models. With regard to usefulness, the pilot cases demonstrated that the developed tool is applicable and useful in assessing production systems, and enables identification of strengths as well as the potential and means for improvement.
Feedback received from the pilot case participants and the consultants also indicated the usefulness of the TUTKA tool. Additionally, the tool was shown to be relatively easy to use, and the ability of the tool and the related assessment process to provide reliable and valid results was demonstrated. Finally, the feedback received from the consultants and the participants of the pilot cases also indicated the ability of the TUTKA tool to pass the weak market test. Thus, the evaluation of the TUTKA tool shows that the study was successful and that it provided novel and useful findings in the field of production and production systems.

In the evaluation and discussion of the study, it was argued that the study fulfilled the validity and reliability criteria. Means and measures suggested in literature to improve and ensure research validity were used in developing the TUTKA tool and the set of key characteristics of a well-performing production system. Furthermore, the detailed reporting of the study was argued to ensure reliability and validity and is intended to enable their evaluation.
8. Discussion

This chapter discusses the results of the study from different perspectives. Firstly, the objectives and research questions set for the study are considered, and the contribution of the study is then presented. Subsequently, the potential users, purposes of use, and ways of using the TUTKA tool are discussed. Finally, directions for further research are suggested.

8.1. Objectives and research questions

The objectives and research questions of the study are presented in Section 1.1. Here, the ability to accomplish these objectives and to answer the research questions is considered.

The primary objective for the study was to develop a tool to assess the current state of a production system and to identify potential and means for improvement. This was then divided into two sub-objectives. The first sub-objective focused on developing a set of key characteristics of a well-performing production system that provide the basis for assessment, while the other sub-objective covered the methods and scale used for production system assessment. The production system assessment tool was also required to be easy to use and to enable rapid assessment of a production system.

This study and its results achieve and fulfil the objectives and sub-objectives presented. The developed production system assessment tool, TUTKA, consists of a set of key characteristics of a well-performing production system, assessment methods, and an assessment scale. The process of assessing a production system using the developed assessment tool was described and then demonstrated by means of pilot cases. The pilot cases showed that the TUTKA tool is useful and applicable in assessing production systems, i.e. it enables assessment of current status and identification of strengths and potential and means for improvement. Furthermore, feedback received from the pilot case participants showed that the developed production system assessment tool, the related assessment process, and the assessment results provide a realistic overview of the current status of the production system and its potential and means for improvement. The assessment process was also found to be relatively quick, requiring approximately one working day of input from the participants, and the assessment tool was considered to be easy to use. The study and the developed TUTKA production system assessment tool thus fulfil the objectives and sub-objectives of the study and the requirements related to the assessment tool and its use.

The following research questions related to the sub-objectives of the study were presented:

Research question 1:
Which characteristics of a production system are central to achieving production objectives and high production performance?

Research question 2:
Which methods enable assessment of a production system based on the key characteristics of a well-performing production system? What kind of scale should be used in the assessment and in presenting the results?

The TUTKA tool and its parts answer these questions. With regard to the first question, 33 key characteristics of a well-performing production system were developed and identified and included in the TUTKA tool. The comments and opinions presented by professionals and experts in the field of production during the process of developing the set of key characteristics, and the
feedback received from the pilot cases indicated and supported the important role of these characteristics in designing, organising and operating a production system. Appropriate assessment methods and an assessment scale were then developed based on a review of available assessment and improvement tools and methods. Questions and claims related to the key characteristics and their realisation in the production system are used as the main assessment method, but additional sources of information, such as process maps and layout pictures, can also be used. The assessment scale is based on maturity models and presents four levels that assess the realisation of the key characteristics and the adaptability of the production system. The pilot cases demonstrated that the assessment methods and scale are useful and applicable in assessing a production system and in presenting the results.

8.2. Contribution
The contribution of this study can be divided into three main parts:

- The novel and useful TUTKA production system assessment tool
- The set of key characteristics of a well-performing production system
- The maturity model based assessment scale that includes novel and useful perspectives

These three parts are expected to be useful for both academics and practitioners in the field of production and production systems, for example in designing, assessing and improving production systems.

The main contribution of the study is the novel and useful tool for assessing production systems and identifying their potential and means for improvement. Comparison of the developed production system assessment tool, named TUTKA, with available tools and models for assessing and improving production demonstrated that the developed tool is novel and distinct from currently available tools and models. The novelty of the TUTKA tool was also indicated by feedback collected from participants of the pilot cases in which the tool was used, and from consultants to whom the tool and the production system assessment process were presented. With regard to the usefulness of the TUTKA tool, the pilot cases showed that the tool can be used to assess the status of production systems and to identify their potential and means for improvement. Furthermore, based on the feedback received, the TUTKA tool and the assessment results facilitate production system improvement, and the tool is useful and applicable to the target companies of the study and to consultants and their customers.

The set of key characteristics of a well-performing production system, which provides the basis for the TUTKA tool and the production system assessment process, represents an important contribution of the study. The process of identifying and developing the set of key characteristics involved a comprehensive literature review of production paradigms, with a focus on lean production, agile manufacturing and mass customization, and production strategy. Furthermore, the key characteristics were evaluated and modified on the basis of information collected using interviews and observation of production systems. As a result, the set of key characteristics of a well-performing production system and their definitions and descriptions combine theoretical and practical perspectives, and are expected to be beneficial to both practitioners and researchers in the field of production and production systems.

Finally, the assessment scale included in the TUTKA tool also provides a contribution to the field of production system assessment and improvement. The assessment scale, developed on the basis of the maturity model approach, was found to be applicable to the developed production system assessment tool and the adopted assessment approach. Although a wide variety of maturity models exist (Copeland 2003; Britton et al. 2007, p. 148), the developed assessment
scale includes novel aspects and therefore provides a new contribution. The majority of current maturity models focus on assessing and improving processes in different contexts such as production or software engineering, whereas the assessment scale developed in this study focuses on production system and its characteristics. The different focus of the assessment scale and its suitability and applicability to production system assessment differentiates the developed assessment scale from the available maturity models and scales. Another useful feature of the new assessment scale is its ability to assess production system adaptability. Flexibility and adaptability of production and production systems are gaining increasing importance and emphasis, for example in agile manufacturing. Thus, the developed assessment scale and its features provide important and useful contribution.

8.3. Purposes of and ways of using the TUTKA production system assessment tool

The TUTKA tool developed by the study can be used in various ways to suit different purposes. It can be used to assess an existing production system or to assist in designing a new production system. In addition, the structure and content of the assessment process can be tailored and modified.

The principal purpose of the TUTKA tool is to assess an existing production system in order to identify its strengths and its potential and means for improvement. This purpose is indicated in the objectives of the study, and the assessment process is described and demonstrated in Chapter 6. In addition to assessing existing production systems, the TUTKA tool can be used during the design of a new production system. In this case, the assessment tool and the set of key characteristics of a well-performing production system can provide valuable guidelines and objectives for the design process, and the tool can be used in evaluating alternative options or decisions made during the process. Use of the tool in this way is potentially highly advantageous, but testing it for this purpose was, unfortunately, not possible during this study. The main reasons for this were that the design and building process of a production system requires a relatively long time frame and, due to the planned schedule, testing of the tool had to be carried out within a short period. Furthermore, due to the economic situation at the time of the study, few possibilities for such testing were available.

The TUTKA tool enables either self-assessment or facilitated assessment process. In self-assessment, the target company uses the assessment tool unassisted, whereas the facilitated process is guided and facilitated by an external person. The facilitated process reduces the amount of input required from the target company because the analysis of collected information and the summary of the results are conducted by the facilitator. Based on his or her experience and knowledge, the facilitator may also be able to provide useful information and practical insights related to the assessment results, for example with regard to identified improvement potential. Therefore the facilitated assessment process is recommended. The facilitated assessment process was tested and carried out in all of the pilot cases and the author of this study acted as the facilitator.

Finally, the assessment process can be modified and tailored. The assessment questionnaire consists of three sets of questions that enable either a more detailed or a more general-level and quicker assessment, as well as inclusion or exclusion of the production system adaptability perspective. Furthermore, the structure of the set of key characteristics enables the assessment of only certain key characteristics or decision areas, and these can be identified and selected in various ways, for example, based on identified improvement objectives. Finally, the assessment process can be carried out with one person or group from the target company, or by conducting separate assessment sessions for separate persons or groups. Results of separate assessment
sessions can, for example, initiate a fruitful discussion by revealing differences in perspectives of the persons or groups.

8.4. Potential users of the study results

The results of the study, i.e. the TUTKA tool and its parts, are argued to be beneficial to the following groups and users:

- Production companies, especially the target companies of the study and companies aiming to change their production approach to make-to-order or assemble-to-order
- Consultants focusing on production and production systems
- Researchers and academics in the field of production

The discussion on the potential users of the TUTKA tool is divided into three parts: firstly, the target companies of this study are considered, then other production company types are considered, and finally, the perspective of consultants and academics is discussed. The discussion on applicability of the results to different groups is related also to the ability to generalise and apply the results of the study in different contexts, and limitations related to this are also presented.

Target companies of the study

This study and its results are argued to be applicable to the target companies of the study, i.e. companies that operate on the basis of the make-to-order (MTO) or assemble-to-order (ATO) approach and produce capital goods that are configured on the basis of a customer order (for a detailed definition see Section 1.3.). The ability to generalise the findings of a research project from a sample to the target population is dependent on the sampling method used, and the use of probabilistic sampling methods that enable generalisation of the results using mathematical properties and methods is typically suggested (e.g., Royer & Zarlowski 2001, p. 148-149; Crouch & Housden 2003). However, in this study, a non-probabilistic sampling method was used, and therefore the applicability and usefulness of the results to the defined target group has to be reasoned on a different basis, by considering the development process.

