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Procedia Manufacturing 38 (2019) 1417–1426

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland.

Assessing the maturity and benefits of digital extended enterprise

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Abstract

Enhancing productivity is a challenge for a whole supply network rather than for a set of separate manufacturing companies. Hence, the concept of Digital Extended Enterprise (DEXTER), a highly competitive manufacturing network, was synthesized. For defining the constituent domains of digitalization, lean manufacturing and extended enterprise, a set of DEXTER models were derived from the literature and the interviews of manufacturing companies. Furthermore, for characterizing the development levels of the particular areas of performance the presented research resulted a DEXTER maturity model. The maturity model comprises of five levels of maturity defined by 69 statements in the key performance areas (KPA): strategy, business model, processes, performance indicators, interfaces and information flow. Finally, the development of four industrial cases over the period of two years were assessed with the DEXTER maturity model and with the key performance indicators (KPI), such as reliability of deliveries and quality. By comparing the findings of the maturity and the KPIs of the case companies, we found that the qualitative and quantitative methods both indicate a leap in productivity. This observation was further reassured by studying the profitability and productivity of the case companies within the period of observation.

Keywords: Digitalisation, Extended Enterprise, Maturity, Productivity

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2351-9789
10.1016/j.promfg.2020.01.146

1. Introduction

This article describes the concept of Digital Extended Enterprise (DEXTER), a competitive form of substantially integrated manufacturing network and the assessment of the business effects of the concept. The concept was studied from a variety of viewpoints in order to attain scientific description, validity and verification to the concept. The first viewpoint was a literature review on the topic, a synthesis based on it, and the second viewpoint was provided by interviews in case companies. The synthesis was a DEXTER concept model, which was further redeveloped into a maturity model. Third viewpoint was a joint research and development project with a multi-case approach. The cases were assessed with a DEXTER maturity model. Finally, the DEXTER maturity model and the concept itself was verified and validated with the case descriptions and quantified information by companies.

The presented research was based on the combination of applying both qualitative and quantitative methods. Moreover, the research was a sequential mixed research, where the application of qualitative methods was dominant and it was followed by the utilization of quantitative assessment of collected data [1]. The characteristics of action research approach were present as the research was done with a close collaboration by five industrial companies and researchers from two institutes. The research approach was based on quantifying qualitative statements on the maturity of key performance areas and studying few quantitative key performance indicators (KPI). The development cases of the companies provided the material for validating and verifying the presented research. However, the research contained also a literature study on the foundations of DEXTER.

The result of the research is a DEXTER model comprising of the DEXTER concept and maturity models. There is a reason to believe that the model is a viable option for studying and assessing the development needs and activities of manufacturing network. Along with KPIs, manufacturing companies can use the model in the planning of the development projects, monitoring the supply networks of the companies and setting goals for the collaborative development initiatives.

The paper is structured so that there is a brief version of literature review and the description of research methods and materials, the content of the DEXTER models and outline the use of the maturity model. Finally, the paper presents the case studies and the test of the model in the assessment of the cases and quantified results of the progress of the companies through the 2-year period. These findings are analyzed and the comparison of information from different sources provided. The article ends up with the conclusions and discussion on the future use of the DEXTER models.

2. Literature on Digital Extended Enterprise

In this section we briefly outline the current state of the art in research on Extended Enterprise and Digitalization. Also, we summarize the findings on few statements and questions that have guided our research project.

2.1. Extended Enterprise

Extended Enterprise (EE) was probably first adopted by big American corporations, such as Chrysler and IBM in the 1990's. The objectives of EE are persistent and distinctive operational transformations that will lead to a set of benefits beyond the results of traditional technical or business process re-engineering cases [2]. According to Davis and Spekman [3] an EE is a collection of companies in the upstream and the downstream of the whole value chain. The aim of an EE is to maximize the effectiveness of product development, minimize total systems costs and improve quality and customer acceptance [4]. According to several authors [3] the approach of an EE requires:

- the adoption of an organizational strategy that aims at total optimization
- each partner focuses on the core competencies the partner has
- flexibility as well as deep and long-term collaboration between equal partners who trusts each another
- the linking of organizations in all the levels of hierarchies
- the long-term planning, i.e. strategy, culture, norms, expectations and understanding of an EE
- transformation from sequential approach to concurrency
- methods, business processes, and technologies that support activities cross-traditional boundaries.

