Tampere University

Samuli Kinnari

DEVELOPMENT OF ENGINE BLOCK MANUFACTURING OPERATING MODEL

Master's Thesis
Faculty of Engineering and Natural Sciences
Examiner: Professor Minna Lanz
Examiner: University Instructor Hasse Nylund
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ABSTRACT

Samuli Kinnari: Development of engine block manufacturing operating model
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Along with the move of Wärtsilä Finland Oy Vaasa area operations into the new Sustainable Technology Hub centre of product development and production, a new engine block manufacturing operation model regarding the casting and machining supply chain was needed to be developed. The model would need to enable successful operation in the changing context of the new *Flow* vision of manufacturing strategy, the new internal MTAC Large Component Manufacturing system capability, and the changing external supply chain operation environment, while pursuing overall business goals of improved lead time, total cost, and throughput.

To investigate, define and develop the new engine block manufacturing operating model, vast areas of interests would need to be covered. Many stakeholder functions should be consulted, and their potential contributions made use of. A common will amongst the stakeholders regarding the way of operating would need to be found. The specific development objectives and considerations would need to be identified and formed into a development plan, with a mapped scope of development work and defined steps of the development process to carry out.

To answer these needs, the thesis facilitated the starting phase of the development process. General meetings and a specifically structured workshop were arranged, to gain commitment and enable discussion of the starting point and the operating model's needs for development. Useful knowledge and insight regarding the development needs were documented, and the initial development process plan was produced. Practical cooperative development activities were carried out in group working sessions, utilizing established creative techniques chosen by literature review, leveraging the participating stakeholders' expertise. The needs for updating an existing out-of-date simulation model of the Wärtsilä internal manufacturing system were investigated, defined, and procured. The thesis results were gained via this multiple-research-methods approach.

The areas of interests, objectives, and general issues to consider during development, were mapped and identified as deemed relevant by the stakeholders via documentation of meeting discussions but mainly via the arranged workshop group working activity results. The identified matters were processed and formed into a Work Breakdown Structure, and later into an Activity Network Diagram, to define the needed preliminary development scope and steps. Group working sessions were facilitated regarding the prioritized machining model development stream. The machining model and its derived manufacturing process sequence for the MTAC Large CM system was preliminary defined. The simulation model was improved, and its structure and functionality updated accordingly, to match the up-to-date plans and process sequence for the manufacturing system. Literature review was carried out on the research approach related theory, and the used creative techniques. Also, on the design of manufacturing systems, pursued manufacturing process performance characteristics, relationships of process laws and factors, and the alternative approaches to process improvement regarding Lean and the Theory of Constraints.

The practical activities of the thesis process facilitated the initial phase of the development process for the new Flow Engine Block Manufacturing Operating Model. The thesis results provide an extensive description of the development needs identified by the stakeholders and the preliminary scope and steps defined for the development process. The new machining model development stream was put into motion, and via its results the machining model was preliminarily defined, enabling further definition of other operating model areas. The simulation model was updated to potentially work as an analysis tool for further decision making, regarding the machining models performance. The practical results of the thesis can be used as a starting point, and its researched theory as reference, and its descriptive findings as guideline, for carrying the operating model development process further in Wärtsilä's internal processes past the thesis scope.

Keywords: Operating model, Manufacturing, Machining, Supply Chain, Development, Design Framework, Process Improvement, Lean, Theory of Constraints, Focus Groups.

TIIVISTELMÄ

Samuli Kinnari: Moottorilohkojen valmistuksen toimintamallin kehitys
Diplomityö
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Wärtsilä Finland Oy:n Vaasan alueen toimintojen siirtyessä uuteen tuotekehityksen ja tuotannon keskukseen Sustainable Technology Hub:iin, syntyi tarve kehittää uusi moottorilohkojen valmistuksen toimintamalli, joka käsittäisi valamisen ja koneistamisen toimitusketjun. Toimintamallin tulisi mahdollistaa menestyksekäs toiminta uuden *Flow* -näkemyksen mukaisen valmistusstrategian, sisäisen MTAC Large Component Manufacturing -valmistusjärjestelmän kyvykkyyden, ja muuttuvan ulkoisen toimitusketjun operatiivisen ympäristön kontekstissa. Pyrkien samalla yleisten liiketoiminnallisten tavoitteiden saavuttamiseen koskien läpimenoaikaa, kokonaiskustannuksia, ja tuotantokykyä.

Moottorilohkojen valmistuksen toimintamallin tutkiminen, määrittäminen, ja kehittäminen edellyttää laajojen intressisalueiden kattamista. On konsultoitava monia sidosryhmätoimintoja ja hyödynnettävä heidän potentiaalisia kontribuutioita. Sidosryhmien yhteinen tahtotila koskien toimintatapoja tulisi löytää. Erityiset kehittämistavoitteet ja muut huomioitavat asiat tulisi tunnistaa ja muodostaa kehityssuunnitelmaksi, sisältäen kehitystyön kartoitetun laajuuden, ja kehitysprosessin määritetyt suoritettavat askeleet.

Vastatakseen näihin tarpeisiin, tutkielma fasilitoi kehitysprosessin aloitusvaiheen. Yleisiä tapaamisia ja yksi tarkoituksenmukaisesti suunniteltu työpaja järjestettiin, jotta saataisiin aikaan sitoutumista ja keskustelua kehityksen lähtökohdista ja toimintamallin kehittämistarpeista. Hyödyllistä tietoa ja näkemyksiä kehittämistarpeista dokumentoitiin, ja alustava kehitysprosessin suunnitelma luotiin. Käytännön yhteistoiminnallisia kehittämistoimenpiteitä toteutettiin ryhmätyöskentelysessioissa, hyödyntäen kirjallisuuskatsauksen perusteella valittuja vakiintuneita luovia tekniikoita, ja osallistuvien sidosryhmäläisten asiantuntijuutta. Wärtsilän uutta sisäistä valmistusjärjestelmää kuvaavan vanhentuneen simulaatiomallin kehitystarpeita tutkittiin, määritettiin, ja hankittiin. Tutkielman tulokset saatiin monitutkimusmenetelmällisen lähestymistavan kautta.

Sidosryhmien merkityksellisinä pitämät kehityksen intressialueet, kehityskohteet, ja yleiset huomioitavat asiat kartoitettiin. Osittain dokumentoimalla tapaamisissa käytyjä keskusteluja, mutta pääosin järjestetyn työpajan ryhmätyöskentelyaktiviteetin tuloksiin perustuen. Tunnistettuja asioita prosessoitiin ja niistä muodostettiin työnositus ja myöhemmin aktiviteettiverkkokaavio tarvittavan alustavan kehitystyön laajuuden ja prosessin askeleiden määrittämiseksi. Ryhmätyöskentelysessioita fasilitoitiin liittyen priorisoituun koneistusmallin kehitystoimiin, jonka myötä alustava koneistusmalli ja siitä johdettu valmistusprossisekvenssi MTAC Large CM -valmistusjärjestelmälle määritettiin. Simulaatiomallia paranneltiin ja sen rakennetta ja toiminnallisuutta päivitettiin vastaamaan sen hetkistä näkemystä valmistusjärjestelmästä ja -prosessisekvenssistä. Kirjallisuuskatsausta tehtiin tutkielman lähestymistapaan liittyvästä teoriasta, ja käytetyistä tekniikoista. Lisäksi käsiteltiin teoriaa liittyen valmistusjärjestelmien suunnitteluun, tavoiteltuihin prosessisuorituskyvyn piirteisiin, prosessilakien ja -tekijöiden välisiin suhteisiin, sekä Leanin ja Theory of Constraints:in vaihtoehtoisten jatkuvan prosessikehityksen lähestymistapoihin.

Tutkielman käytännön toimet fasilitoivat *Flow* -moottorilohkojen valmistuksen toimintamallin kehitysprosessin alkuvaiheen. Tuloksina tutkielma tuottaa kattavan kuvauksen sidosryhmien alustavasti tunnistamista kehitystarpeista, kartoitetusta kehityksen laajuudesta, ja määritetyistä kehitysprosessin askelista. Uuden koneistusmallin kehitystoimet käynnistettiin, ja sen tulosten myötä alustava koneistusmalli määritettiin, mahdollistaen muiden toimintamalllin alueiden tarkemman määrittelyn. Simulaatiomalli päivitettiin, jotta se voisi potentiaalisesti toimia analyysityökaluna päätöksen teon tukena, liittyen koneistusmallin suorituskykyyn. Tutkielman käytännön työn tuloksia voidaan hyödyntää jatkokehityksen lähtökohtana, käsiteltyä teoriaa suosituksina, ja kuvauksellisia löytöjä ohjenuorana, toimintamallin kehitysprosessia pidemmälle jatkettaessa Wärtsilän sisäisissä prosesseissa, tämän tutkielman laajuuden ulkopuolella.

Avainsanat: Toimintamalli, Valmistaminen, Koneistaminen, Toimitusketju, Kehittäminen, Kehitys Viitekehys, Prosessikehittäminen, Lean, Theory of Constraints, Ryhmähaastattelu.

PREFACE

This thesis is a result from the practical work that started in November 2019 and finished in June 2020, and from the writing process which for a very long time afterwards was set on hold, but which was finally finished now in October 2022.

I want to thank all participants from Wärtsilä Finland Oy, particularly Tero Kujamäki and Rami Hakala, for firstly providing the opportunity to carry out this thesis work, and for the further career opportunities continuing to this day.

I want to thank Hasse Nylund for acting as the university side supervisor for this thesis and for being a great teacher during the years of my studies at Tampere University.