The process of developing the TUTKA tool and the set of key characteristics of a well-performing production system was intended to ensure the applicability of the results to the target companies of the study (see Chapter 4). In developing the initial set of key characteristics of a well-performing production system based on a literature review, the aim was to identify such characteristics that can be applied by the companies considered. Then, the applicability and usefulness of the set of key characteristics to the target companies was evaluated and improved in an iterative process with the input of experts with profound experience in production, production systems. The assumption is that if the applicability and usefulness of a set of key characteristics are evaluated and information for modifying and improving them is collected until consensus is reached, the resulting set of key characteristics is very likely to be applicable and useful to the entire population, i.e. the target companies of this study. In this case, the principle of theoretical saturation was used to indicate that consensus had been reached. Then, because the TUTKA tool is based on the key characteristics, the applicability of the set of key characteristics contributes towards and ensures the applicability of the TUTKA tool to the target companies.

The pilot cases in which the TUTKA tool was used support the arguments presented above and demonstrate the applicability of the tool to the target companies of this study. The results of the pilot cases and the feedback from the participants showed that the TUTKA tool was applicable
and useful to the pilot companies (Section 7.3.). Based on this, it can be assumed that the TUTKA tool is applicable and useful also to other companies belonging to the target group of the study. This assumption is supported by Kasanen et al. (1993, p. 259-260), who state that “If, for instance, a working solution is produced to a management accounting problem of a firm, it is likely that this solution applies to other firms of the same type, too”. Furthermore, they also point out that “it is quite likely that a solution which works in one firm is useful in several other similar firms” (Kasanen et al. 1993, p. 261).

Other production companies

The results of the study are argued to be applicable and useful to companies aiming to implement a make-to-order or assemble-to-order production approach, but the applicability to other companies not belonging to the target group of the study is considered limited. This can be explained and reasoned based on the process of developing the TUTKA tool and the observations made during that process.

The TUTKA tool and the key characteristics of a well-performing production system included in it have been argued and reasoned to be applicable and useful to companies operating on the basis of a make-to-order or assemble-to-order approach. Additionally, the tool is seen to be applicable and useful, and the key characteristics able to provide useful guidelines and ideas for designing and organising a production system, also for companies aiming to implement these production approaches. Thus, such companies are also potential users of the results of this study. This argument is supported by pilot cases E and F, in which improvement potential and ideas related to changing the production approach from engineer-to-order towards make- or assemble-to-order were identified.

Apart from companies aiming to implement a make-to-order (MTO) or assemble-to-order (ATO) production approach, the usefulness and applicability of the TUTKA tool to companies not belonging to the target group of the study, i.e. possibility to generalise the results in other contexts, may be limited. This results from the approach adopted and the decisions made in developing the tool. Rather than aiming to develop an industry- or company-generic assessment tool, the aim of the study was to develop a tool that is applicable and useful to a clearly defined industry sector and company type. The effects of this decision and limitations related to the applicability and usefulness of the results of the study have been noticed also in the interviews and in the pilot cases. Four persons from subcontracting companies not belonging to the target companies of the study participated in the evaluation of the set of key characteristics of a well-performing production system, and considered the applicability and usefulness to their own companies limited. Due to the subcontractors’ limited responsibility for the design of the parts and products produced and supplied to the main company, product architecture characteristics were not seen to be relevant or useful to them. In addition, due to the broad product variety resulting from serving several main companies, a functional layout was considered the more suitable than a product-based layout emphasised in the TUTKA tool. Furthermore, pilot cases D and F indicated that engineer-to-order (ETO) approach has an effect on applicability and usefulness of the TUTKA tool and assessment results, and that ETO companies may find the assessment and its results less useful than the target companies of the study. As an example, often in ETO approach product variety is broader and production volume for a given product is lower than in MTO or ATO approaches. For this reason, ETO companies may find, for example, production flexibility and functional layout more relevant and important than characteristics related to production efficiency and product-based layout included in the TUTKA tool.

Thus, the production approach and the role of a company in a production network have an effect on the applicability and usefulness of the results of this study. This, however, was expected and is the result of the decisions made during the design and progress of the study. The decision to
focus on a certain industry sector and company type is nevertheless considered important and beneficial. A typical drawback related to the alternative option of developing industry- or company-generic tools is that the tools and the characteristics or practices included in them remain at a rather general level, which reduces their usefulness in improving production (Muda & Hendry 2002a, p. 295). Hence, the decision to limit the target group is seen as an enabler and prerequisite for developing a production system assessment tool that is applicable to these companies and that provides sufficiently detailed and practical advice for improving their production systems.

**Consultants, researchers and academics in the field of production and production systems**

In addition to production companies, the results of the study are argued to be useful to consultants, researchers and academics working in the field of production and production systems. The ways and purposes of using the results include practical production system improvement processes or research work.

Use of the TUTKA tool, for example in assessing an existing production system, can be facilitated by any external person who has a good knowledge and understanding of the tool and its use. Hence, for example consultants or researchers can serve as the assessment process facilitators, which makes the tool useful also to them. This is indicated and supported by the willingness of the consultants to use the developed TUTKA production system assessment tool in their own companies and with their customers (Appendix 8, Section 7.7.).

This study and its results are also expected to be beneficial to researchers and academics in the field of production and production systems research. For example, identifying and developing the key characteristics of a well-performing production system involved a thorough literature review covering production strategy and production paradigms such as lean production, agile manufacturing and mass customization, interviews and evaluation with professionals, and production system observations. The resulting set of key characteristics thus combines practical and theoretical perspectives and information and is seen to provide useful basis and input for further research on design, operation and improvement of production systems and processes.

**8.5. Directions for further research**

Directions for further research focus on further developing and improving the TUTKA tool and can be summarised as follows:

- Inclusion of production strategy and strategic level decisions into the production system assessment tool and process
- Developing the tool to cover production networks
- Extending the tool to cover the entire production system improvement process
- Increasing the level of detail of the production system assessment tool and process
- Inclusion of new aspects and paradigms of production and production systems into the tool
- Developing a workbook to support using the tool

The first potential direction for further research relates to company and production strategy. Discussion related to these aspects (Section 2.1) focused on identifying the strategic decisions and objectives relevant and useful for the target companies of this study and on clarifying the strategic level decisions or assumptions on which the development of the TUTKA tool was based. Also, the importance of correspondence between the strategies, objectives and decisions at different levels was highlighted. However, production strategy or strategic decisions are not
included in the TUTKA tool or the related assessment process. Hence, including strategic aspects, e.g. decisions and objectives, in the assessment tool and process provides possibilities for further research and development. As an example, the further developed assessment tool and process could include assessment of whether production-related decisions correspond to and support the strategy and objectives of the company. Another interesting concept related to this direction of further research is strategic agility, which is related to a company’s ability to adapt to and prosper in a rapidly changing business environment. Doz and Kosonen (2009) emphasise the increasing importance of strategic agility and define it as “the ability to continuously adjust and adapt strategic direction in core business, as a function of strategic ambitions and changing circumstances, and create not just new product and services, but also new business models and innovative ways to create value for a company”. Long (2000, p. 39) provides a definition that is more closely related to production and its objectives and performance by stating that strategic agility can be described as “being able to produce the right products and services at the right place at the right time at the right price for the right customers”. To conclude, including strategy and strategic agility in the TUTKA tool would require significantly broadening the focus and scope of assessment, but could provide useful and interesting aspects to the assessment tool and process.

Furthermore, the scope of the TUTKA tool and the assessment process could be extended to cover a broader part of the production network. This study focused on a single company, the main contractor of a production network, but in addition to improving the company’s own production system and processes, the entire production network should be considered and improved. Some of the key characteristics included in the TUTKA tool can be applied to and considered in the context of a production network, but there is a clear need and potential to further develop the tool and to include new key characteristics that enable consideration of the entire production network.

The TUTKA tool, that currently focuses on the initial stages of the improvement process, i.e. assessing the current state and identifying the improvement potential of a production system, could also be further developed and extended to cover a broader part of the improvement process. Such development work could involve supplementing the TUTKA tool with additional tools, guidelines and examples that assist, firstly, in planning the changes and improvements, secondly in implementing them, and, finally, in standardising the improved status and performance of the production system.

In contrast to broadening the scope and focus of the assessment, further work can also be directed at increasing the level of detail of the TUTKA tool and the related production system assessment process. The current version of the tool is intended to provide a relatively quick overview of the current status of a production system. The level of detail could therefore be increased, for example, by including new key characteristics, by elaborating their definitions, or by adding new assessment methods and questions. This could be carried out either for the entire assessment tool or for a certain decision area included in the tool. As a result, the improved version of the TUTKA tool could provide more detailed and practical information and assistance for production system improvement.

Another way of further developing and improving the TUTKA tool involves including additional aspects and paradigms of production into the tool and the set of key characteristics of a well-performing production system. Although the literature reviews carried out during this study covered lean production, agile manufacturing and mass customization, the TUTKA tool could be developed further by identifying and adding new objectives, practices and characteristics of production and production systems from paradigms and aspects that have not been covered in detail. For example, sustainable production that considers the entire lifecycle of products and
production systems and covers several aspects of sustainability, such as societal, economical and ecological, could provide useful input and insights for further development of the TUTKA tool.

Finally, using the TUTKA tool could be made easier by developing a workbook that provides guidance on conducting an assessment process. In addition to providing an overview of the assessment process and describing the set of key characteristics, such a workbook should provide advice and guidelines on how each of the key characteristics is assessed or scored to a certain level on the assessment scale based on the responses to the questions and the additional information provided, and on summarising the assessment results and the suggestions for improvement. Such a workbook would be useful both in self-assessment and facilitated production system assessment.
9. Summary and conclusions

This study aimed at providing support and assistance to its target companies in improving their performance and competitiveness. More specifically, the focus was on production and production systems and the objective was to develop an assessment tool that enables assessment of the current state of a production system and identification of its potential and means for improvement. Mechanical engineering companies that produce customer-specific products on the basis of a make-to-order or assemble-to-order approach were considered and focused on, and the study and its results were required and intended to be useful and applicable to these companies.