As summary, the idea of an EE is to enhance and to optimize the operations of the whole supply chain with the aid of improved integration, communication and co-ordination abilities [2]. However, the collaboration and co-operation was not supposed to occur on the level of operative transactions only. Rather, the "*co-operation is defined as parties in an exchange relationship working together to reach a predetermined mutually beneficial goal*" [[4], p. 45], which can be achieved through strategic partnership as well as mutual exchange of financial and strategic information. In practise, the means of an EE are mechanisms that enable collaboration and communication between heterogeneous organizations and systems. Furthermore, conceptual and data models, organizational structures and processes and software technologies are needed for the planning and realization of an EE [7].

2.2. Digitalization

Browne et al. [2] emphasized the integration and communication aspects of an extended enterprise already in the 1990's. Ever since, the role of information technology (IT) as a means of business driver and the enabler of transformation has gained importance in traditional businesses and operations [8], [9]. IT is an integrative factor in the improvement of effectiveness and efficiency. The intangible investments, such as the digitalization and the development of knowledge, aim to improve the profitability of the companies' internal operations, which will improve efficiency. EE and digitalization enable innovations, because people with a different background and from different organizations can communicate and work together better [11]. An example of this is an intermediary virtual prototype [12].

Digitalization enhances transparency within and between organizations [13]. Social technologies to streamline communication and collaboration, as well as in the lowering of organizational barriers, make it possible to lower the limits of EE [14]. According to McKinsey's, 70% of the companies utilize social technologies and 90% of those companies have reported business benefits related to the use of social technologies.

However, the already existing IT systems of companies can be the enablers of transformation. For example, Pulkkinen et al. have claimed that the capturing, sharing and re-using of product related knowledge, information and data is one of the key enablers of business transformation towards systemic customization [15]. Furthermore, they have pointed out that the maturity on Product Lifecycle Management is an essential factor in the transformation, while defining re-usable assets requires proper organization, planning, documentation and structuring of product families and standard designs.

2.3. Summarizing literature: open questions

The contribution of literature to Digital Extended Enterprise is the set of definitions and requirements as well as the observations of benefits in very large companies, such as Chrysler Corporation and IBM. Digitalization is a modern concept that emphasizes the transformative potential of new technologies, but the existing IT systems and approaches can enable transformations, along with the new solutions such as social technologies.

Based on these findings, open questions on Digital Extended Enterprise arose:

1. What Key Performance Areas of Digital Extended Enterprise are relevant to industry and can the progress of an Extended Enterprise measured with the KPAs?
2. Is it possible to apply Digital Extended Enterprise with a manufacturing supply network formed mainly by SMEs producing low volumes of highly customized products?
3. Is it possible recognize the qualitative and quantitative business and manufacturing effects of utilizing Digital Extended Enterprise approach?

Even though there are several publications defining the EE and postulating the successful adoption of it, it is still questionable how to define the EE in the era of digitalization. In addition, the examples come from large companies, which is not the case with the majority of suppliers and customers. Thus, the first question is justified. Despite of the success in some cases, it is interesting if a whole set of supplying companies benefit from the Digital Extended Enterprise approach. In addition, the means of measuring transformative actions and success with Digital Extended Enterprise is still open even when the direct cause effect relation could not be defined. Therefore, it is justified to ask the second and the third questions.

3. Research approach, methods and progress

This paper is based on two-year co-innovation project: a research project on Digital Extended Enterprise and the set of networked company development projects on the same theme. The research project was planned and initiated after a longer internal research and development project with the original equipment manufacturer (OEM) of mineral crushing and screening equipment. The business context of the OEM Company is the low volume of the configured to order products that comprise of complex mechatronics and heavy machinery. The order book of the OEM Company was gradually rising throughout the 2018 and the turnover rose from approximately 550 million € to nearly 700 million € / quartile. The internal project had enhanced the internal maturity of product lifecycle management in the OEM Company (Pulkkinen et al. 2017). One of the objectives of the co-innovation project was to disseminate and to develop further the knowledge and the methods developed in the prior project. Another objective was to study the aspects of EE in the business context of companies and especially enhance the operation of the supply network.