Carrying out the thesis process was challenging, but also a great opportunity to learn, not only from the thesis topic itself, but from my personal strengths and weaknesses regarding my knowledge, skills, and ways of working. I can finish this thesis and my studies as a much wiser man, on my way to start the next chapter in my life.

I really want to thank my friends, family, and relatives who pushed me forward throughout my studies and the thesis process. I especially want to thank my girlfriend Vendi and our dog Harmi, for always being there to support me in the good times and the bad times, patiently waiting for me to stop sitting at the computer.

Vaasa, 29 October 2022

Samuli Kinnari

CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

3D	Three-dimensional presentation
5FS	Five Focusing Steps improvement method
AGV	Automated Guided Vehicle
AND	Activity Network Diagram
CAD	Computer-aided Design
CAM	Computer-aided Manufacturing
DCV	Delivery Centre Vaasa
EBMOM	Engine Block Manufacturing Operating Model
Flow	The title for a vision of manufacturing strategy defining the EBMOM
Large CM	Large Component Manufacturing
MDU	Machining Delivery Unit
MTAC	Manufacturing Technology Acceleration Centre
PMC	Portal Machining Center
R&D	Research and Development
ROI	Return On Investment
STH	Sustainable Technology Hub
TOC	Theory Of Constraints
VSM	Value Stream Mapping
WBS	Work Breakdown Structure
Wärtsilä	The customer company for the thesis

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1. INTRODUCTION

This thesis is written for Wärtsilä Finland Oy, Smart Manufacturing & Innovations -unit. A company which provides lifecycle solutions in the marine and energy markets, with two main businesses: Marine Business and Energy Business. A key offering provided by Wärtsilä for these markets are engines, utilized in vessels and power plants. [1]

The main structural component for any engine is the engine block, upon which the rest of the engine components are assembled on. The Wärtsilä engines are in general very large, and the engine blocks are high value items with a lengthy manufacturing process and large effect on the total lead time of the manufacturing of the engine. Therefore, the engine block is considered a vital component, which manufacturing operating model's performance is important to secure. In this thesis, research work is carried out regarding the development of a new engine block manufacturing operating model (EBMOM).

A key area of interest for the operating model, regards the question on how the engine block machining model will be redesigned according to a changing vision of manufacturing strategy, while enabling high performance production in the new circumstances of changing internal and external supply chain capabilities and environment. The subsequent further areas of interests regard, what changes this newly designed machining model then implies on other areas of the engine block manufacturing operating model.

1.1 Background & motivation for thesis

From 2020 onwards Wärtsilä Finland Oy is moving its operations including all of its functions and personnel in Vaasa area, into the new Sustainable Technology Hub (STH). A centre for research, product development and production, in Vaskiluoto, Vaasa. [2] Among other things, the new STH facilities, will provide new manufacturing technology for the manufacturing of engine blocks in the form of the Manufacturing Technology Acceleration Centre (MTAC) and its subsystem the Large Component Manufacturing -system (Large CM). In general, the manufacturing strategy and concept of operations regarding engine block manufacturing is envisioned to change according to the new "Flow" vision of it. The new Large CM system will change the in-house engine block manufacturing capability and changes made in the upstream supply chain and downstream operations will affect the external capabilities.

The thesis research problem can be formed as follows:

- Along with the move of Wärtsilä Finland Oy Vaasa area operations into the new STH center of product development and production, a new EBMOM regarding the casting and machining supply chain is needed to be developed, to successfully operate in the changing context of the *Flow* vision of manufacturing strategy, MTAC Large CM system manufacturing capability, and the rest of the changing operation environment, while pursuing overall business goals of improved lead time, total cost, and throughput.

The shift to this new environment enables, and necessitates, to bring changes into the current engine block manufacturing operating model. Different stakeholder functions and experts identify various questions in their areas of interest, to study and develop solutions for, in order to define the new operating model. In this thesis, the needs for development work identified by the stakeholders should therefore be mapped, the development process planned, and the development streams started to carry development towards the definition of a common vision for it. The development of the new EBMOM should be facilitated in cooperation with stakeholders to an extent feasible in the scope of this thesis. Literature review should be carried out on the relevant established theory that supports the facilitation of practical cooperative development activities, and the carrying out of independent analysis and supporting material creation activities. The thesis should aim to provide basis for starting the development of the operating model and its continuation after the thesis scope.

1.2 Objectives for the thesis

The research questions to answer, the goals to achieve, and the scope of research, were defined in the beginning of this thesis, and refined along the process. The final definition represents what was later deemed more realistic within the thesis constraints, and according to the role eventually set for it. The research questions are as follows:

1. What is the current Engine Block Manufacturing Operating Model (EBMOM)?
2. How is the common state-of-will found regarding the way of operating in the new EBMOM?
3. What areas of interest and issues to consider are identified regarding the development of the new EBMOM?
4. What is the development scope and the steps to achieve operation according to the new EBMOM?
5. How is supply chain lead time, total cost, and throughput improved in the new EBMOM?

The research goals were set as follows:

- To Investigate, facilitate, and manage the overall development process of defining the new EBMOM and answering of research questions to the extent feasible in the thesis time constraints.

The research scope was defined as follows:

- Research the development of the new EBMOM concerning the manufacturing and supply chain of Wärtsilä engine blocks, from start of casting, through machining, to delivery for start of assembly in the context of STH environment and set business goals, without the need to comment on detailed solutions or final implementation.

1.3 What the thesis offers

The completed thesis offers answers to the research questions mainly through the utilization of the research methods of *Focus Groups*, *Creative Techniques, Qualitative Data Analysis* and *Literature review*. To produce useful knowledge and insight regarding the development process of the Engine Block Manufacturing Operating Model via the *Descriptive Case Study* research strategy. Simultaneously delivering the practical development activities of the initial development process, by leveraging the participating stakeholder's expertise on the topic, via the *Technical Action Research* strategy. The complete structure of the thesis is shown in figure 1 and in more detail in attachment A.

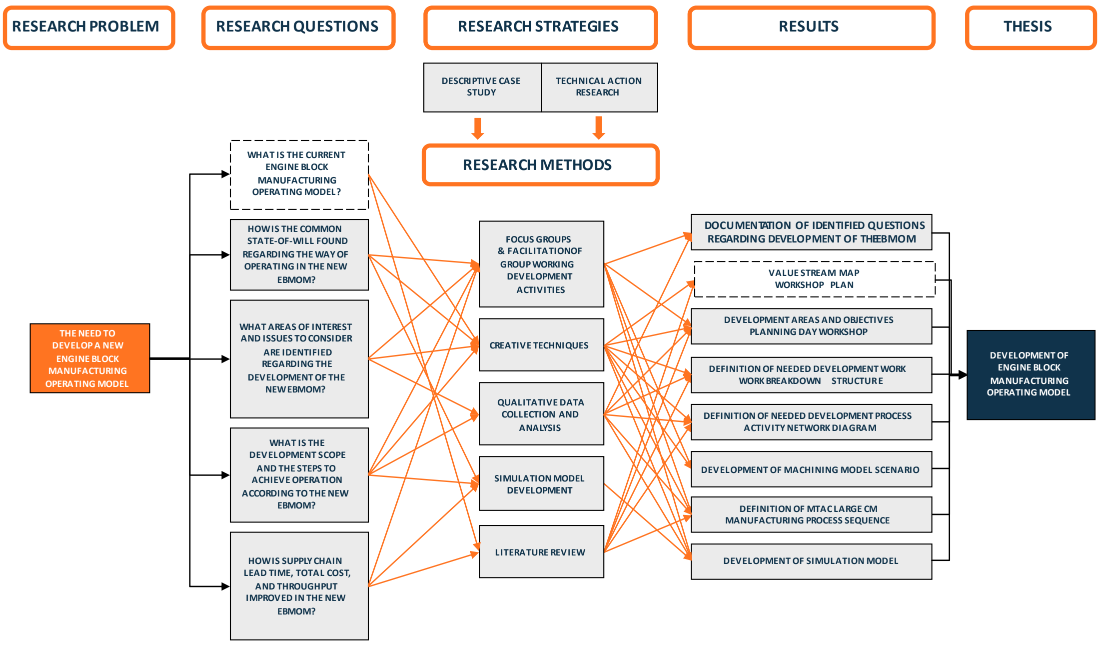

Figure 1. *The structure of the complete thesis.*

2. LITERATURE REVIEW

This literature review section focuses firstly on the theory relating to the chosen research strategies and methods, through which the thesis process was approached in terms of data collection, processing, analysis, and producing of results. The section continues with theory relating to areas of the thesis topic, that provide background and basis for answering the research questions during the scope of the practical activities in this thesis process, but also for the continued development efforts after the scope of this thesis.

2.1 Design science research

Johannesson & Perjons describe that, design science is the scientific study and creation of artefacts, which are used to solve practical problems of general interest. Artefacts and the knowledge about them are research outcomes for design science. *Design* and d*esign science* appear to be similar with the focus on development of novel artefacts. The difference is the aim for generalisability and contribution to knowledge of general interest in design science. [3] Järvinen describes that, design knowledge outcomes concern the three aspects of design. The *object-design* regarding the actual design of the artefact, *realization-design* concerning the plan for building or implementing the artefact, and *process-design* regarding the plan for use of methods for problem solving and creating solutions for the artefact. [4] Three main requirements for design science research stem from this difference. Producing new knowledge of general interest requires the use of rigorous research methods. Secondly, the produced knowledge needs to relate to an existing knowledge base for the results to be well founded and original. Additionally, the results need to be communicated to both the practitioners and other researchers. [3]

2.1.1 Research activities, process model, and focus

In their book, Johannesson & Perjons introduce a process model with 5 steps of activities to conduct a design science research project. The model is shown in figure 2, containing the five activities and the controlling methods and utilized resources as rectangles on top and beneath them, also the logically related inputs-output relationships as arrows. [3] The authors explain the activities as follows:

Explicate problem:

- This activity concerns investigating and analysing a practical problem. The problem is formulated and justified for its significance and not only local, but general interest. Its underlying causes are identified and analysed.