The design science and constructive research approaches were followed and applied in the study, and in the development of a production system assessment tool, named TUTKA, and its three parts. Firstly, the set of key characteristics of a well-performing production system that provide the basis for the assessment tool and the assessment process were developed in an iterative process. The process involved identifying an initial set of key characteristics based on a literature review, and then evaluating and improving the set based on interviews, observation of production systems and literature. In the subsequent phases, the assessment methods and assessment scale were developed based on the set of key characteristics and a review of available tools and models for assessing and improving production. Then, in order to demonstrate the applicability of the developed tool, it was tested in six pilot cases. Furthermore, to provide information for evaluating the study and its results, feedback was collected from the pilot case participants and from consultants to whom the TUTKA tool and the related assessment process were presented.

The results and contribution of this study consist of the TUTKA production system assessment tool and its three parts: the set of key characteristics of a well-performing production system, the assessment scale, and the assessment methods. The pilot cases, and the feedback collected from the participants and consultants demonstrate that the TUTKA tool is applicable for assessing production systems, and enables identification of useful potential and means for improvement. Therefore, the objectives of this study and the requirements for the assessment tool have been achieved and fulfilled. Furthermore, the novelty of the tool from both the practical and theoretical perspective was demonstrated, and the study is seen to provide a useful contribution to practitioners and researchers in the field of production and production systems.

The TUTKA tool and the set of key characteristics of a well-performing production system are considered applicable and beneficial to the target companies of this study, and the tool can be used for improving an existing production system or for designing a new production system. The applicability and usefulness of the TUTKA tool in production system assessment and improvement was demonstrated by pilot cases and feedback received from them. The developed assessment tool is also considered to be a useful instrument for consultants, whom can serve as the facilitator of the production system assessment process. Furthermore, the process of developing the set of key characteristics involved a comprehensive literature review, theme interviews and observation of production systems, and the results are considered useful for researchers working in the field of production and production systems. Finally, although the TUTKA tool and the key characteristics can provide useful guidance to all companies aiming to implement a make-to-order or assemble-to-order approach, the applicability and usefulness of the study’s results to companies not belonging to the target group of the study may be limited.
References


Appendices

APPENDIX 1. The sections, principles and breakdown points included in the SHEN model
APPENDIX 2. Categories and best practices included in the SCMAT tool
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APPENDIX 4. The assessment questionnaire included in the TUTKA tool
APPENDIX 5. Questionnaire used to collect feedback from the participants of the pilot cases
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APPENDIX 8. Feedback received from the consultants.
APPENDIX 9. Feedback and review reports of conference articles
APPENDIX 1. The sections, principles and breakdown points included in the SHEN model


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<th>Section 1: Generate enquiries/sales</th>
<th>Principle</th>
<th>Breakdown points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrate the functions of production and marketing</td>
<td>1. Initial understanding between production and marketing</td>
<td></td>
</tr>
<tr>
<td>production and marketing in all processes</td>
<td>2. Production and marketing functions work together in responding to customer enquiries</td>
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<tr>
<td></td>
<td>3. Having a systematic database system to enable MTO companies to respond to customer enquiries</td>
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<td></td>
<td>4. Achieve 50 per cent reduction in time to respond to customer enquiries</td>
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<td></td>
<td>5. Understanding its competitors and having a systematic method for calculating price and delivery lead-time (i.e. strike rate matrix)</td>
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<tr>
<td>Design for products, processes and improved supplier relationships</td>
<td>1. Train employees in understanding all the product specifications, product design rework and purchasing process/knowing their suppliers</td>
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<tr>
<td></td>
<td>2. Having a minimum number of parts, forgings or suppliers for each product</td>
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<td></td>
<td>3. Having a computerised design database with designs that can be altered for new orders and a direct computer link with the customer and the shop floor</td>
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<td></td>
<td>4. Achieve 50 per cent “repeat business” which makes it possible to establish partnerships with some of the suppliers</td>
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<tr>
<td></td>
<td>5. Achieve 80 per cent “repeat business”</td>
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<tr>
<td>Collaborate with customers</td>
<td>1. Company helping the customers define their current needs in the form of product specifications and design</td>
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<tr>
<td></td>
<td>2. Establish a personal relationship between employees and customers</td>
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<tr>
<td></td>
<td>3. Having good communication among employees, a common understanding of organisational objectives and customers’ current needs</td>
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<tr>
<td></td>
<td>4. Getting customer representatives on the project</td>
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<td></td>
<td>5. Helping the customers meet their goals, rather than providing customers’ wants</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Section 2: Operations and capacity</th>
<th>Principle</th>
<th>Breakdown points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplify the shop floor</td>
<td>1. Improve visibility, use simple storage systems to reduce search times</td>
<td></td>
</tr>
<tr>
<td>Improve scheduling and workload control to cut flow time</td>
<td>2. Improve locations of raw materials, WIP, etc., to cut distances for movement of materials and tools</td>
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<td></td>
<td>3. Train shop floor employees on the importance of using the storage systems and of taking responsibility for their own housekeeping</td>
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<tr>
<td></td>
<td>4. Implement housekeeping so that work areas are clean as well as ensuring that the storage systems are properly used</td>
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<td></td>
<td>5. The operator takes over his own housekeeping</td>
<td></td>
</tr>
<tr>
<td>Cut the start up/changeover time and improve preventive maintenance</td>
<td>1. Train associates in set-up/changeover reduction and basic preventive maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Achieving 10 per cent average reduction in set-up/changeover time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Operators can take over their own preventive maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Achieving 30 per cent average reduction in set-up/changeover time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Employees achieve 50 per cent reductions in set-up/changeover times across all processes</td>
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</tbody>
</table>
### Section 2: Operations and capacity (continued)

<table>
<thead>
<tr>
<th>Principle</th>
<th>Breakdown points</th>
</tr>
</thead>
</table>
| Improve information flow | 1. Job priorities are clearly understood by all and everyone is working to the same plan  
2. Having a systematic method to communicate the plan including manual systems such as a planning board or “work to lists” produced by an appropriate software package  
3. Office transactions, labour transactions cut by 25 per cent  
4. Internal transactions cut by 50 per cent and 80 per cent of external transactions are done by fax/Internet/EDI  
5. Internal transactions cut by 80 per cent and 99 per cent of external transactions are done by fax/Internet/EDI |

### Section 3: Human resources

<table>
<thead>
<tr>
<th>Principle</th>
<th>Breakdown points</th>
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</thead>
</table>
| Make essential improvements in skills and flexibility | 1. Implement a training programme for all associates to increase relevant skills  
2. 80 per cent of associates are flexible in appropriate skills and able to work on other machines when needed  
3. 99 per cent of associates are flexible in appropriate skills and able to work on other machines when needed  
4. Experts teach operators to do repairs; downtime cut by 50 per cent  
5. Operators become technicians; downtime cut by 80 per cent |
| Everybody involved in change and strategic planning – to achieve a unified purpose | 1. Encourage employees to make suggestions to improve the process  
2. Having strategic planning  
3. Sharing information and records with shop floor employees  
4. Systematic public recognition/celebration of achievement  
5. Variety of low-cost awards to both teams and individuals |

### Section 4: General continuous improvement

<table>
<thead>
<tr>
<th>Principle</th>
<th>Breakdown points</th>
</tr>
</thead>
</table>
| Improve quality and implement appropriate performance measures | 1. Practice the principles of quality  
2. Understanding (through training if necessary) in universal customer wants: speed, flexibility, quality or value (QSFV)  
3. QSFV are dominant performance measures  
4. Second order performance measures (e.g. labour productivity, variance) no longer managed  
5. Maintain a culture that supports continuous improvement in all processes |
| Gather customer feedback and benchmarking | 1. Gathering customer-satisfaction data, review complaints and make continuous improvement on products and services  
2. Gathering data on future customer needs  
3. Gathering competitive samples and best practice data  
4. All associates involved in customer/competitive best practice  
5. The company implement full-scale benchmarking for its processes |
| Promote/market/sell every improvement | 1. Having good advertisements with effective placing (newspaper, magazine, etc.) for the target customers  
2. Positive QSFV trends featured in selling, bids, proposals, ads  
3. Registration; certifications; local awards (ISO-9000, Ford Q1, state award)  
4. Other local/national/global awards  
5. Reverse marketing: out of strength, you choose whom you sell to |
## APPENDIX 2. Categories and best practices included in the SCMAT tool