The OEM Company organized a supply chain management (SCM) team, which defined the overall goals on throughput time and costs (by -15%), the improvement of the reliability of delivery times by 15% and higher quality as the generic key performance indicators (KPI) of Digital Extended Enterprise. In addition, the transparency of engineering changes was to be improved in the project. The team and the suppliers agreed upon such a clear and challenging targets in the percentages of KPIs that any traditional cost cutting approaches did not appear feasible. Thus, only collaborative approach became a suitable option and the team helped the suppliers to plan their development sub-projects.

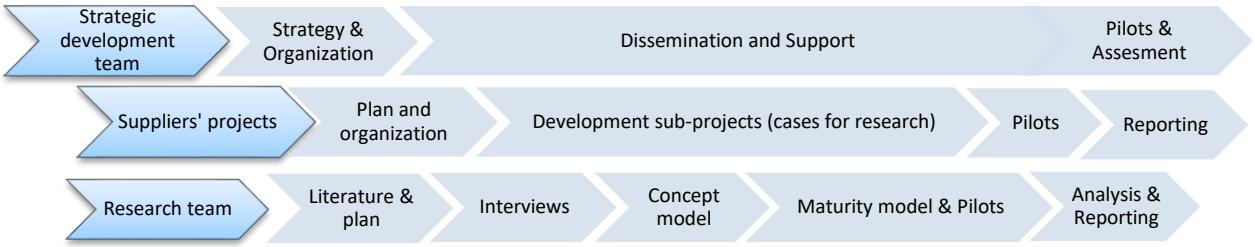

Figure 1. The sequence and concurrency of co-innovation project

During the project, the SCM team participated in the problem solving of the suppliers' sub-projects according to the strategy of the team (see Figure 1). This way the OEM coordinated the sub-projects indirectly and disseminated the pre-existing knowledge on the topics of production development, such as lean, six sigma, 5S and manufacturing execution systems (MES). In addition, the OEM Company attained knowledge on the situation of the suppliers at the same time. The strategic procurement development team visited suppliers' premises on monthly basis, on the average. The team became the key player in the Extended Enterprise and the whole project. The IT systems, such as ERP and Supply Management systems, of the OEM Company provided the KPI data. Therefore, the team was able to monitor the performance of the companies in respect with the KPIs.

Along with the planning and organization of suppliers' sub-projects, a research project was started with a scheme on DEXTER based on literature. This provided knowledge on the key performance areas (KPA) of an EE and digitalization, and aided in the formulating of questions for the initial interviews of companies. The interviews provided information on current state of the companies as well as gave the validation of KPAs of Digital Extended Enterprise. After the initial interviews, a concept model on the Digital Extended Enterprise was defined and further refined with the companies. Several versions of concept models and KPAs were formulated, which eventually led to a Digital Extended Enterprise Maturity Model. Again, the model was further refined mostly with the strategic procurement development team.

The collaboration between the OEM, suppliers as well as research team from two organizations was frequent. Apart from participating in the sub-projects, modelling and interviewing companies, the R&D consortium defined pilot projects on mutually relevant topics. These were the production control in a supply network, the engineering change management in a network, the use of virtual prototypes and enhanced 3D models and the effect of Digital Extended

Enterprise approach. Eventually, the consortium prepared assessment and reports of the experiences and methods as well as the effect of adopting Digital Extended Enterprise in the network.

The information on the development projects, the characteristics of Digital Extended Enterprise and its operation was being collected with a variety of methods and media. The interviews provided mostly qualitative information, such as development efforts within KPAs. The IT systems offered quantitative data for KPIs, such as reclamations per supplier in a month. The maturity model provided both qualitative information on the KPAs and quantitative data on KPIs. We consider this approach beneficial in validating and verifying the results of the co-innovation project.

4. Models on Digital Extended Enterprise

The first research question challenged us to seek out the definitions on Digital Extended Enterprise and to ground it to the practice of the companies. The models that first visualize the approach were chosen in order to enable discussion with practitioners. Second, the management of the development team requested the use of model to other purposes than just definitions. Thus, a variant of the model was defined for the purpose of assessment of companies. Due to the limitations of paper length, literature review and longer presentation on the DEXTER models is provided in another paper [16].