Define requirements:

- This activity provides an outline for the solution to the explicated problem. The explicated problem is transformed to the demands for the artefact as defined requirements on its functionality, structure, and environment.

Design and develop artefact:

- An artefact is created that addresses the explicated problem and fulfils the defined requirements set for its functionality and structure.

Demonstrate artefact:

- The developed artefact is used in a proof-of-concept situation proving the feasibility of the artefact in solving an instance of the explicated problem in the required environment.

Evaluate artefact:

- The activity determines how well the artefact fulfils the requirements set for it, and to what extent it can solve the original problem which set forth the research. [3]

According to the authors the process should be performed in an iterative way with any activity able to produce output for any other activity. The figure also shows that any research strategy or method should be considered, and in it is common to utilize multiple ones, since different design activities can require or utilize best different approaches. [3]

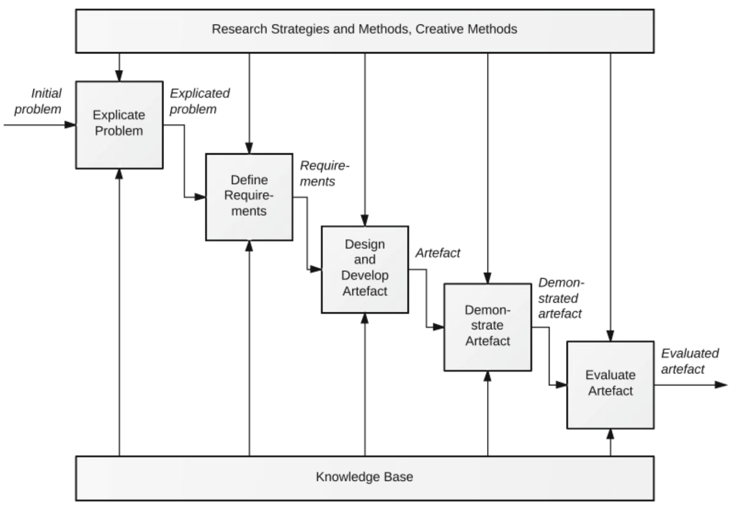

Figure 2. *The design science research project process model. [3]*

The authors argue that it is common to not perform all the five activities of the framework in depth in one project. The projects focus might lay on one or two of the activities, and typically five different cases of design science research can be recognized: [3]

Problem-focused:

- A problem is investigated rigorously. Root cause analysis and empirical studies are carried out extensively and comprehensively to explicate the problem. Requirements are defined by less detailed investigations and the design of the artefact is only outlined.

Requirements-focused:

- Start with a defined problem accepted as is, or slightly explicated. Thorough investigations are carried out to define requirements for the development of the artefact based on extensive literature review and in interaction with relevant stakeholders. The design of the artefact is only outlined.

Requirements- and development-focused:

- The focus is on a combination of thorough requirement definition and complete artefact development through research and creative methods. Problem explication is not performed, but a demonstration or a lightweight evaluation of the artefact is carried out.

Development- and evaluation-focused:

- The focus here is on development and evaluation of the artefact. The project will start from an existing requirement specification and through research and creative methods the artefact will be produced. A detailed demonstration and a thorough evaluation will be carried out.

Evaluation-focused:

- Even though no novel artefact is developed, an evaluation study can be a part of a larger design science project and still contribute to the design science in a greater sense. An evaluation study may also be an exaptation of an existing artefact to a new problem. Requirements definition will often be included, as it works as a basis for the rigorous evaluation. [3]

2.2 Research strategies

The intent of research is to produce reliable and useful knowledge based on empirical evidence and logical arguments. Many research strategies and methods have been developed to support researchers in creating, structuring, and presenting their results. A researcher needs to determine which one to choose that fits the goals and environment of the study. A research strategy is a plan to conduct a research study. It guides the researcher in planning, executing, and monitoring the study. A research method guides the research work on a more detailed level, on how to collect and analyse data. [3]

2.2.1 Technical action research

The technical action research strategy aims to deliver functional improvements. It addresses practical problems that appear in real-world settings. The research strategy is particularly common in areas where practitioners themselves can contribute to the improvement of their own practices. [3] The action research strategy in general can be characterized as follows:

Focus on practice:

- The study is carried out in real environment where practitioners act.

Change in practice:

- The researcher acts as a change agent who changes and evaluates the local practice.

Active practitioner participation:

- The practitioners actively contribute with their knowledge to help solve practical problems.

Cyclical process:

- Research is conducted in a feedback loop where needed changes are diagnosed, planned, introduced, evaluated, and reflected upon.

Action outcomes and research outcomes:

- The results of the research should be valuable to the local practice but also contribute to the academic knowledge base. [3]

Tiainen, Aittoniemi, Haukijärvi & Yli-Karhu emphasize that, for action research it is important that its directly connected to the target organizations operations and its existing need for development, providing a systematic framework for the problem-solving situation. [5] The authors explain 6 cycles of development:

1. The problem is defined for basis of evaluation with a current-state description. The needs, goals, and assessment criteria for development are clarified utilizing the expertise of the target organization.
2. It is decided on, what actions will be taken to problem solve in gradual steps through multiple development cycles. Research information is brought in to support the situation.
3. The actions are implemented through utilization of internal, external, and the researcher's expertise.
4. The development results success is assessed against the defined criteria.
5. Learning outcomes from development are recognized regarding contributions to theory and practice, and identified problem-areas, concepts, and models. [5]

Johannesson & Perjons argue that, the dependence on the researchers and practitioners' inputs can be significant in different situations, having a negative or positive effect on the process. Regarding the researchers and participants, both might force their irrelevant views, preconceptions or interests on the practice or be able to suggest essential or fresh views in case their expertise and knowledge exceeds those of the other. What is challenging for researchers, is the attempt to generalise their results which are often tied to the certain local practice. Additionally, a likely issue is the practitioners being too busy from ordinary work to contribute actively to the research. [3]

2.2.2 Descriptive case study

In a descriptive case study, the researcher aims to produce a rich and in-depth description and insight of an instance and its environment. [3] The case study research strategy can be characterised as follows:

Focus on one instance:

- To study the vast complexity in a single instance of focus.

Focus on depth:

- To obtain as much detailed information as possible.

Natural setting:

- The instance is studied in its independent existence from the research without modifying its natural context.

Relationships and processes:

- The study should account for all the processes and relationships within the instance and its environment.

Multiple sources and methods:

- Multiple information sources and data collection methods should be used, to obtain rich and many faceted knowledge. [3]

A case study addresses either a single instance or in some cases a small number of instances. An instance can be studied in a single point in time or over time in a longitudinal study. The choice of instance to be studied depends on the determined phenomenon to investigate, which in turn depends on the research question to be answered. Findings from the studying of an instance can be either generalised to an entire class of similar instances, or they can be investigated further in case of special and unusual features. A case study researcher needs to clarify the extent to which the results are representative for a class of similar instances. [3]

2.2.3 Simulation

Johannesson & Perjons describe that, simulation is a research strategy that investigates an imitation of behaviour of a real-world process or a system over time. Simulations are used to reproduce, analyse, and make predictions about complex systems. Simulations are commonly run-on computers where software is used to build an abstract model of the system being simulated. Simulations are useful when testing on the real-world process is impossible or undesirable. Simulation can be effective for evaluating certain aspects of an researched artefact. [3]

Geng recommends, taking the following steps carry out a simulation project:

1. Define the project's purpose, scope, needed resources, time and budget.
2. Collect, analyse, and validate the input data that defines the to-be modelled system with the correct assumptions.
3. Build and develop the simulation model with an appropriate software.
4. Verify, validate, and debug the model to a state of credible representation of the real system.
5. Conduct experiments and statistically meaningful simulation runs for results of the to be evaluated scenarios.
6. Present the results and their findings for basis of recommendations and for making of informed decisions. [6]

The steps can be carried out in parallel, in an iterative fashion of refinement and redefinement. The objectives and constraints of the study, and the carrying out of sensitivity analysis, determine the further steps towards meaningful results. Simulation considers interdependencies and variability, producing in other ways unobtainable insights, creating basis for better design and management decisions. Simulation can reduce risks with starting new operations, or making changes to the existing. [6]

2.3 Research methods

Data collection of a researched phenomenon is a key part of any research study. Various data collection methods can be used. Some data collection methods are commonly associated with certain research strategies, but any data collection method can be useful for a given research strategy. In research projects commonly only a single data collection method is utilized, but the use of multiple methods can improve accuracy, widen the point of view, and bring confidence in the results. Combining research strategies and methods is called the mixed methods approach. In general, numeric data is collected by quantitative methods, and other types of data by qualitative methods. [3]