<table>
<thead>
<tr>
<th>Category</th>
<th>Best practice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategy</strong></td>
<td>A clearly stated supply chain strategy exist</td>
</tr>
<tr>
<td></td>
<td>The strategy is customer focused</td>
</tr>
<tr>
<td></td>
<td>The supply chain strategy is aligned with each company’s strategy, vision and mission</td>
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<tr>
<td></td>
<td>The degree of collaboration in the supply chain is decided and based on analysis of factors such as strategic importance of product, availability of product and degree of customisation</td>
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<tr>
<td></td>
<td>Supply chain partners share risk, costs and rewards when improving supply chain performance, i.e. incentives are aligned</td>
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<tr>
<td></td>
<td>Processes, components and products are redesigned in collaboration with suppliers and customers (concurrent engineering)</td>
</tr>
<tr>
<td></td>
<td>All roles and responsibilities are clarified in the supply chain so that conflict is avoided</td>
</tr>
<tr>
<td></td>
<td>Roles and responsibilities and roles of each actor are distributed to optimise performance in the supply chain</td>
</tr>
<tr>
<td></td>
<td>Corporate Social Responsibility and Health Security and Environment issues are focused, i.e. the company strive to understand and respond to the expectations of all stakeholders in society</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>The supply chain has a strategic use of customer decoupling-point where products are designed for postponement and mass-customization</td>
</tr>
<tr>
<td></td>
<td>Planning, forecasting and replenishment are coordinated in the supply chain</td>
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<tr>
<td></td>
<td>Local control and management of production sites are integrated in the supply chain’s global control and management</td>
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<tr>
<td></td>
<td>The performance management system translates supply chain strategy into objectives, metrics, initiatives, and tasks customised to each group and individual in the supply chain</td>
</tr>
<tr>
<td></td>
<td>Key Performance Indicators address financial and non-financial perspectives, internal and external perspectives, and short-time and long-time perspectives (i.e. they are balanced)</td>
</tr>
<tr>
<td></td>
<td>Key Performance Indicators are automatically measured and reported in same format throughout the supply chain; providing consistency and comparability</td>
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<tr>
<td></td>
<td>Risk awareness (risk indicators, contracts, alternative suppliers or transporters etc) is an integrated part of supply chain management</td>
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<tr>
<td></td>
<td>Contingency plans for supply chain events exist</td>
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<tr>
<td></td>
<td>The supply chain has a holistic and visual representation (control model) of how production and logistic processes are conducted</td>
</tr>
<tr>
<td><strong>Processes</strong></td>
<td>There is a seamless ordering process from customer request to delivery of product</td>
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<tr>
<td></td>
<td>There is a seamless procurement process through integrated manufacturing and supplier relationships</td>
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<tr>
<td></td>
<td>There is a seamless planning processes performed by dedicated supply chain teams representing a cross-division of the supply chain</td>
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<tr>
<td></td>
<td>Key customer groups are continuously re-defined, profit-monitored and diversified according to product and service-level</td>
</tr>
<tr>
<td></td>
<td>Processes are standardised (defined, updated and documented) to enable plug and play connectivity between supply chain actors</td>
</tr>
<tr>
<td></td>
<td>Continuous and incremental improvement is focused and gives tangible results</td>
</tr>
<tr>
<td><strong>Resources</strong></td>
<td>The supply chain is continuously seeking and implementing leading production technology</td>
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<tr>
<td></td>
<td>The supply chain has a strong focus on core competences</td>
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<tr>
<td></td>
<td>The supply chain has a high utilisation of machines and facilities</td>
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<tr>
<td></td>
<td>The supply chain has a high utilisation of transportation vehicles and inventories</td>
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<tr>
<td></td>
<td>The supply chain has a high utilisation of personnel and waste is minimised</td>
</tr>
<tr>
<td></td>
<td>The supply chain can manage an unexpected large increase in demand (&gt; +20%) and deliver within agreed short-time delivery conditions</td>
</tr>
<tr>
<td>Category</td>
<td>Best practice</td>
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<tr>
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<tr>
<td>Materials</td>
<td>The flow of materials in supply chain is directed and well defined</td>
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<td></td>
<td>Distribution is optimised through route planning, cross-docking etc.</td>
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<td></td>
<td>Delivery of products and/or complementary services from different actors in the supply chain is synchronized to fulfil customer needs</td>
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<td></td>
<td>Products are modularised to improve flexibility</td>
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<tr>
<td></td>
<td>Inventories are minimised</td>
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<tr>
<td></td>
<td>A small inventory of key product components are kept to prevent manufacturing delays</td>
</tr>
<tr>
<td></td>
<td>Different supply chains are created for different product lines to optimise capabilities for each product line</td>
</tr>
<tr>
<td>Information</td>
<td>A supply chain ICT strategy is clearly stated</td>
</tr>
<tr>
<td></td>
<td>Information is collected, processed, visualised and presented in a centralised decision point (dashboard), to enable efficient decision making</td>
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<tr>
<td></td>
<td>Information is visualised in all processes, both value-adding and administrative</td>
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<tr>
<td></td>
<td>A system is implemented that provides all actors equal access to forecasts, inventory status, point-of-sales data and plans</td>
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<tr>
<td></td>
<td>Data capturing technologies and IT-systems facilitates decisions based on data and information that are in real-time</td>
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<tr>
<td></td>
<td>Bar codes, sensors and/or RFID are used for track and trace functionality throughout all supply chain processes (supply, manufacturing, distribution)</td>
</tr>
<tr>
<td></td>
<td>All supply chain actors’ ICT systems are integrated</td>
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<tr>
<td></td>
<td>ICT systems have modular standardised interfaces to provide connectivity through a plug and play functionality between actors in the network (creating virtual networks)</td>
</tr>
<tr>
<td>Organisation</td>
<td>Cross functional and inter-organisational teams are established to improve supply chain performance and eliminate the hand-offs across functional boundaries</td>
</tr>
<tr>
<td></td>
<td>Supply chain actors have flexible and empowered labour force trained to carry out different processes</td>
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<td></td>
<td>The supply chain actors have knowledge about advanced supply chain management tools and best practices and have good understanding of all supply chain processes and their interaction</td>
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<td></td>
<td>Best-in-class people possess the key positions for supply chain management</td>
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<td></td>
<td>There exist an healthy organisation culture supporting the overall supply chain strategy and stating “we’re all in this together”</td>
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</table>
APPENDIX 3. Sections, subsections and principles included in the LESAT tool


<table>
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<th><strong>Section I: Lean transformation / leadership</strong></th>
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<tbody>
<tr>
<td><strong>Subsection</strong></td>
<td><strong>Principles</strong></td>
</tr>
<tr>
<td>Enterprise strategic planning</td>
<td>Integration of lean in strategic planning process</td>
</tr>
<tr>
<td></td>
<td>Focus on customer value</td>
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<tr>
<td></td>
<td>Leveraging the extended enterprise</td>
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<tr>
<td>Adopt lean paradigm</td>
<td>Learning and education in “lean” for enterprise leaders</td>
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<td></td>
<td>Senior management commitment</td>
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<td></td>
<td>Lean enterprise vision</td>
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<td></td>
<td>A sense of urgency</td>
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<td>Focus on the value stream</td>
<td>Understanding current value stream</td>
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<td>Enterprise flow</td>
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<td></td>
<td>Designing future value stream</td>
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<td>Performance measures</td>
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<tr>
<td>Develop lean structure and behaviour</td>
<td>Enterprise organizational orientation</td>
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<td>Relationships based on mutual trust</td>
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<td>Open and timely communications</td>
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<td>Employee empowerment</td>
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<td>Incentive alignment</td>
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<td></td>
<td>Innovation encouragement</td>
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<td>Lean change agents</td>
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<tr>
<td>Create &amp; refine transformation plan</td>
<td>Enterprise-level lean transformation plan</td>
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<td></td>
<td>Commit resources for lean improvements</td>
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<td></td>
<td>Provide education and training</td>
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<tr>
<td>Implement lean initiatives</td>
<td>Development of detailed plans based on enterprise plan</td>
</tr>
<tr>
<td></td>
<td>Tracking detailed implementation</td>
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<tr>
<td>Focus on continuous improvement</td>
<td>Structured continuous improvement processes</td>
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<tr>
<td></td>
<td>Monitoring lean progress</td>
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<td></td>
<td>Nurturing the process</td>
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<td>Capturing lessons learned</td>
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<td>Impacting enterprise strategic planning</td>
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<tr>
<th><strong>Section II: Life-cycle processes</strong></th>
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<tbody>
<tr>
<td><strong>Subsection</strong></td>
<td><strong>Principles</strong></td>
</tr>
<tr>
<td>Business acquisition and program management</td>
<td>Leverage lean capability for business growth</td>
</tr>
<tr>
<td></td>
<td>Optimize the capability and utilization of assets</td>
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<tr>
<td></td>
<td>Provide capability to manage risk, cost, schedule and performance</td>
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<td></td>
<td>Allocate resources for program development efforts</td>
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<tr>
<td>Requirements definition</td>
<td>Establish a requirements definition process to optimize lifecycle value</td>
</tr>
<tr>
<td></td>
<td>Utilize data from the extended enterprise to optimize future requirements definitions</td>
</tr>
<tr>
<td>Develop product and process</td>
<td>Incorporate customer value into design of products and processes</td>
</tr>
<tr>
<td></td>
<td>Incorporate downstream stakeholder values into products and processes</td>
</tr>
<tr>
<td></td>
<td>Integrate product and process development</td>
</tr>
<tr>
<td>Manage supply chain</td>
<td>Define and develop supplier network</td>
</tr>
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<td></td>
<td>Optimize network-wide performance</td>
</tr>
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<td></td>
<td>Foster innovation and knowledge-sharing throughout the supplier network</td>
</tr>
<tr>
<td>Produce product</td>
<td>Utilize production knowledge and capabilities for competitive advantage</td>
</tr>
<tr>
<td></td>
<td>Establish and maintain a lean production system</td>
</tr>
<tr>
<td>Distribute and service product</td>
<td>Align sales and marketing to production</td>
</tr>
<tr>
<td></td>
<td>Distribute product in lean fashion</td>
</tr>
<tr>
<td></td>
<td>Enhance value of delivered products and services to customers and the enterprise</td>
</tr>
<tr>
<td></td>
<td>Provide post delivery service, support and sustainability</td>
</tr>
<tr>
<td>Subsection</td>
<td>Principles</td>
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<tr>
<td>Lean organizational enablers</td>
<td>Financial system supports lean transformation</td>
</tr>
<tr>
<td></td>
<td>Enterprise stakeholders pull required financial information</td>
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<tr>
<td></td>
<td>Promulgate the learning organization</td>
</tr>
<tr>
<td></td>
<td>Enable the lean enterprise with information systems and tools</td>
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<td></td>
<td>Integration of environmental protection, health and safety into the business</td>
</tr>
<tr>
<td>Lean process enablers</td>
<td>Process standardization</td>
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<td>Common tools and systems</td>
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<td>Variation reduction</td>
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</table>
APPENDIX 4. The assessment questionnaire included in the TUTKA tool