4.1. Concept model

The definitions of concept model included following KPAs: the strategy of extended enterprise, organizations, processes, supply network structure, business indicators, change management, products and services, IT as an enabler, information flows and interfaces. Researchers presented the concept model as a mind map diagram composed of all the KPAs, which the case companies found to be important in relation to the effectiveness of an Extended Enterprise network. The implications of practical aspects in each KPA were documented from each interview in the concept model. This served the development of the extended enterprise: the relevance of each domains was assessed and pilot projects were being derived on the basis of the concept model.

However, conducting interviews, documenting and assessing was tedious and time consuming. Moreover, the assessment was based on collecting opinions of the current state. It became evident that an extended enterprise needs a faster and more structured approach to discover the statuses and development targets within organizations.

4.2. The maturity model

For enhanced understanding of the state of an extended enterprise, a structured method for assessing the state of the KPAs of an EE was a needed. One should conduct the assessment with uniform measures and methods to collect equivalent information. This can ensure valid comparisons of the states of KPAs in different organizations and stages and the development of an EE could be monitored from a different viewpoint than only following the KPIs.

We developed several versions of the maturity model by the iterating the model with the SCM team. For the use of maturity model, we defined a questionnaire that contained questions in the following six main KPAs:

- Strategy
- Business Model
- Processes
- Performance indicators
- Interfaces
- Information flow

The model was set up in the Microsoft Form questionnaire with 76 questions and 69 of them were multiple-choice questions with five options. Generally, these five answers represent the maturity level on a scale of zero to four, four being the most developed or mature state. The maturity model was used for collecting information on the status of the companies both prior the project and at the latter stage of the project. Every company answered each questionnaire twice. Once considering the state of spring 2018 and once as to what the state was in the first quarter of the year 2016, i.e. in the beginning of the research and development project. Thus, the development of the companies concerning the KPAs of Digital Extended Enterprise could be assessed.

5. Results

In this section, the results from different sources of information are presented. The comparison of data from different sources is acknowledged, as the comparison and different sources provides more reliable understanding on the studied topic [1].

5.1. Case company reports

The companies were asked to summarize their development within the project. In general, the suppliers claimed that the project was fruitful as the results were good and the developed methods and IT would persist after the project. All the companies had developed the visualization and sharing of production information internally with manual methods and/or software.

Figure 2. The evolution of production control table (from left to right) during 2016-2018 [17]

This development can be exemplified with the evolution of production control table in one company (see Figure 2). The company first outlined the table with the aid of OEM development team (the leftmost picture in Figure 2). This was further developed according to the needs of workers and employees as presented in the middle of the Figure 3. Eventually, the company adopted a new ERP system that enabled corresponding visualization as can be seen in the rightmost picture of the Figure 2. The ERP the company had had before was not capable to visualize the situation in of production. Also, the latest version of the table could be shared with any other company, if agreed.

All of the supplying companies had Lean initiatives, such as 5S and enhancing of internal logistics and information flow. Two out of four suppliers developed also their external logistics and three companies took into use new information technology for production control. One supplier developed its own supply network with the methods disseminated by the OEM Company's SCM team and was able to reduce the throughput time from 42 days to 30 and eventually to 16 days. Another company reported 25% shorter throughput time. All the companies acknowledged improved engineering change notifications by the OEM. One supplier begun to deliver also problem reports for the ECM process of an OEM. One company defined and classified the production items according to demand, which enhanced the control of production. As the SCM team and suppliers collaborated, solutions to large number of the detailed problems, such as quality and delivery issues, were created within the project.

One might assume that all the development projects required extra effort and the hiring of new personnel, but the number of the personnel did not rise in general. On the average, the volume of production rose by one third during the period of observation. Even though the cost of steel rose by 40% during 2016-2018 in Europe, the profit of all companies increased. In fact, the productivity of the companies rose, because in proportion to the count of personnel the profit of the supplying companies rose by more than 100% in each of the supplying companies.

It is arguable, whether the improvement of productivity is due to the DEXTER or not, but the supplying companies did not run any other development initiatives during the period of observation. In addition, no business transactions that could have had an effect on the productivity emerged during the period. Naturally, the dynamic business environment kept changing throughout the period and the global markets of OEM were progressing. However, there is a reason to believe that without DEXTER the companies would not have been able to achieve higher volume, increased throughput and profit with same amount of resources.