2.3.1 Focus groups

Johannesson & Perjons describe the method as such, where a group of key stakeholders participate to discuss a specific topic. Focus groups can be seen as a form of interview. The aim is to understand and consider the topic from the participants perspective. Focus groups allow interaction between the participants in various ways, which enables creativity and deep assessment of the topic. Two roles need to be played by researchers in focus groups, a moderator, and a note-taker. The roles' tasks are to encourage to contribute, to guide and document the discussion and feed it with relevant questions and comments. Discussion is guided to reveal problems of the instance. [3] According to Ovaska, Aula & Majaranta, utilizing focus groups is a good method to uncover the participants needs, preferences, reactions, and functional ideas regarding development activities. Alternatively, the participants can be offered examples and propositions to comment on. [7] The focus group is documented by note taking, audio recording or transcribing. A risk in focus groups is observer dependency and uneven participant contribution. The results depend on the interpretation and analysis of the researcher, which can make them subjective. Strong participants can overpower the discussion into a certain direction. The method is a good way to tap into a large amount of knowledge and different point of views, which might be otherwise invisible for the researcher. [3]

2.3.2 Interviews

As described by Johannesson & Perjons, the method is a communication session between the researcher and a respondent. The researcher defines questions to be asked and controls the interviews agenda. Interviews are effective at gathering complex and sensitive or privileged information. Three types of interview structures are commonly recognized, structured, semi-structured and unstructured. A structured interview consists of fixed set of questions, and predetermined answers to choose, and a semi-structured interview consists of a set of questions, free to discuss in any order with answers given by the respondents in their own words. An unstructured or freeform interview allows the respondent to talk freely without the restriction to specific questions. The more structured the interview is, the faster it is to carry out and interpret the results. However, a less structured interview is better at investigating a complex issue since the respondent can process the topic with less restrictions. During an interview the researcher should interact with the respondent to gain answers as informative as possible, by prompting, probing, and checking. Prompting is about encouraging the respondent to start speaking. Probing means asking for more details. Checking is to ensure that the answer was understood correctly. The researcher needs to document the interview either by recording and or field notes for interpretation and analysis later. [3] According to Tiainen, in qualitative research, interviews are often used either as the sole source, or one of multiple data collection methods. Also, in order to consider interviewing as research, the data collection and analysis is required to be systematic. [8]

2.3.3 Data analysis

Data analysis is the act of deriving valuable information from quantitative or qualitative data, in order to interpret an investigated phenomenon. Acquired raw data needs to be processed in multiple steps of preparation, interpretation, analysis, and presentation before any conclusions can be drawn. Large volumes of data need to be transformed into a more manageable and meaningful form, with data analysis methods. [3]

In **quantitative** data analysis different types of numerical data can be manipulated by various mathematical terms. Descriptive statistics is used to describe a sample of data. The description is commonly carried out through tables or charts and by defining various aggregate measures such as *mean*, *median*, *mode*, *range*, or *standard deviation*. inferential statistics is used to draw extending conclusions about a population that the sample represents or if there is a relationship between two variables or a difference between populations. The analysis is commonly carried out by calculations of coefficients or tests such as the *correlation coefficient*, *the chi-square test* or *t-test*. [3]

In **qualitative** data analysis other types of data is analysed which cannot be analysed numerically as such. Data collection and analysis is commonly carried out at the same time where partial results drive the plan for how to collect more. The analysis tends to proceed from researching particular subjects, to producing general statements of the phenomenon. Data analysis is often influenced by various factors relating to the specific researcher conducting it. [3]

2.4 Creative techniques

The following chapters describe theory relating to creative techniques chosen to be used in the thesis practical development process, with *Cumulative Group* as a fitting technique for data collection in the thesis circumstances, and with *Workflow Modelling*, *Work Breakdown Structure* and *Activity Network Diagram* as appropriate tools for producing practical development activities supporting descriptive materials.

2.4.1 Cumulative Group

According to Innokylä, the method is a way of small group working, which promotes the strengths of individual working and interaction between participants in gradual steps, with the aim of speeding up and ensuring efficient ideation by removing mental and social barriers to support discussion, evaluation, comparison and cooperation. [9] Sirola-Korhonen states, the method is used to create a knowledge base, stimulate interest, interact and engage, problem solve, or to search for a shared vision with participants [10].

In the method, first the topic to be discussed is introduced through a presentation or other source material to help orientate the participants to the topic [10]. Preliminary questions should be formed about the group work topic to guide performing the upcoming tasks. Such questions that will prompt discussion in conflicting points of views, steer onto main points to address, or define problems to create solutions for. [9] Next the idea of the cumulative group is explained to participants and the goals for working are defined and the upcoming grouping steps are explained [10].

The steps of the small group working are as follows:

1. The participants are given a task, first to carry out as individuals [9]. They focus on taking notes alone with their thoughts on the topic of the task [10].
2. Next, instructions are given for a pair discussion, where knowledge, views are compared and ideas are worked on [10]. Pairs are formed and the outputs of each are refined into the joint output of the pair [9].
3. The pairs are then combined into ever larger groups step by step and the joint outputs further refined [9].
4. The method can be stopped at any suitable point when finally the groups present their outputs of the task to everyone [9]. The groups can gather their ideas in presentations, or onto a visible display, or the facilitator can compile the groups' thoughts and make a joint summary of the matter [10].

The appropriate group size is 8 persons at minimum to enable three stages [10]. The strength of the method is found in groups of 10 to 15, optimally 8 or 12 participants, where efficient and nonbiased discussion is difficult to achieve due to group size. The method is suitable for situations where the participants have different backgrounds or discussion styles. With the method, everyone can have an effect on the output of the task and participate more evenly in the group working activities, even if some participants are more vocal than others, if some think better in silence, if some have difficulty participating, or if the topic is controversial. [11] Another strength is the speed of gathering coordinated or even common views on a topic. [9] The method moves the given topic forward, gaining new perspectives when the composition of the group is changed [12].

2.4.2 Workflow modelling

Sharp & McDermott state, that workflow models are commonly created as swim-lane diagrams, due to their good readability and ability to simply highlight relevant process variables. Variables of *who* (actor in the steps), *what* (steps in the process), and *when* (sequence of workflow between steps), which help not only modelling but the understanding of the process. Swim-lane diagrams show a process from beginning to end at any desired level of detail. They can be used to understand what happens in the as-is workflow or to what is designed to propose as the to-be workflow. It traces the path of a single work item as it flows through the process [13]

The authors describe a workflow swim-lane diagram as follows:

- The diagram is composed by having their own labelled and marked out swim-lane for each actor.
- Each step is represented by a labelled (in verb-noun form) rectangle with rounded corners placed in the actor's swim-lane.
- Arrows of flow indicate the sequence and dependency between the steps of the workflow, based on rules, requirements, or arbitrary reasons. Flow inputs enter a step from the left and outputs leave from the right, not top or bottom.
- Flows are the passing of work from one step to another, as routes, events, communications, or transitions. A flow from one actor to another that crosses the swim lanes is called a handoff.
- Concurrent steps are depicted as parallel in the chart. Collaborative steps between actors are depicted as parallel, while connected by dotted lines across the swim-lanes over uninvolved actors.
- If steps can happen in any sequence or interleave but must complete before the next step, they are placed within a larger box without flow arrows in between.

- The workflow in a process can be sequential, where work flows from one step to the next in order. Or parallel, where one step is followed by flows to several steps proceeding independently. Or conditional, where a decision step is involved, followed by several steps from which only one flow is followed, based on rules.
- In sequential and conditional flows only one flow line leaves the right edge of the step but for conditional flow it splits into alternative branches labelled to indicate the relevant decision outcome for the path. For parallel flows a separate flow line leaves for each flow that will occur. [13]

The authors argue that three important conventions demonstrated in figure 3 are in the essence of effectively creating a useful, approachable, and easy to read swim-lane chart:

1. Sequence and dependency as in time flows from left to right (ensuring an easy to read and cohesive chart).
2. The simplest possible set of symbols are used (ensuring approachability of chart and focus on vital information of flow of work, instead of noise of unvital information on how the work is done).
3. Every actor holding the work is shown (ensuring a complete workflow). [13]

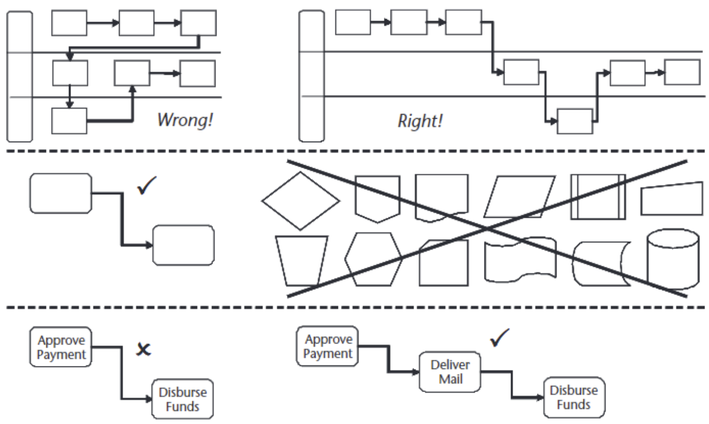

Figure 3. *Three conventions of a good swim-lane chart by Sharp & McDermott. [13]*

The authors recommend that to efficiently produce a simple swim lane workflow diagram as a start of a project, it is key for all participants to acknowledge that the workflow will be traced through the process in multiple passes, first without details or exceptions. [13]

For this, the authors suggest the following three stages and accompanying questions:

1. Who gets the work next?

The purpose of this question is to force forward motion through the process to create a result for the workflow modelling customer. Straying the discussion from acquiring an answer for this specific question only, should be avoided. If flows in multiple directions or alternate flows based on decisions are faced, the most common main route should be followed. The amount of work in each step does not matter, a rectangle is drawn when an actor holds the work, whether value is added or not, or the work simply moved or delayed in the contribution. Only the flow of work, sequence of handoffs, is attempted to depict at this point. [13]

2. How does it get there?

The purpose of the question is to uncover more of the actors, still missed by the previous question. To trace the flow more accurately, the flow of handoffs between actors is focused upon, to reveal actors that just move the work along. [13]

3. Who really gets the work next?

The purpose of this question is to reveal even more still unidentified actors. Wherever the work flows to a particular actor, it is asked if some other person, system, or other mechanism is involved. Through these three questions, a simple model is created. While lacking lots of information, and not answering all questions, it already enables a much better understanding of the modelled process, and can establish a basis for realization of main factors and enablers impacting process performance. [13]

2.4.3 Work breakdown structure

A Work Breakdown Structure (WBS) takes requirements set by project stakeholders and turns them into work that needs to be completed in a logical sequence for delivery of the project. It is used to organize the tasks of a project into hierarchies and related areas, from larger activities to smaller components, and defined milestones to deliverables. The work for a project is decomposed with a top-down or bottom-up approach depending on which is more practical in the use case. The WBS often takes a form of a hierarchical tree diagram chart, with the following levels which help control and organize work: [14]

- The total project.
- Major deliverables.
- Milestones (representing an important event, set of activities or subproject).
- Major activities (summary of tasks).
- Work package (activity with unique deliverable and estimated time and cost). [14]

Campbell argues that, the organization of a WBS can be based on various point of views, whatever enables most clarity in managing and breaking down the work, such as: [14]

- Project phase.
- Organizational structure.
- Physical location.
- Systems and subsystems. [14]

The author explains that the lowest level unit in the WBS, a work package, must be tracked and therefore able to assign a time estimate and a cost for. Higher level items only function as an organizational tool to summarize the combining of work packages which together completes components of the project. The following five steps are suggested to be followed to create a functional WBS: [14]

- Work must be broken into independent packages that can be sequenced, assigned, scheduled, monitored.
- The work packages should be defined at an appropriate level of detail regarding the length and complexity of the project and reporting period.
- The work packages should integrate into a total system, ultimately completed by the carried-out tasks, achieved milestones developed deliverables.
- The work packages should be presented so that they clearly communicate the deliverable and time for completion.
- Verification needs to be done to make sure that defined work packages, when completed, achieve all the project goals and objectives. [14]

The author states that, the schedule and resources for the project can only be planned after creating a complete WBS and activity list with identified dependencies consisting of these four different logical relationships: [14]

- Finish-to-start: A task must be completed before starting the next one.
- Finish-to-finish: A task must complete before a parallel task can be completed.
- Start-to-start: A task must start before a parallel task can start.
- Start-to-finish: A task must start before a parallel task can be completed. [14]

In his book Campbell reminds that, as progressing through the project, more information will be gathered and learned. This allows the WBS to be refined to greater accuracy, predictability, and completeness. The core team members and key stakeholders should be utilized to help progressively elaborate the WBS to new revisions. [14]

2.4.4 Activity network diagram

An activity network diagram (AND) is the logical representation of scheduled project activities and definition of project work sequence, drawn left to right in chronological order of the activities, while revealing the needed workflow. The AND shows the interrelationships of activities in the WBS hierarchy and can be used for scheduling and monitoring progress and completion as in figure 4. The AND does not demonstrate hierarchical relationships in a project, so it is usual to complete the WBS before the AND. [14]

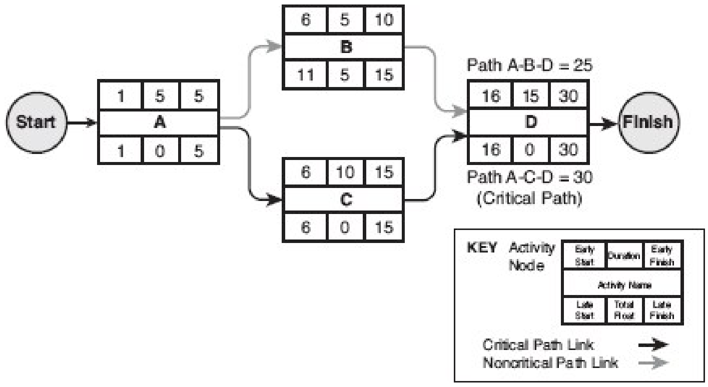

Figure 4. *Example of a simple Activity Network Diagram by Campbell. [14]*

In the diagram, lines are drawn between activities indicating dependencies. Arrowheads are placed on the lines indicating direction of workflow. A task on the left side must be completed before the task on the right can begin. The activity nodes hold the description of each task. Group of tasks that lead to a deliverable, are identified by parallelograms. Tasks that happen at the same time are in the same column but in a different row. Lines can cross to different rows demonstrating how activities relate to each other. [14]

Campbell states, that for projects with multiple parallel tasks, a critical path must be determined to identify the time required to complete the project. The critical path is a sequence of tasks, which times added together, form the longest duration of the project. If a task on the critical path is delayed, the project is delayed, unless you can make up the time further down the critical path. Due to each task on the critical path must follow its predecessor in a specific order, therefore all tasks following a late task will be late. [14]

Completion of tasks not on the critical path can be more flexible in terms of time, since their delay doesn’t necessarily delay other tasks downstream. This results in enabling them a flexible start and finish date called *float*, which is calculated by:

Total float = Latest possible finish date – earliest possible start – duration (1)

The amount of float is the amount of time the activity may be delayed from its earliest possible start date without delaying the project finish date. If the total float for a task equals 0, then the task is on the critical path. [14]

2.5 Manufacturing system design

According to Hopp & Spearman, the design of manufacturing systems and their operations are tasks with high complexity, vast scale, containing multiple quickly changing objectives, which take place in a highly competitive environment. A solution that works across all manufacturing environments does not exists, and if a system is created that performs extremely well today, failure to continue improving it is an opportunity to be overtaken by competition. Each company must utilize its resources and develop an effective strategy. The strategy should be supported with appropriate policies and operations, and be continuously improved. [15] A definitive design methodology of exact scientific basis does not exist for manufacturing system design, so a key component needed for approaching this, is a framework of tools, methods and processes, for making sense of the underlying manufacturing operations and relations of design variables. [15][16]

2.5.1 Manufacturing system design framework

In their manufacturing system design framework manual, Vaughn et al. constructed a framework in the context of the *Massachusetts Institute of Technology Lean Aerospace Initiative,* consisting of the infrastructure design, product strategy, and structure design elements. The framework is visually represented in figure 5. [16]

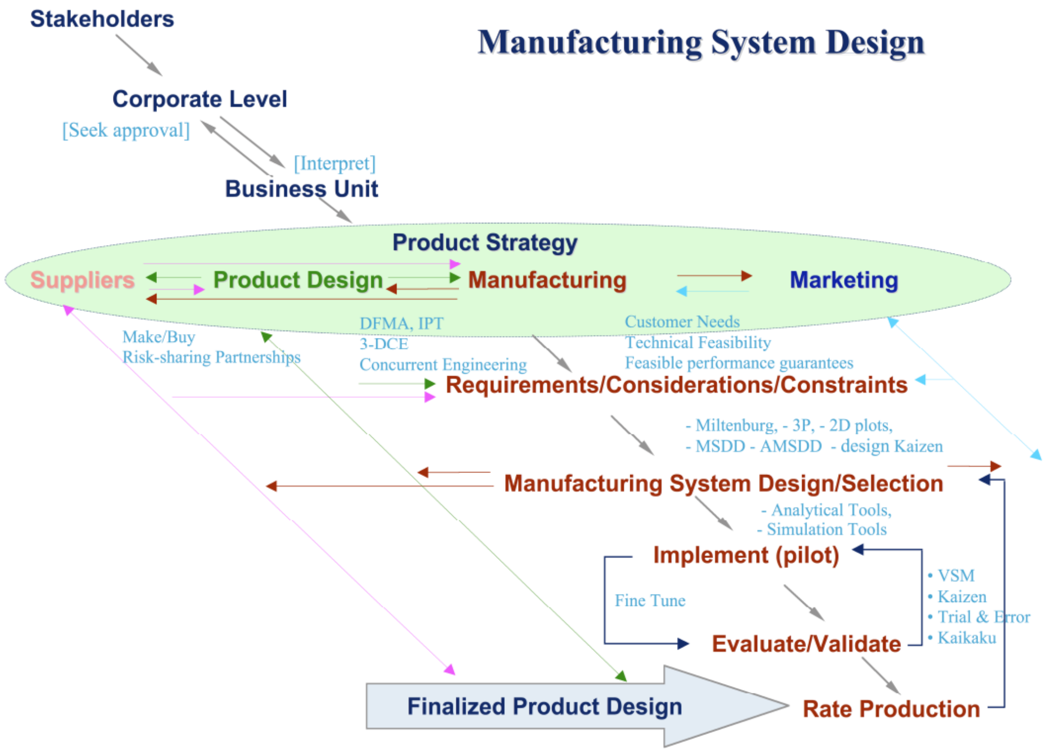

Figure 5. The manufacturing system design framework by Vaughn et al. [16]

In the framework by Vaughn et al. the **infrastructure design** portion spans the items on top of the green ellipse in the framework. This element defines the operating policies, organizational structure, position, and in general all the activities associated with the overall operating environment of the system, which satisfies the systems' stakeholders. The portion is alternatively called as the *strategy formulation body*, which aligns the corporate-level, business-level, and manufacturing-level strategies.