The questions for each key characteristic of well-performing production system are presented in the following way:

**Key characteristic of well-performing production system**

Q1: General level question or claim related to realisation of the key characteristic (question set 1)
Q2.X: Detailed question(s) related to realisation of the key characteristic (question set 2)
Q3.X: Question(s) related to adaptability of production system (question set 3)

**PRODUCT ARCHITECTURE DECISION AREA**

**Product architecture is modular**

Q1: Products consist of building blocks (modules) that have specified interfaces

Q2.1: The interfaces of the modules enable interchangeability, i.e. changing a module or its functions or features in such a way that the change does not affect other modules of the product

Q2.2: Building blocks (modules) of a product can be tested separately before assembling the product

Q3.1: Modular product architecture and specified interfaces of modules enable introducing and adding new functions and features to current modules

Q3.2: Modular product architecture and specified interfaces of modules enable adding new modules to the product

Q3.3: Current modules can be used in new products

**Product platforms are used**

Q1: Products of a certain product family or a product model have a common entity (e.g. a subassembly or subassemblies) which is independent of the customer order

Q2.1: The production process of the product platform is standardised and the same process can be used for different products of the product family

Q3.1: New product variations or versions do not cause changes to the product platform, i.e. the functions and features of a product can be changed or added without changing the product platform

**Product structure consists of predefined parts and subassemblies**

Q1: Customer-specific product consists of predefined parts and subassemblies

Q2.1: Product variety offered to customers is clearly predefined

Q2.2: Customer-specific product variant can be defined and customised based on the customer order without product design (i.e. only selecting the required predefined parts and subassemblies is required)

Q2.3: Compatibility of and interaction between parts used in products are known

Q3.1: Available predefined parts and subassemblies enable broader product variety than is currently offered to customers (i.e. product variety can be increased by combining available predefined parts and subassemblies in a new way)

Q3.2: The effects of and changes required by new or modified parts and subassemblies to the resources of the production system (equipment, tools, personnel and skills) can be identified before starting production of the new or modified parts and subassemblies

**Levels in product structure simplify the structure of the production system and support production control**

Q1: The levels of product structure enable identifying building blocks or subassemblies of a product and using them in designing and managing the production system and in controlling production

Q2.1: The levels of product structure (building blocks, subassemblies) enable correspondence between product structure and production system structure

Q2.2: The levels of product structure simplify production management by enabling procurement and production control at the level of subassemblies or building blocks (rather than at part level)

Q2.3: Product structure does not contain excess/unnecessary levels (i.e. all levels in the product structure are useful in terms of structuring and controlling the production system)

Q3: Level 4 is not assessed.
PRODUCTION SYSTEM STRUCTURE DECISION AREA

Production system consists of production units that are responsible for certain parts of a product
Q1: Production system consists of production units and each production unit is responsible for a certain entity or entities of products
   Q2.1: The product(s) of a production unit can be completed in the production unit
   Q2.2: Order impulse for a part or a subassembly can be addressed to only one production unit
   Q2.3: Production units enable a branch-type of production process, i.e. building blocks of a product can be produced in parallel in the production units
Q3.1: New parts and subassemblies that differ from current ones in terms of physical dimensions and characteristics (e.g. weight, size) can be handled and produced in production units
Q3.2: New equipment that is required by new features and functions of products can be added to production units without changing the unit structure of the production system
Q3.3: New production units that are required by parts and subassemblies of products can be added to the production system
Q3.4: Size and production volume of production units can be adjusted to meet changing volume and capacity requirements (e.g. increasing or reducing capacity and production volume).

Production system structure corresponds to the structure and production process of products
Q1: Production system structure corresponds to the structure and production process of products
   Q2.1: Production units are arranged and located based on the structure and production process of products
   Q2.2: Equipment is arranged and located based on the structure and production process of products
   Q2.3: Material flow is unidirectional
Q3.1: New production units can be added to the production system so that the correspondence between production system structure and the structure and production process of products is maintained
Q3.2: Equipment can be added to production units so that arrangement of equipment corresponds to the structure and production process of products

Distances between production units and distances between production equipment are short
Q1: Sequential production units and machines are arranged and located in close proximity to each other
   Q2.1: Short distances between production units and between machines enable and encourage production and transportation in small batches
Q3.1: Short distances between machines can be maintained even if new machines are added to production units
Q3.2: New production units can be added to the production system so that distances between production units remain short

Production system structure makes it possible to observe the state of and the prerequisites for production
Q1: Production system structure makes it possible to observe the state of production (e.g. capacity and loading of production units, meeting the production schedule) and the prerequisites for production (e.g. availability of materials)
   Q2.1: Layout of production system and arrangement of production units enable identifying material flow and phases of the production process
   Q2.2: Materials, parts and subassemblies (both incoming and outgoing) of each production unit have defined locations
   Q2.3: Required tools have defined and clearly marked locations in production units
Q3: Level 4 is not assessed.

Layout and organisation of workplaces eliminate non-value-adding work and support value-adding work
Q1: Required equipment, materials and tools are located in workplaces so that non-value-adding work is minimised and value-adding work is supported (e.g. ergonomic working positions)
   Q2.1: Workplaces contain only necessary and required materials, tools and equipment
   Q2.2: Tools and materials are located according to their use
   Q2.3: Locations of material and tools enable ergonomic working positions and working at correct height
   Q2.4: Locations of material and tools enable working without exerting undue force or stretch
   Q2.5: Need to move, lift or rotate materials, parts or products before or during the work task is minimised
   Q2.6: Operators’/employees’ need to move during the work task is minimised (e.g. possible to work in one place, eliminating need to pick up materials)
Q3.1: Ergonomic working positions can be maintained if new tools and materials are added to workplaces
Q3.2: New tools and materials can be located in workplaces according to their use
PRODUCTION PROCESSES AND MANAGEMENT DECISION AREA

Dissimilar main processes of production are identified and separated from each other
Q1: Different and dissimilar processes have been identified and separated from each other
  Q2.1: Different kinds of products (e.g. according to ABC-classification) are produced in separate processes
  Q2.2: Processes of assembled part production and spare part production are separated
Q3: Level 4 is not assessed.

Processes of production units are defined
Q1: Processes and tasks within production units are defined and described
  Q2.1: Definitions of processes and tasks include/cover:
    • required materials, tools and equipment
    • activities included in the process or task
    • correct and safe work procedures and issues related to occupational health and safety
    • order of processes and tasks
    • duration of (allowed time for) process or task
    • output of process or task (product drawings/pictures, required quality level etc.)
    • responsibilities and rights of production units
  Q2.2: Definitions and descriptions of processes and tasks ensure reliable material flow and output (ability to meet the requirements of the following unit/phase)
  Q2.3: Definitions of processes and tasks and their level of detail enable learning and improving performance in line with the learning/experience curve
  Q2.4: Defined processes enable systematic assessment and improvement of processes
  Q2.5: Definitions of processes and tasks support teaching and training of new employees
Q3.1: Defined processes enable changing processes and procedures in a controlled way
Q3.2: Definitions of processes can be easily adapted to meet new requirements and needs

Processes and procedures between production units are defined
Q1: Processes and procedures between production units are defined
  Q2.1: Material flow and material processes between production units are defined and definitions cover:
    • lead or delivery time of products
    • batch sizes of orders and production
    • locations where products are delivered and stored
  Q2.2: Information flow between production units is defined and definition covers:
    • communicating order and requirement information (when and how information is transferred)
    • communicating changes in order or product specification
    • communicating disturbances in production
Q3.1: Processes and procedures can be changed and new ones can be defined easily and effectively through cooperation between the production units

Plans and procedures for responding to production disruptions, problems and delays are in place
Q1: Disruptions, problems and delays in production are handled in a predefined way
  Q2.1: We have defined procedures for communicating production disruptions (communication paths and support staff)
  Q2.2: We have defined procedures for handling and resolving problems and disruptions in production
  Q2.3: We have defined procedures for identifying and removing root causes of problems and disruptions
  Q2.4: Resources (personnel, material, equipment) and prerequisites (e.g. substitutive resources, subcontractors) of production enable handling production during problems and disruptions
  Q2.5: Overtime work or extra shifts can be easily used to meet or catch up production schedule
  Q2.6: Time is reserved in production schedule for maintenance, catching delays etc.
Q3: Level 4 is not assessed.
Cost-efficient and flexible processes are combined by late-point differentiation and appropriate positioning of order penetration point

Q1: Standard and customer specific parts of production system and production processes have been identified
   Q2.1: Differentiation of products is delayed, i.e. customer-specific features and functions of a product are realised and created in the last parts of the production process
   Q2.2: Lead time of the customer-specific part of the production process is less than or equal to the required delivery time
   Q2.3: Standardisation and efficiency are emphasised in the standard part of production process
   Q2.4: Standard part of the production process can be controlled using stock-based control (order- or forecast-based control is not needed in standard part of the production process)
Q3.1: The customer-specific part of the production process allows producing wider product variety than is currently offered to customers
Q3.2: The customer-specific part of the production process can be easily changed or adapted to meet new requirements

Responsibility for production control is allocated to production units

Q1: Production units have, within certain limits, responsibility and ability to decide scheduling and control of production within the unit
   Q2.1: Production scheduling and control is divided into two levels:
      • Higher or general level is responsible for coordinating production units and generating overall delivery or production schedules
      • At lower level, production units are responsible for scheduling and controlling production at equipment level based on the overall delivery schedules
Q3.1: Current scheduling and control system can be used with broader than current product variety
Q3.2: Current scheduling and control system can be used for different (both higher and low) production volume
Q3.3: New production units can be added and included into the current scheduling and control system