5.2. The maturity assessment of Digital Extended Enterprise

The maturity data was exported from the Microsoft Forms to MS Excel where the statements of companies were transformed into quantitative data according to a coding in the five levels of maturity. In the coding, each statement or an answer to a question depicted a certain level of maturity in a KPA. The average values of levels describe the level of maturity within a KPA (see Table 1). In addition, the separate topics of KPA could be addressed. In such a way, it was possible to give both generic estimates and detailed assessment of maturity as a feedback.

Table 1. The average development of suppliers in respect to Key Performance Areas (most developed **KPAs highlighted**)

An example of a column heading	Year 2016	Year 208	Δ (2016-2018)
Processes (general)	1,3	1,8	0,5
Production and logistics processes	**1,3**	**2,6**	**1,3**
Engineering Change Management processes	1,3	2,2	0,9
Product Processes	1,4	2,0	0,6
Strategy	**1,2**	**2,6**	**1,4**
Leadership & Management	1,3	2,3	1,0
Metrics and evaluation	**1,2**	**2,6**	**1,4**
Interfaces	1,5	2,3	0,9
Information flow	1,7	2,1	0,4

As highlighted in the table 1, the supplying companies focused on strategy, production and logistics process as well as measuring and evaluating their performance. However, these areas were also least mature in the beginning and the overall maturity of the case companies was not very high in 2016. Instead, the information flow was at rather good level already in 2016 and was not addressed to the same extent.

Figure 3. An example of maturity visualization: the development of some topics in the *Processes* KPA

When considering the strategy of the whole EE, the companies considered the overall level of communication and collaboration rather good already in 2016. Probably due to this, the EE achieved rather limited progress on the matter and the overall strategy of an extended enterprise remained somewhat unclear. The organizations reported both high initial level and rather remarkable progress in the capability and motivation of developing their operations to meet changing requirements. The initial maturity of digitalization was weak, but the companies regarded a remarkable progress also in the capabilities related to the motivation and capabilities related to digitalization.

The maturity of processes rose especially in the engineering change management, which is not surprising because it was included in the project plan and collaboration and transparency on the matter was a topic of a pilot project. However, the companies did not improve much in the utilization of digital models, such as 3D product models. Obviously, this is due to the good level of already existing use of product models. For example, all the suppliers had a limited access to the PLM system of the OEM. The companies took a big leap in the mutual operations management and quality control as well as in the measuring of their own performance.

According to our model, the selected KPIs and the maturity of performance measurement rose remarkably during the project. For example, the companies were much more aware of item costs in the end of the project than before. In addition, the companies considered remarkable enhancement in the overall delivery capacity of the network, which had been rather poor before.

In general the company reports were rather similar than the maturity model, which is not surprising, because the source of the information is the same. However, the maturity model describes more about the means than the ends. Probably the most differing factor was the limited progress of information flow (according to the maturity model), while all the companies reported improvement in internal information flow in their own reports. The overall awareness of the company as a part of a network, even an extended enterprise was improved. This is hard to measure with the KPIs and in most cases it was not emphasized in the case reports either. Thus, collecting the feedback in the form of reports not only ascertained the findings but also brought new topics to be included in the maturity modelling and unforeseen aspects on the benefits of Digital Extended Enterprise. In addition, the aspects of satisfaction and future prospects were not taken into account in the maturity assessment, but they are viable options in the future

5.3. Key Performance Indicators generally and in each case

As mentioned, the OEM Company was able to monitor the performance of its suppliers. Some of that data is directly related to the KPIs. For example, the delays of the suppliers (see Figure 4) was easy to monitor and it indicated the performance of the supplying company's reliability of delivery time. As mentioned, the reclamations are another topic of the same kind indicating the quality performance of a supplier (see Figure 5).

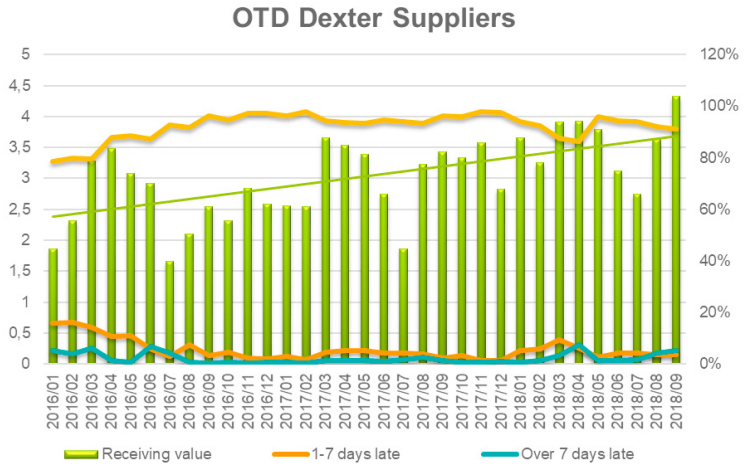

Figure 4. The development of on time deliveries (OTD) and received value for case suppliers over the course of project [18]