According to Vaughn et al. manufacturing strategy helps the business build and maintain a competitive advantage, and prepare for future competition by providing the following:

- Alignment and integration of manufacturing with business and corporate strategy.
- Decisions that base on long-term objectives.
- Assurement of long-term product capability and competitive differentation.
- Clear communication between management levels.
- Basis for decision making on improvement and capability building activities. [16]

The next level in the framework concerns **product strategy**, which fundamentally aligns manufacturing and other functions with the corporate strategy, regarding a single product or a family of products. Vaughn et al. represent product strategy as the overlapping area of *marketing*, *product design*, *manufacturing,* and *supplier integration*. They argue that the relationship leads to the understanding of the true customer needs and their technical feasibility, leading to a product definition enabling high performance manufacturing. It links the top infrastructure portion of the framework to the structure design portion below, by having the strategy and inputs from the functions generating a set of requirements, considerations, and constraints for the manufacturing system design. [16]

The lower portion of the framework spans the activities of **structure design**, where the manufacturing system design is conceptualized, piloted, and refined in separate phases, but with design activities from all the functions proceeding concurrently in parallel, as represented by the arrows. This way the product and manufacturing system design would progress at the same time, as the suppliers' design or modify their systems and processes accordingly. The authors emphasize, that the concurrent design activities should all converge to the final product and system design at the same time. [16]

In their book, Bellgran & Säfsten emphasize that the composition of working teams, project management, information flow and communication are critical. Developing production systems is also a complex task with many aspects to consider, and no single educational or experience-based background provides enough understanding to identify consider all their influence. Therefore, the system designer members in working teams should represent a vast scope of functions and disciplines and needed expertise. Additionally, facilitators such as system analysts, project managers and systems engineers' are needed to support and facilitate the activities in the project. [17]

The previously mentioned requirements, constraints, and considerations originating internally or externally, have a mandatory or voluntary effect on the product and the manufacturing system design. They set goals to meet for the system to succeed. In their manual Vaughn et al. describe these inputs as such, which require further inputs of their own, from the other various functional areas. The manufacturing system is then designed to achieve the set requirements. At high-level they are described by the authors as: [16]

> *"The product designers provide the information that translates into the product complexity, frequency of design changes and capability of processes to do what their designers require. Marketing provides the knowledge of needed production volume and mix and variability of those values. The suppliers and the capability of their processes could potentially impact the make/buy decisions or supplier selection for different components. Finally, the manufacturing component contains the information of the internal process's capabilities, available skill levels, core competencies, as well as what resources and investment are required to pull everything together."* [16]

At the bottom of the framework, the **implement**, **evaluate**, **validate**, **rate produce** and **modify** loops are illustrated. The former loop requests for the implementation of the designed manufacturing system on a smaller scale, to test, fine tune and eventually ramp-up production. The authors suggest that this can be accomplished using computer simulation or whatever method that subjects the system design to practical tests, which reveal potential problems, provide opportunity for new ideas and solving of problems, to enable smooth operation at rate production. According to the authors, the final latter loop of rate production and modification, firstly emphasizes the need for a cycle of continuous improvement, but secondly continues the linked cooperation with the different functions, as the manufacturing system design process is never complete, as long as the system is in operation. [16]

2.5.2 Objectives defining manufacturing systems

According to Bellgran & Säfsten, **manufacturing strategy** is commonly divided to *content* and *process*. The *content* of manufacturing strategy consists of *competitive factors* with which the company aims to compete in a certain market, and of *decision categories,* which represent the company's capabilities used to reach its targets. The side of *process* describes the strategy's formulation and implementation. [17]

Decision categories are areas that comprise of a number of questions the company has to deal with and make decisions about, to support the chosen *competitive factors*. The authors divide the common decision categories on a high-level to 7 categories, which are explained as follows:

- **Production process:** Regards decisions about the process type, layout, and technological level; Concerning how processes and activities are arranged to handle production volume and the number of variants. How the physical resources are arranged? What are the technical solutions?
- **Capacity:** Regards decisions about the available amount and flexibility of personnel, technology, and buy and sell capacities in relation to demand.
- **Facility:** Regards decisions about the amount, competencies, and position of the system in relation to market, raw material, suppliers, logistics. Also, about the choice of focus for the system, in the point-of-view of the general manufacturing process or the specific manufacturable products properties.
- **Vertical Integration:** Regards decisions about the vertical positioning of the production process and other activities in the supply chain. This relates to choices about make or buy decisions, which further regard decisions about the desired control of product realization process, technology and knowledge development, and relationships with upstream and downstream partners.
- **Quality:** Regards decisions about the approach to managing and securing the quality dimensions of the output of the system and its activities.
- **Organisation and human resources:** Regard the decisions about the structure, roles and responsibilities, competence and award system in the company's departments and functions, to utilize available resources in the best possible way.
- **Production Planning and Control:** Regards decisions about the principles for managing material handling and production in different detail levels. In master planning it regards the decisions about the customer order decoupling point, splitting the flow of production to forecast and customer order -based production. In

requirements planning, it regards the methods to ensure available materials and components. In detailed planning, about the methods to manage order release, sequencing and use of specific resources. [17]

Competitive factors are properties used to describe the company's objectives. The authors state, that they can be performance measures, or competitive priorities. The four competitive factors that are commonly considered as the most important are:

- **Cost:** Which refers to the ability to produce and deliver cost efficiently, regarding the supply, and product-, and process design.
- **Quality:** Refers to the ability to meet customer needs and expectations of experience of value or meeting of specifications.
- **Flexibility:** Refers to the ability to adapt production quickly and efficiently to any necessary changes by volume or capability.
- **Deliverability:** Refers to the ability to deliver with reliability, speed of lead time, according to plan, and on time. [17]

In addition to manufacturing-strategy-based objectives, in their book Hopp & Spearman derive basis for operations decisions, that enable the fundamental objective of a company, "*making a return on investment (ROI) over the long term*". [15]

ROI = profits / assets (1)

Supporting subordinate objectives as seen in figure 6, are derived hierarchically by the authors, to link high-level financial measures into lower-level operations measures. [15]

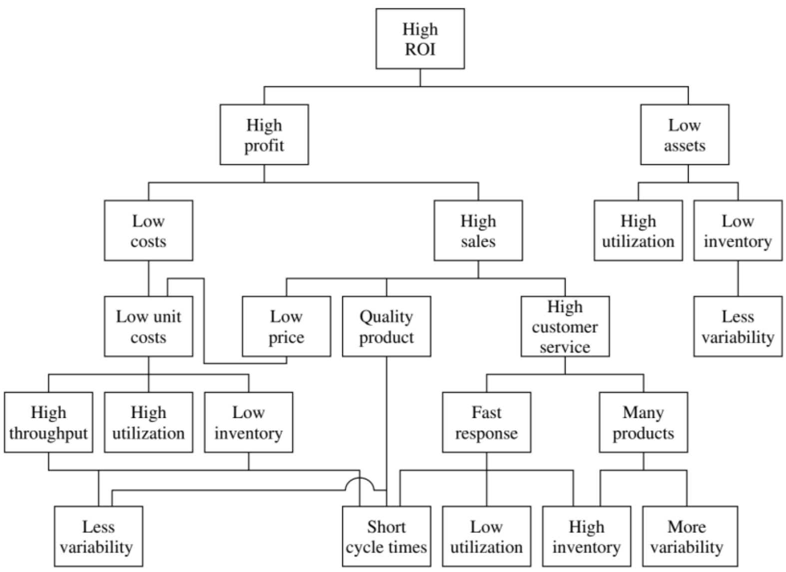

Figure 6. *Hierarchical objectives in a manufacturing organization. [15]*

2.6 Manufacturing process performance characterization

According to Bellgran & Säfsten, productivity and efficiency are also the most common measures describing the performance of manufacturing systems and processes, in addition to profits, ROI, and other financial terms. Productivity is an absolute measure of the relation between the output achievements of production and the input efforts required, while efficiency considers doing things right regarding the inputs, and doing the right things regarding the outputs, in order to add value and avoid waste. [17]

2.6.1 Process efficiency types

According to Modig & Åhlström, **flow efficiency** is a relatively new form of measuring process efficiency. It focuses on flow units receiving value in a process from various activities. [18] Cox & Schleier state, that in the flow centric viewpoint, units are observed to dynamically move through the process and transform from raw material to finished product, through being worked on by various resources. The essence is in the transformation by operations and the added value. [19] In the point of view of flow efficiency, activities are considered either *value-adding* or *non-value-adding*. The classification is made in the point of view of the customer, which has direct and indirect needs regarding the ordered product or service. Direct needs concern creating a concrete outcome, while indirect needs concern the experience along the process. Fulfilling either of these needs provides value for the customer. Thus, an activity that adds value to the processed flow unit directly, or indirectly for the customer is concerned a value-adding activity and is pursued, and an activity that does not add value is a wasteful or non-value-adding activity and should be avoided. Flow efficiency is defined as a measurement of the sum of value-added activity time in relation to the throughput time of the flow unit. The time period is defined from the time a need is identified to the time it is satisfied. [18]

$$\text{Throughput time} = \text{Time a need was satisfied} - \text{Time a need was identified} \qquad (2)$$

$$\text{Flow efficiency} = \text{Value-added time}/\text{Throughput time} \qquad (3)$$

Resource efficiency is a more traditional form of measuring process efficiency. It focuses on the resources producing value within a process. [18] In the resource centric viewpoint processes are observed from a static perspective, where materials move from one working resource to another. In the traditional view resources drain or consume costs. To manage cost is to manage the efficiency of each resource. [19] Resource efficiency is strived for due to opportunity cost, which is the loss resulted by not utilizing a resource to its fullest capacity, and therefore losing the opportunity to produce value with the tied-up money elsewhere [18]. In cost accounting point of view, when resources work, they absorb cost into inventory, which is considered as increasing profit. Therefore, any production is generally encouraged. [19] Resource efficiency is defined as a measurement of how much a resource is utilized in relation to a specific time period [18].