Close cooperation between production units is supported and enabled

Q1: Cooperation between the production units which aims at improving the production system and its operation is supported and enabled
   Q2.1: There are clear customer-supplier relationships between production units
   Q2.2: Information flow and communication between production units is open and effective
Q3.1: Cooperation between production units simplifies and supports changes in product variety and/or production volume
PRODUCTION EQUIPMENT DECISION AREA

Production equipment fits the requirements of the products and processes and the objectives of production
Q1: Production equipment (machines, tools etc.) enables continuous production flow and production at a quantity and pace equal to customer demand
   Q2.1: Production equipment enables achieving quality standards and cost objectives
   Q2.2: Accuracy of production equipment enables producing products “complete at one go” (i.e. product is ready to be processed in the following step without finishing or corrective actions between phases)
   Q2.3: Production equipment enables producing the quantities required by customers
   Q2.4: Lot sizes are defined based on customer needs and orders (rather than on the basis of characteristics of equipment e.g. setup times or machine costs)
Q3.1: Production equipment enables producing broader than current product variety
Q3.2: Production equipment enables cost-efficient and profitable production of higher and/or lower than current production volumes

Changeover and set-up times of equipment are short
Q1: Short changeover and set-up times enable production in batch sizes that correspond to customer requirements and product structure (i.e. batch sizes do not depend on changeover and set-up times of equipment)
   Q2.1: Share of changeover and set-up times of production lead time is small
   Q2.2: Most set-up time is external time, i.e. set-up can be done while the machine is running
Q3: Level 4 is not assessed.

Production equipment enables integration and reduction of production phases
Q1: Production equipment enables integration and reduction of production phases
   Q2.1: Multifunctional equipment is used and/or machines are combined into entities that enable combining more than one production task or phase into one phase that can be completed without manual interruption
Q3: Level 4 is not assessed.

Production equipment is reliable and available for use
Q1: Production equipment is reliable and available for use when needed
   Q2.1: Breakdowns or malfunctions of equipment do not cause disturbances to production or decrease reliability of production and deliveries
   Q2.2: Breakdowns or malfunctions of equipment do not cause delays in the production process
   Q2.3: Production equipment has long time between failures
   Q2.4: Production equipment can be repaired quickly
   Q2.5: Production equipment are maintained based on a planned maintenance program
Q3: Level 4 is not assessed.

Production equipment is easy to use
Q1: Use of production equipment for daily tasks is easy and does not require recurrent learning or reading of manuals
   Q2.1: Easy-to-use equipment enables employees to operate multiple machines
   Q2.2: Ease of using the equipment minimises non-value-adding work and supports value-adding work
Q3: Level 4 is not assessed.

Production equipment supports occupational safety and ability to work
Q1: Production equipment ensures occupational safety and enables ergonomic working positions
   Q2.1: Production equipment enables ergonomic working positions (e.g. correct height, no need for excess stretch or force)
   Q2.2: Production equipment does not cause accidents or reduce ability to work
Q3: Level 4 is not assessed.

Value-adding work, transportation and handling are supported and simplified by appropriate tools and auxiliary devices
Q1: Value-adding work and required transportation and handling are supported and simplified by auxiliary devices
   Q2.1: Value-adding work is supported with auxiliary devices such as assembly and working stands, tables
   Q2.2: Transportation, moving and handling of parts and materials between and within manufacturing units and workplaces are simplified and supported with auxiliary devices such as conveyors and lifters
   Q2.3: Auxiliary devices enable and support ergonomic working positions
   Q2.4: Tools and devices used in handling and transportation enable and encourage using small batch sizes
Q3: Level 4 is not assessed.
INFORMATION AND COMMUNICATION DECISION AREA

Information and communication support and enable decision-making
Q1: Information and communication enable deciding (at all levels of the production system) what, when, where and how to produce.
   Q2.1: Production plan and schedule are available for all production units
   Q2.2: Communication and available information enable identifying and tracking the progress and status of products
   Q2.3: Communication and available information enable identifying and tracking the status of production units (load, adherence to production schedule etc.)
   Q2.4: Available information can be easily used and modified
   Q2.5: Excess or inadequate information does not complicate or delay decision making and using information
   Q2.6: Available information is timely and reliable
Q3.1: Usefulness and reliability of information can be ensured when production volume or product variety changes (e.g. methods of controlling and managing product data and changes in product specifications)

Information transfer and communication follow systematic and predefined principles and procedures
Q1: The defined procedures and principles of communication and information flow specify when, how, where and in what format information is provided and transferred
   Q2.1: Systems and methods for communication and information flow have been defined (how and in what form information is provided and transferred)
   Q2.2: Information needs and flows within the production system have been identified and defined (where information is needed and transferred)
   Q2.3: Definitions of communication and information flow cover
      - order and production schedule information to production units
      - required forecasts and foreknowledge of production plan or orders
      - status of production, especially disruptions
      - changes of order or product specification
Q3.1: Systematic communication and information flow enable controlled production ramp-up of new products
Q3.2: Principles and procedures of communication and information flow can be adapted and changed in a controlled way

Information and communication systems used in the production system are compatible and integrated
Q1: Information and communication systems used in the production system are compatible and integrated
   Q2.1: Compatible and integrated information and communication systems enable automatic information exchange and flow across the production system and between different information and communication systems used within the production system
   Q3.1: New information systems can be added to the information system architecture (e.g. interfaces enable adding new information systems and information exchange with new systems)

Information and communication systems are reliable and available for use
Q1: Information and communication systems are reliable and available for use when needed
   Q2.1: Malfunctions, failures and interruptions in use of information and communication systems do not cause disruptions to information flow
   Q2.2: Malfunctions, failures and interruptions in use of information and communication systems do not cause disruptions to production
   Q2.3: Time between failures and malfunctions is long
   Q2.4: Maintenance of information and communication systems is systematic and planned
Q3: Level 4 is not assessed.

Visual information and control systems are used in the production system
Q1: Observing the structure of the production system, production schedule and status of production are supported by means and systems of visual control
   Q2.1: Sequence of production phases and production process are clearly marked and displayed with help of visual means e.g. painting, colour or number codes and boards
   Q2.2: Means of visual communication and control (e.g. pull inventories, kanban cards, production schedule boards) enable identifying the production schedule and production order
   Q2.3: Correct inventory areas and places for materials, parts and subassemblies are clearly indicated
   Q2.4: Number of items in inventory areas can be identified without counting
   Q2.5: Means of visual information and control enable identifying and following correct and standard procedures and support occupational safety (e.g. pictures and presentations of procedures, safety signs and symbols)
Q3.1: Visual information and communication system can be easily expanded and extended to cover new resources and production units
HUMAN RESOURCES DECISION AREA

Teamwork and team organisation are used in production
Q1: Employees are organised into teams that operate the production units
   Q2.1: One team operates one or more production units of the production system
   Q2.2: Responsibility of the team and its operation/performance (e.g. meeting the production schedule) is defined and allocated to a certain member of the team
Q3.1: Skills and capabilities of teams enable producing broader than current product variety
Q3.2: Number of teams or number of members in teams can be adjusted according to changes in required product volume and capacity

Employees are cross-trained and skills of employees meet the requirements of work tasks and processes
Q1: Employees are cross-trained and skills of employees correspond to the requirements of products and production processes
   Q2.1: Skills of employees enable performing the tasks and processes in a correct way
   Q2.2: Employees are able to perform several tasks and work in several workplaces and/or operate several machines
   Q2.3: Cross-trained employees support and increase flexibility of production
Q3.1: Cross-trained employees and skills of employees enable producing products with new characteristics and features
Q3.2: We are able to identify the need for training and new skills of employees prior to a change (e.g. introducing new products or modifying the production system or process)

Personnel policy and arrangement of working time support operational flexibility and reliable deliveries
Q1: Personnel policy and arrangement of working time support operational flexibility and reliable deliveries
   Q2.1: Flexibility of working hours and/or arrangements for overtime work and extra shifts enable adjusting personnel capacity according to orders and required production volume
   Q2.2: Personnel resources can be adapted (added or reduced) according to changes in production volumes (e.g. with temporary staff)
Q3: Level 4 is not assessed.

Commitment to work and involvement in improving production system and production processes are promoted
Q1: Employee motivation and commitment to their work and its improvement are supported with incentive and initiative programs
   Q2.1: Incentive and award systems that support the desired actions of employees are in place
   Q2.2: Employees are encouraged and supported to improve their work tasks and the entire production system
   Q2.3: A defined and incentivised suggestion or initiative system is in place for employees
Q3.1: Pay, incentive and award systems can be easily adapted to meet new objectives (caused by changes in production volume or product variety)

Occupational safety and ability to work are emphasised and ensured
Q1: Occupational safety and ability to work are emphasised and ensured by monitoring, training, information, and protective equipment
   Q2.1: Employees are given training in correct working methods and positions and occupational safety
   Q2.2: Employees are provided with adequate protective equipment
   Q2.3: Occupational safety and ability to work are promoted e.g. by documenting and monitoring accidents and by displaying posters and notes that are related to occupational safety and ability to work
   Q2.4: We aim to seek and remove causes for accidents and reduced ability to work
Q3: Level 4 is not assessed.
APPENDIX 5. Questionnaire used to collect feedback from the participants of the pilot cases
(Translated by the author from the Finnish original.)

Name of pilot company

Tool for assessing the production system and identifying improvement potential

Feedback questionnaire related to the assessment process, assessment tool and the results of the assessment

Thank you for the opportunity to test the developed production system assessment tool in your company, and for the possibility to utilise the information collected and observations made in my doctoral thesis. I kindly request you to fill in the questionnaire below and to provide your feedback and opinions on the production system assessment tool, the assessment process and the results of the assessment. The questionnaire includes multiple-choice questions as well as open-ended questions. The responses will be used in evaluating the developed production system assessment tool and its usefulness. The responses can be connected to your company and to the assessment results. You are welcome to either fill in the questionnaire during the current session or to return it later using the enclosed envelope.