The Figure 4 illustrates the value creation (green bars) by the suppliers, the percentage of short delays of less than a week (orange thick lines) and the percentage of the long delays of week or longer (green thick line). The figure illustrates the lower values of delays in the end of the period under review (2 years), while there is a large fluctuation in the demand (received value). In addition, the KPI of quality indicated similar, positive development as the number of reclamations had halved in the average (see Figure 5).

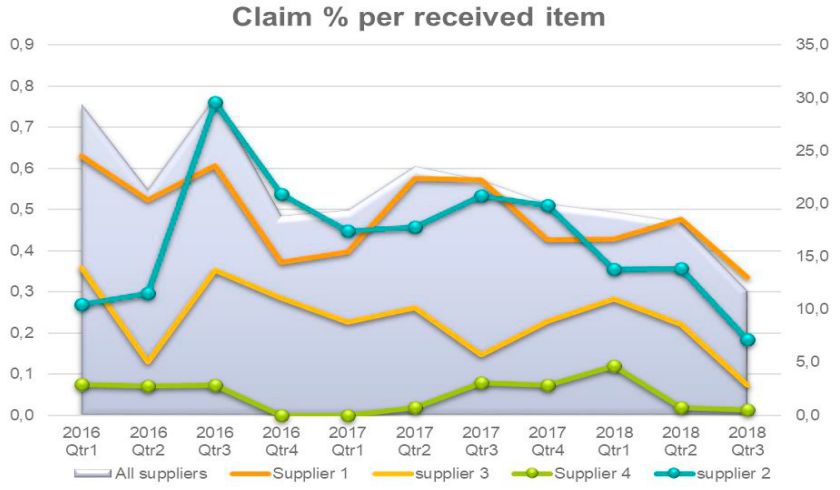

Figure 5. The development of suppliers' quality within the period of two years [18]

On top of the information gathered from the IT systems of the OEM Company, suppliers reported positive progress on e.g. throughput time by re-considering the stock values and positions in manufacturing processes. As it was in the case of maturity model, the feedback and reports of suppliers appeared to be a valuable addition to quantitative data collected by the OEM.

6. Conclusions

The concept and the embodiment of Digital Extended Enterprise was presented in order to answer research questions on the definition, application and effects of it in practice. The approach was to visualize and to model the concept for practitioners and put it in a test by gathering the comments, the situation of the companies and plausible development targets on the model. Along with the responses the aspects that are significant to the companies were highlighted and the importance of those Key Performance Areas that are essential were distilled. Thus, a subset of the definitions from literature became the embodiment of the concept. Furthermore, a maturity model was derived for the assessment of the adoption of Digital Extended Enterprise in practical development projects.

The business context, which differs from the literature, challenges academics and practitioners. The literature is based on large companies that produce high volume of rather similar products. The case of this research was different, but as successful as in literature. Thus, it is possible to apply Digital Extended Enterprise with a manufacturing supply network formed mainly by SMEs producing low volumes of highly customized products.

The effects of Digital Extended Enterprise are positive, as maturity assessment, company reports and KPIs appear to be aligned in most of the studied aspects. The benefits of Digital Extended Enterprise are the capability of producing parts and assemblies reliably while increasing productivity. The reliability was measured with time and quality in changing conditions, where new versions of items were being released frequently and market fluctuations make predictions challenging. This had to be done without the excessive increase of costs. Transparency, sharing of high quality information and collaboration are key topics that enable an EE. Instead of utilizing social technologies, new and agile versions of old IT systems, such as ERP, appear to be favorable.

Acknowledgements

We acknowledge the companies and their personnel for making this research possible. In addition, the funding by Business Finland (formerly known as Tekes, the national technology and innovation development center) was necessary for the project.

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