Resource efficiency = Time resource is utilized / Specific time period (4)

2.6.2 Process operating laws

Three laws commonly define: How processes operate and the relationship of key process factors.

Little's law tells us that throughput time is affected by the number of flow units in the process and the process cycle time. Flow units in process are those units within the system boundaries that have started the process but not exited yet. Cycle time is the average time between units completing the process. [18]

Throughput time = flow units in process × cycle time (5)

The law of bottlenecks states that the throughput time in a process is primarily affected by the stage of the process that has the longest cycle time. This stage lengthens the throughput time the most and limits the flow in the entire process. This stage is called the bottleneck. Bottlenecks in processes have two key characteristics:

- A queue forms in front of the bottleneck stage in a process due to the inability to process products as fast as the other stages.
- The stages after a bottleneck stage will not be fully utilized due to having to work at the limited pace of the bottleneck stage instead of their higher nominal pace.[18]

The law of the effect of variation concerns the relationship between resource utilization, throughput time, and variation based on the "Kingman's Formula". The relationship is understood best visualized and is shown illustrated in figure 7.

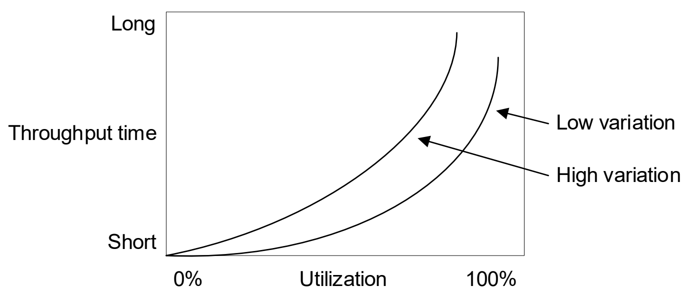

Figure 7. *Illustration of the relationship in "Kingman's Formula" between resource utilization, throughput time, and variation. Adapted from source [18].*

The figure shows how:

- The higher our resource utilization is, the longer the throughput time gets.
- The relation of utilization increase to throughput time growth is exponential.
- Higher variation increases the throughput time at all levels of utilization. [18]

2.6.3 Relationships of process factors and efficiency

The three previous laws define what lengthens throughput time:

- Little's Law states that **throughput time** increases when there is an increase in the number of **flow units** in process or when the **cycle time** increases

Increased amount of **flow units** in process is caused by buffers and **variation** in operation times. An excessive **cycle** time is caused by the insufficient **capacity** of resources, or downtime by **variation**. [18]

- The law of bottlenecks states that throughput time increases when there are **bottlenecks** in the process

Bottlenecks appear in processes due to the nature of how customer needs can be fulfilled. Commonly, the work needed cannot be done in a single stage by a single resource and needs to be split into phases and carried out in a certain order with various resources. The split is difficult to realize in a balanced way. The **amount of work** in each stage and **available capacity** for each resource will vary, and bottlenecks will appear. A bottleneck can be eliminated by adding extra resources or making the existing resource work faster. However, a new bottleneck will then appear in another stage of the process. Bottlenecks lengthen the **throughput time** due to the waiting times it induces. [18]

- The law of the effect of variation states that throughput time increases as **variation** in the process increases and the process gets closer to one hundred percent utilization.

Variation exists in all processes bringing variation to the processing times. It can be classified in to three main sources:

1. Resources, which might work faster or slower than other resources and are prone to downtime reducing their capacity.
2. Flow units, which might require more or less work than other flow units and are prone to quality issues, developing more work by needs of rework or scrap.
3. External factors, which might affect flow unit arrival time and make it not evenly distributed or forecastable. [18]

In a process made up of different stages, **variation** in the processing time in one stage will lead to variation in arrival time in the following stage. This generates unrecoverable wait time for either the flow unit to get processed, reducing **flow efficiency**, or wait time for the resource to get a new flow unit to process, reducing **resource efficiency**. [18]

Flow efficiency was defined as a measurement of the sum of **value-adding activity time** in relation to the **throughput time**. To achieve high flow efficiency in a process, lengthening the throughput time should be avoided, unless the added throughput time consists of more value-adding time than **non-value-adding time** and will therefore increase the ratio. Increasing flow efficiency, is about maximizing the density of the value transfer, so eliminating non-value-adding activities from the process should be pursued. The principle is to ensure that each flow unit is always being processed by a value-adding activity. [18] To have efficient management of flow, it implies that the movement of flow units through the process is smooth and fast without stoppages. Therefore, buffers and inventories of built-up work-in-progress **flow units** are undesirable. [19].

Resource efficiency was defined as a measurement of the time the resource is utilized in relation to a specific time-period. The **throughput time** of a flow unit is not a relevant factor here. Regarding resource efficiency, a high percentage of **value-adding activity** time is also pursued here, but in the point of view of the resources. The resources try to add as much value as possible. To ensure high resource efficiency, work must always be available for the resources to process, to avoid having the resources wait. Therefore, the usage of buffers and inventories is desirable. This results in the need for increasing the amount of work-in-progress **flow units** in the process [18].

The relationships of process laws, -factors and the efficiency types, demonstrate that it is difficult to combine high **flow efficiency** with high **resource efficiency**. This is due to contradicting general principles of how to improve them by affecting the various process factors. But most importantly **variation** is shown to be a key factor negatively affecting both efficiencies. While being impossible to completely remove from a process, removing, reducing and managing variation can improve both efficiencies. [18]

2.7 Continuous process improvement towards perfect state

Based on the previously explained relationships. Modig and Åhlström argue, that by choice a process can operate anywhere within the area of resource and flow efficiency not limited by variation. [18] This area is illustrated in figure 8.

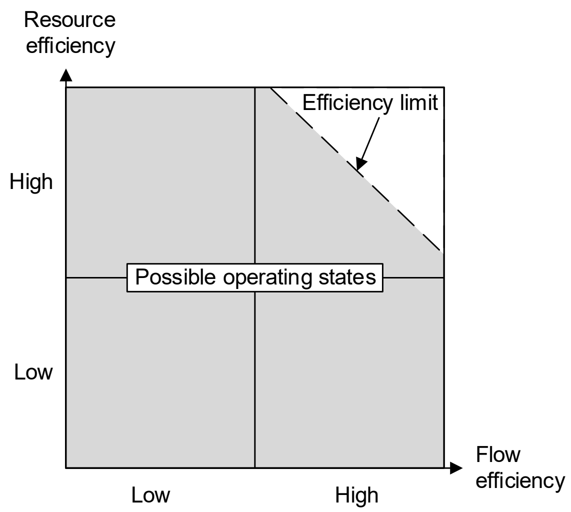

Figure 8. *The possible operating area regarding resource- and flow efficiency, as limited by the amount of variation. Adapted from source [18].*

A process with 100% resource- and flow efficiency, would operate in the perfect state. It would utilize its resources fully and meet customers' needs in an optimal way. However, this state is impossible to achieve. The factor of variation in both supply and demand prevents a process from achieving the perfect state. To achieve it, access to all information regarding the customers current and future needs would be needed. Perfect predictability of demand with knowledge of what, when and in what amount. Additionally, the process would require perfectly flexible and reliable resources, which could meet all the possible customer needs in any situation. Perfect capability to supply what is needed, when and in what amount without problems. However, it is typical for customer demand to be variable and therefore it is difficult to predict. Perfect resources are also impossible to have, and at least their reliability would inevitably contain variation. [18]

The better the organization can develop capabilities to handle the two conditions of **predictability of demand** and **flexibility and reliability of supply**. The closer to the operating limit set by variation they can move to. The operating state depends on whether the organization behind the process prioritizes **resource- or flow efficiency**. It is the task of business- and operations strategy to choose where to position and move itself in the area based on its environment, and how, and what kind of value does the company want to provide to its customers. [18]

Focusing too much on **resource efficiency** tends to actually increase the amount of work to do. It is often believed that resources are being utilized efficiently, but they are not. Much of the utilization comes from non-value-adding activities through three sources of inefficiency, this is called the **efficiency paradox.** Low **flow efficiency** and **superfluous work** is created, a waste difficult to realize as such but which can't be ignored. [18].