Multiple-choice questions

The following questions and claims relate to the developed production system assessment tool, the assessment process carried out in your company, and the results of the assessment. Select the alternative that best describes your view and opinion using the following scale and alternatives:

1. disagree, 2. partly disagree, 3. partly agree, 4. agree

1. The assessment approach (evaluating and assessing the characteristics of the production system) is well-suited for assessing the current state of the production system.
2. The results and observations of the assessment process provide a correct and realistic view of the current state and the improvement potential of the production system.
3. The assessment process and its results highlighted useful improvement potential and ideas for improving the production system.
4. I could recommend the production system assessment process and assessment tool to other companies belonging to the target group of this research project.*

* Brief definition of the target companies:
- Finnish mechanical engineering companies that produce customer-specific, configured capital goods
- Companies operating on the basis of a make-to-order or assemble-to-order approach
- Annual production volume in the region of hundreds or a few thousand

Open-ended questions

Question 1: Your opinion on the suitability and applicability of the production system assessment process and the assessment approach (comparing the characteristics of the production system with the key characteristics identified in the research project) for assessing the current state and identifying the improvement potential of a production system. E.g. does the assessment cover the relevant areas and characteristics of a production system, does it enable identification of essential and relevant improvement potential?

Question 2: Were the assessment process and its results useful in identifying the improvement potential of the production system and in improving the production system? Can the assessment process and its results be used in improving the production system and how?

Question 3: How would you compare the developed production system assessment tool, the assessment process and its results with other tools and models for assessing and improving production used in your company (e.g. performance measurement)? For example, differences between the tools or models, advantages, weaknesses, amount of work and effort required etc.

Question 4: Other comments, development ideas etc. related to the research project, the production system assessment tool or the assessment process.

Thank you for your time and co-operation,

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Tampere University of Technology
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040 512 1024
APPENDIX 6. Feedback received from pilot case participants

Multiple-choice questions:
1. The assessment approach (evaluating and assessing the characteristics of the production system) is well-suited to assessing the current state of the production system.
2. The results and observations of the assessment process provide a correct and realistic view of the current state and the improvement potential of the production system.
3. The assessment process and its results highlighted useful improvement potential and ideas for improving the production system.
4. I could recommend the production system assessment process and assessment tool to other companies belonging to the target group of this research project.

Answer options: 1. disagree, 2. partly disagree, 3. partly agree, 4. agree

Table 20 Responses to the multiple-choice questions

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<tr>
<th>Case A, respondent 1</th>
<th>Question 1</th>
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Open-ended questions:

**Question 1:** Your opinion on the suitability and applicability of the production system assessment process and the assessment approach (comparing the characteristics of the production system with the key characteristics identified in the research project) for assessing the current state and identifying the improvement potential of a production system. E.g. does the assessment cover the relevant areas and characteristics of a production system, does it enable identification of essential and relevant improvement potential?

Case A, respondent 1: Very extensive but naturally at the same time superficial/general level assessment, does not enable deep and detailed assessment

Case A, respondent 2: In my opinion, most important (current) areas and topics were taken up in the assessment

Case B, respondent 1: It was an ok system. Of course quite general-level/superficial, but understandable, because such a broad area is discussed. Quality issues and aspects could be considered more?

Case B, respondent 2: Is well suited and applicable for assessment as long as the respondent has a critical attitude and perspective towards the company and its operation. Improvement potential is highlighted and this can be considered and evaluated in more detail if needed. Effects of personnel should be emphasised more. Including productivity measures would also be good.

Case C: Covers all areas and aspects, but assessment should be carried out as an interview, because some questions require explanation to be understood and interpreted correctly. Relationships and dependencies between topics and areas (e.g. product – production system) are brought up well.

Case D: Our “ignorance” of products being produced makes assessing production difficult.

Case E, respondent 1: The assessment tool is well-suited and applicable for quick assessment of a production system and it covers the most important areas that have an effect on production.

Case E, respondent 2: Enables identification (of improvement potential). Questionnaire quite comprehensive, covers the basic issues.

Case F, respondent 1: Yes.
Case F, respondent 2: Enables identification of improvement potential surprisingly well.
**Question 2:** Were the assessment process and its results useful in identifying the improvement potential of the production system and in improving the production system? Can the assessment process and its results be used in improving the production system and how?

*Case A, respondent 1:* Backs up conceptions and opinions, and provided some good reminders related to the product architecture and structure. Certainly usable.

*Case A, respondent 2:* Were useful, most of them are already known and being improved => provides confidence that the right areas and issues are being improved

*Case B, respondent 1:* Results were useful but not very surprising. That is, most of the improvement needs and potential were known, but very good that they were brought up. Improvement potential was summarised well.

*Case B, respondent 2:* Results mainly useful. More detailed questions that enable better structuring of the problems highlighted need to be identified.

*Case C:* Were useful. Results can be used, although they didn’t highlight anything new, they show dependencies and relationships between issues and assist in prioritising objects and needs for improvement.

*Case D:* Can be used. Results should be used in layout planning.

*Case E, respondent 1:* The assessment process didn’t bring up anything new, because naturally we know the strengths and weaknesses of our production system in advance. My opinion is that the assessment tool can be better used in situations where there is a need to compare for example two systems that are previously unknown to the assessor.

*Case E, respondent 2:* The assessment tool summarises issues of the production system that the interviewees report and recognise. The result of the assessment and analysis can be considered as a summary of the strengths and weaknesses of the system. A checklist for improvement, does not identify new, unidentified weaknesses or deficiencies.

*Case F, respondent 1:* (Useful) In assessing and evaluating the applicability of the product to the current model of operations. For improving the order-delivery process.

*Case F, respondent 2:* The results were similar to what we have identified as central improvement needs and objects. Hopefully the results can be used, at least the issues can be presented further.

**Question 3:** How would you compare the developed production system assessment tool, the assessment process and its results with other tools and models for assessing and improving production used in your company (e.g. performance measurement)? For example, differences between the tools or models, advantages, weaknesses, amount of work and effort required etc.

*Case A, respondent 1:* The production system assessment tool examines the situation from a broader perspective rather than performance over a given period. Amount of effort required is small, but on the other hand the results are very much dependent on the persons carrying out the assessment.

*Case A, respondent 2:* The production system assessment tool examines and considers the potential and objects of improvement in more detail and with broader scope than for example an assessment using performance measures.

*Case B, respondent 1:* This (assessment tool) provides a more holistic perspective.

*Case B, respondent 2:* This assessment tool took a different perspective and in my opinion provides and can be used as a good, general, “umbrella model”. The results can be easily clarified and further evaluated with help of proven conventional tools.

*Case C:* Previous methods, e.g. performance measurement, show results only, not dependencies, relationships or priorities. The results and benefits provided by the assessment tool are very good compared to the time and effort used.

*Case D:* 

*Case E, respondent 1:* We don’t have any other assessment tools as comprehensive as this. Performance measures indicate a certain performance level of the production system, but don’t explain the reasons for the good or poor result.

*Case E, respondent 2:* We don’t have anything similar to this. We use different KPI’s as measures.

*Case F, respondent 1:* The tool developed by the research project is suitably quick and light/lean in terms of structure.

*Case F, respondent 2:* Differences and comparison between different assembly systems helped to clarify issues (e.g. requirements of the line assembly).
Question 4: Other comments, development ideas etc. related to the research project, the production system assessment tool or the assessment process.

Case A, respondent 1: How could the assessment be more objective? Use of performance measures? Repeatability?
Case A, respondent 2:

Case B, respondent 1: Good system. Causes you to consider issues and aspects in more detail.
Case B, respondent 2: Good. new perspective that can be improved and developed further and, in my opinion, also commercialised. A useful and necessary start to the improvement process in companies that are at the beginning of the process and tracking improvement.

Case C: Questions could be clarified a bit, but should always be supported by or complemented with discussion. The tool is a good basis for discussion, but not suitable for a separate questionnaire.

Case D: Introducing production to the researcher and making the researcher acquainted with production could be valuable and could be useful also to the research and the assessment.

Case E, respondent 1
Case E, respondent 2: In research, the assessment tool could be applied in comparing different kinds of systems, for identifying similarities, differences, success factors etc.

Case F, respondent 1
Case F, respondent 2
APPENDIX 7. Questionnaire for collecting feedback from the consultants
(Translated by the author from the Finnish original.)

Tool for assessing a production system and identifying improvement potential
Questionnaire related to the production system assessment tool developed as a doctoral research project.

Please answer the questions below and evaluate the production system assessment tool developed in the research project, its usefulness, its applicability for improving production, and the novelty of the developed tool. The researcher will use the responses in assessing and evaluating the research project and the developed production system assessment tool.

Applicability of the assessment tool for assessing and improving a production system; usefulness of the assessment tool:
Question 1: How would you evaluate the applicability of the developed production system assessment tool and the adopted assessment approach to assessing and improving production systems and production? How can the assessment tool be used in improving production and production systems?

Question 2: How would you evaluate the usefulness of the developed assessment tool in improving production and a production system? (e.g. Does the assessment cover relevant areas and topics, does it enable identification of useful improvement potential?)

Usefulness of the assessment tool for your company:
Question 3: How would you evaluate the usefulness of the developed assessment tool for your company and for your customers? How could the tool be used in your company?

Question 4: Would you be interested in applying and using the assessment tool in your company?

Comparing the developed assessment tool to other assessment and improvement tools and models; novelty of the developed assessment tool:
Question 5: How would you compare the developed assessment tool and the adopted assessment approach (comparing the characteristics of a production system) to available assessment and improvement tools and models? (e.g. Is the developed assessment tool different from available tools and models? How? Does the developed production system assessment tool provide something new to assessing and improving production systems and production? What?)

Other comments and ideas related to the research project or the developed assessment tool:

Thank you for your time and co-operation,

Mikko Koho
Researcher, M.Sc (eng.)
Tampere University of Technology, Department of Production Engineering
mikko.koho@tut.fi
040 512 1024
APPENDIX 8. Feedback received from the consultants.
(Translated by the author from the Finnish original.)

**Question 1:** How would you evaluate the applicability of the developed production system assessment tool and the adopted assessment approach to assessing and improving production systems and production? How can the assessment tool be used in improving production and production systems?

**Forte Engineering:** An overview of the production system is quick to conceive. Requires participants to put their mind to it, as well as proper guidance and introduction, but is worth doing. How are possibly contradictory answers interpreted? Areas of focus for improvement can be found. Themes are very important in my opinion. Improvement plans can presumably be simulated by changing and improving the targets for improvement and seeking new problems or bottlenecks (?)

**Swot Consulting Finland:** The assessment tool is used to assess and evaluate how well the characteristics of the assessed production system correspond to the identified best practices and principles of the production system for the defined type of business and operation. Hence, the developed tool is not (and is not intended to be) generally applicable and is meant to be used for defined companies. The applicability of the tool is naturally dependent on how well the best practices and principles of the production system have been identified. In my opinion the tool is well-suited and applicable to assessing defined, key aspects of the Finnish export industry. According to my understanding, the tool can be used for inspection and evaluation of plans for new production systems and for identifying structural problems (=systemic causes of problems) of existing production systems.

**T2O Consulting:** The good thing about the tool is that it compares the products and production to an ideal factory concept. It identifies differences, shortcomings and improvement areas compared to an ideal set-up. The tool does not directly list identified problems or seek their root causes. I would suggest that the ideal factory concept could be developed to be more detailed and that an ideal concept for the products and production related to the target of the assessment could be developed prior to the assessment. The tool is useful and seems to be quick.

**Question 2:** How would you evaluate the usefulness of the developed assessment tool in improving production and a production system? (e.g. Does the assessment cover relevant areas and topics, does it enable identification of useful improvement potential?)

**Forte Engineering:** Cf. previous answer, areas of focus can be found and identified easily. Connections to sales, planning and product development need to be improved and strengthened, because most of the problems in production are caused by incomplete or delayed information.

**Swot Consulting Finland:** The tool covers the defined production system assessment well. The tool is not intended for assessing production operations and processes. This can be assumed to related to and caused by the identified best practices of operational processes of the selected research subjects (companies producing configured products based on orders). Assessing and considering information flow and communication and the OPP is, however, very close to processes. The tool is not intended to actually identify improvement opportunities (improvement potential) in the production system, because the assessment does not include performance measurement. Within the definitions and limitations made, the tool makes it possible to identify targets for improvement.

**T2O Consulting:** It mainly identifies areas of improvement, and further work is required to clarify the actual improvement potential and opportunities. It provides a good overview of the production system, which can be complemented with a limited and specified analysis and additional improvement tools.

**Question 3:** How would you evaluate the usefulness of the developed assessment tool for your company and for your customers? How could the tool be used in your company?

**Forte Engineering:** A quick analysis could be repeated at regular times or periods, or to assess and measure improvement efforts. What kinds of commensurable measures could be developed?

**Swot Consulting Finland:** The tool may well be useful for customers whose business idea corresponds to the research subjects and definitions of the research project. If the strategic decisions of the company are not clear, neither this nor any other tool will be able to provide additional value to the company. The tool could be used in inspecting and evaluating production system planning and for identifying the improvement potential of existing production systems in the preliminary phase.

**T2O Consulting:** We do not have a direct need for the assessment tool, since we have been developing such tools for different purposes for over ten years. Our tools combine experience, know-how, and best practices from Japan, USA and Europe as well as comparisons with tools of other consultants. We have our own data collected from over 200 machine and engineering companies. Porsche Zuffenhausen, Mori Seiki Chiba and Fanuc Fuji Complex have received the highest scores. Others are quite far behind. This does not mean that the tool you have developed is bad in any way. It is different and generic.
**Question 4:** Would you be interested in applying and using the assessment tool in your company?

**Forte Engineering:** As an improvement and design consultant I would use this tool as part of current state analysis.

**Swot Consulting Finland:** Yes.

**T2O Consulting:** We are ready and willing to use it and recommend it if the customers situation is such that an overview is needed and the company does not have prior experience of assessment.

**Question 5:** How would you compare the developed assessment tool and the adopted assessment approach (comparing the characteristics of a production system) to available assessment and improvement tools and models? (e.g. Is the developed assessment tool different from available tools and models? How? Does the developed production system assessment tool provide something new to assessing and improving production systems and production? What?)

**Forte Engineering:** I would consider its best feature to be its quickness and ability to create or provide an overview (themes). Improving essential details is likely to require additional tools or scaling the assessment and making it more detailed.

**Swot Consulting Finland:** Focusing on companies that have a typical approach and mode of operations for Finns and that are important to the Finnish export industry makes the tool different from other similar approaches. The assessment method as such cannot be said to significantly differ from available approaches. The assessment tool works as well and is as useful as the best practices and principles that provide the basis for the tool.

**T2O Consulting:** The method seems to be a typical question and assessment method in which the performance or object is compared to an ideal model. The fact that it focuses on the core product, production and know-how, and provides a fairly good overview of these, is different.

In my opinion your tool clearly has academic importance and significance.

**Other comments and ideas related to the research project or the developed assessment tool:**

**Forte Engineering:** Identification of improvement themes could be improved and strengthened. Input data from sales and planning/product design is also worth considering. Similarly, feedback from production. Could follow-up measures be developed and included in the tool? The needs of different interest groups need to be taken into account in the measures and in evaluating the effects of actions. Similarly, estimation of the effects of quick actions and actions requiring resource planning would be of interest. Usually, simply identifying and acknowledging the current state often results in the first steps towards improvement.

**T2O Consulting:** Analytical comparison to other analysis and benchmarking methods of production based on literature and internet information by the researcher would be desirable in the dissertation. Detailed comparison may be impossible, since no one wants to reveal their own tools.
APPENDIX 9. Feedback and review reports of conference articles


<table>
<thead>
<tr>
<th>Paper Number:</th>
<th>CARV07 - 101</th>
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<tbody>
<tr>
<td>Author(s):</td>
<td>M. Koho, S. Torvinen</td>
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<tr>
<td>Title:</td>
<td>Framework for Evaluating and Improving Manufacturing Systems</td>
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**GENERAL QUESTIONS**

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**SCIENTIFIC CONTRIBUTION & CLARITY**

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**OVERALL RECOMMENDATION:**

- Accept paper with no changes: ☒
- Accept paper after major changes: ☐
- Accept paper after minor changes: ☐
- Reject paper: ☐

Comments to Author(s):
### Paper Review Form

**Paper Number:** CARV07-104

**Authors:** H. Keled, S. Torvinen

**Title:** Framework for Evaluating and Improving Manufacturing Systems

### General Questions

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### Scientific Contribution & Clarity

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### Overall Recommendation:

- Accept paper with no changes ☑
- Accept paper after major changes ☑
- Accept paper after minor changes ☑
- Reject paper ☑

**Comments to Author(s):**

"Good framework, but lesser content. I apply it in industry. A recommended."
**ICMR2007: – Referee Report Form**

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<th>PROPOSING A NEW SCALE FOR ASSESSING MANUFACTURING SYSTEMS</th>
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<tr>
<td>Authors</td>
<td>Mikko Koho¹, Seppo Torvinen²</td>
</tr>
<tr>
<td>Paper Ref. No</td>
<td>DMU10</td>
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**OVERALL RECOMMENDATION**

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<th>Accepted with major revision</th>
<th>Rejected</th>
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**COMMENTS**

It is interesting paper and nicely written. But the framework need to be validated not necessarily for the conference but it could be for future work.

Dear Mikko Koho

We are happy to inform you that your paper entitled "A new tool for assessing make-to-order production systems", submitted to SPS'08, has been accepted for presentation and inclusion in the proceedings.

Below, you will find attached the reports of the reviewers.
Please consider the reviewers' comments carefully when preparing the final version of your paper.

===================================== 
Reviewer: 1
Relevance to Symposium : Strong Accept
Contributions : Accept
Originality of the results : Accept
Methodology : Accept
Practical results : Weak Accept
Presentation : Weak Accept
Language : Strong Accept

Summary: This is a very interesting attempt to create (yet another) assessment tool for improving production systems.

Details: The work behind the paper is a well performed and interesting development effort. The presentation is a bit laborious and repetitious and would gain in reader interest if the repeated explanations of what the work consists of were replaced by more details of the content of the work. Nevertheless it belongs to the conference and will surely meet its audience.

===================================== 
Reviewer: 2
Relevance to Symposium : Strong Accept
Contributions : Weak Accept
Originality of the results : Accept
Methodology : Accept
Practical results : Weak Accept
Presentation : Strong Accept
Language : Accept

Summary: It's a good article, based on a well performed research project. It could however be shorter in the introduction where things are repeated several times and more detailed in the end where the rationale for selecting the different key characteristics is omitted (there is ref to another paper though). The practical use of the tool is yet to be proved.
The language and structure of the article is good. No revisions are needed for acceptance.

Details: The assessment tool has not been tested yet, and it is quite possible that the tool will just diminish without leading to any positive results in the make-to-order manufacturing industry. The impact will depend upon if and how the tool will be marketed. It is a huge difference between having companies to agree upon the benefit of a new tool during an interview and the companies actually using the tool actively by themselves.