4. The time delay to fulfil the primary need of a flow unit caused by a long throughput- or waiting time, can make the flow unit develop unnecessary secondary needs through a time-based chain reaction of cause-and-effect.
5. An increased amount of flow units magnifies the effect of the creation of their secondary needs and expands the scope and number of things for the resources to need to manage. Thus, the resources end up creating secondary needs of their own that need to be fulfilled before fulfilling those primary needs of the flow units.
6. The superfluous work already created by the two previous factors further increase the needed working time and number of things to handle simultaneously by the resources. It increases the risk for disruptions and information loss, which leads to mistakes or needs of restarting work. Secondary needs end up creating additional secondary needs. [18]

Instead, with a focus on **flow efficiency**, **superfluous work** can be eliminated from processes and the **efficiency paradox** can be resolved. Decreasing **throughput time** and the **amount of flow units** in process will eliminate secondary needs of **non-value-adding activities** of work, by reducing the number of needed work restarts, handling and managing of flow units. Flow units will flow quickly through the process and be dealt as efficiently as possible with minimal time standing still. Resources will be freed up of wasteful activities and be more flexibly available for truly **value-adding activities**. [18]

An **operating strategy** that focuses on reducing variation with the intention of improving flow efficiency, works then as a basis for improving resource efficiency. Improvement through this kind of operating strategy eliminates non-value-adding superfluous work and waste, which helps to resolve the efficiency paradox and moves the process towards the perfect operating state. A common operating strategy like this is called "**Lean**", which is majorly based on the philosophy defined by the Toyota Production System. [18]

2.7.1 Process improvement through Lean

A **Lean** operating strategy can be realized by various **means**. Any means that result in reduction of variation to improve flow efficiency is a good mean. Means can be defined on different **levels of abstraction**, starting from the highest-level means, and continuing to lower-level means:

1. Integrated **values**, define how to behave and reduce variation in how we are.
2. Applied **principles** define how to think and reduce variation in prioritization and decision making.
3. Standardized **methods** define what to do and reduce variation in how we do it.
4. Implemented **tools** define and reduce variation in what we have. [18]

For example, in the case of the Toyota Production System:

- Values regarding continuous improvement and respect for people were set.
- Principles were applied as; **Just-In-Time**, which means creating efficient flow through the whole organization's processes while working to fulfil only the customer's needs. **JIDOKA**, which means creating awareness in an organization and its processes to prevent, identify and eliminate all problems detrimental to achieving flow, and creating opportunities for development and improvement.
- Regarding methods; **Value stream mapping** was developed to analyse the information and material flow in processes, and to identify value-adding and wasteful non-value-adding activities. ***5S*** was developed, where the goal is to improve workflows and reduce problems and waste through organization and improvement, by 5 phases of implementation, *sorting*, *structuring*, *shining*, *standardizing*, and *sustaining*.
- On the lowest level of tools; ***Visual planning boards*** is a common tool associated with Toyota, which intention was to make the process more visible, to observe if the flow is normal or deviated and should be dealt with. [18]

It's important to understand that the realization of a Lean operations strategy is a continuous journey. It is not a static state to achieve, but a dynamic one with constant improvement to pursue, even though Lean based improvement can also be split into smaller projects with clear milestones in a more tool-based, method-focused fashion. [18]

In general, when realizing an operations strategy such as Lean, solutions should be developed that fit into the context they are utilized. The means at the lowest level of abstraction are the most dependent on context. Inspiration can be drawn from for example Toyota's means, but what is key is that organizations should understand Lean and find their own solutions. [18]

2.7.2 Process improvement through Theory of Constraints

The concept of Theory of Constraints (TOC) is that improvements that are not directed at the performance of the weakest link, the **system constraint**, will not improve the performance of the total system, and is ultimately wasteful. Therefore, focus of improvement should be on the constraint. [19]

TOC is about improving and managing the performance of the system constraint in the context of the interdependencies and variability of the process, and with the help of other parts of the system, which affect these leverage points. In TOC, logical thinking processes, cause-and-effect, is applied to understand and improve processes. The approach is to understand the system, its goal, and measurements. Total process improvement is pursued, not just localized improvements. [19]

The **Five focusing steps (5FS)** is a mid-level mean of TOC. A method for achieving continuous and step-change process improvement. Carrying out 5FS enables the process to continuously exploit and elevate its true potential by unlocking it through identifying, exploiting and elevating the performance of its system constraint. [19] Since the nature of a TOC system is to have an unbalanced process, some resources will have capacity surpassing the market demand, and some below it. These are called **bottlenecks**. One resource will have the lowest capacity, this is the system constraint. [19]

According Eliyahu M. Goldratt [20], the steps of 5FS are:

> *”Step 1: Identify (or choose) the system constraint.*
>
> *Step 2: Decide how to exploit the system constraint.*
>
> *Step 3: Subordinate all other decisions to the above.*
>
> *Step 4: Elevate the system constraint.*
>
> *Step 5: If, in Step 4, the constraint is broken, then go back to Step 1. Don’t let inertia become the constraint.”* [20]

In the 1st step of the **5FS**: The system constraint is identified, by comparing the load placed on each resource to the total amount of production and setup required at that resource to satisfy market demand. However due to inaccuracies in data, this often fails to identify the real bottleneck. Alternative procedures for identifying the bottleneck should be explored, based on the type of production flow of the process. Choosing the bottleneck is key for the entire business strategy not just for manufacturing operations. [19]

In the 2nd step of the process: The constraint is analysed in terms of how its capacity is currently wasted, and therefore negatively impacting the system's throughput. [19] The reasons for underutilization are clarified and the gap between the constraints theoretical capability and average usage is bridged. *Low-level means* such as data collection, and analysis tools such as *Pareto techniques*, *Fishbone diagrams* and *5 Why Analysis* can reveal the root causes. [21] To exploit the constraint; Its performance of throughput should be maximised, while efficiently managing inventory and operating expense. Ensured that it does not run out of work, and that the planned work and available materials are only of those that are required to meet very near-term demand. Buffers and correct work scheduling and releasing should be utilized. [19] Additionally, setup times, downtime and other wastes of time and capacity should be minimized. Elimination of causes for underutilization can be carried out with low-level means of quality or productivity tools like *Six Sigma*, *Poka Yoke*, *Design of Experiments*, *Single Minute Exchange of Dies*. [21]

In the 3rd step of the process: The system's resources and activities of material release and processing up- and downstream of the bottleneck, should perform in a way that supports the planned flow through the constraint, according to the decisions made in the previous step. The management and control of actions at non-constraints provide the possibility to execute the process with the highest possible performance. Overproduction needs to be prevented, therefore, non-constraints are required to work on a level that supports the constraint but not higher, with the cost of lower resource efficiency for a specific resource, but with the benefit of better flow efficiency for the entire system. [19]

In the 4th & 5th steps of the process: To improve the performance further, the limit of the constraint must be elevated by increasing capacity. [19] However, the low-risk high-reward potential of unlocking capacity with the as-is resources could be missed if the exploitation and subordination of steps 2 & 3 are not fully completed. Additionally, applying 5FS might move the constraint to another point in the process and the new constraint might require a whole new way of managing the whole system. In any case, at this point the process should be considered to be restarted as the inertia of continuous improvement should be prevented from becoming the constraint. [21]

3. DEVELOPMENT PROCESS

This section describes in chronological order the practical part of the thesis process. It explains what the needs for this thesis were, at Wärtsilä Finland Oy Smart Manufacturing & Innovations unit at the time of starting this thesis. A short description is given about the previous investigations on the topic. It is described, how the thesis research plan was gradually defined through understanding gained from multiple thesis starting meeting discussions, and how the approach to development activities were formed. How the needed development work and process for the development project of the *Flow* Engine Block Manufacturing Operating Model (EBMOM) were identified and defined. Finally, the initial detailed development streams started in the scope of this thesis are described.

3.1 Thesis starting point and topic definition

Prior to the first meetings regarding the thesis, the author had worked at Wärtsilä Finland Oy for 9 months in the area of design for manufacturing regarding machined components in the New Product Introduction unit. The author's preliminary understanding was that along with the overall changes brought by the Sustainable Technology Hub (STH) project, the development of a new EBMOM was a topic of interest, and the thesis would deal with at least parts of its development process. Regardless of the prior experience at Wärtsilä, the author had relatively minimal knowledge of the thesis topic's conceptual framework, or the surrounding STH project.

3.1.1 Previous investigations on the topic

As a first step, to start familiarizing with the thesis topic and its related theoretical concepts, the thesis author requested to receive introductory material from the thesis supervisor regarding the overall STH project and regarding any possible pre-existing investigations on the topic of developing the new EBMOM.

Two pieces of presentation material regarding the topic, was received. The first material was a presentation from the year 2016, of a business case study focusing on analysis of the current- and potential future-state engine block manufacturing supply chain structure, regarding the foundry and machining process. [22] In the analysis a new supply chain structure was drafted according to a new "Flow" vision of manufacturing strategy, where in general the placement of rough machining phases of the engine block manufacturing would be in larger proportion moved to external suppliers, while focusing in-house in larger proportion regarding the critical competencies of fine machining phases. This vision was argued to ultimately secure better quality, capacity, and flexibility, in an optimized and cost minimizing way regarding the whole supply chain. The analysis considered what would be the few possible operating scenario alternatives regarding the management, roles, and the operative drivers for material and information flow in the future-state supply chain, if it was restructured according to this vision. The investigation mapped some of the would be changed responsibilities, general pros and cons, and open questions identified for each scenario, on the areas of Enterprise Resource Planning, Supply Chain Management, and Business Analysis. The investigation also contained high-level process descriptions of material-, and information flows and timelines for the at that time as-is 2014 engine block supply chain, and for the visioned future-state engine block supply chain process titled *Flow*. The *Flow* process was preliminarily designed according to the at that time seen future STH operating environment. [22]

This previous investigation provided the author with a good introduction in a few different points-of-views. To perceive the very preliminary vision of the future-state *Flow* supply chain structure at STH, as a part of the to-be developed *Flow* EBMOM. Also, to understand the considerations already noted of the various potential scenarios on basis of which the operation model could be further developed upon.

Presentation material was also received by the author, regarding the preliminary plans for the STH Manufacturing Technology Acceleration Centre Large Component Manufacturing (MTAC Large CM) system. [23] The presentation contained information about the vision and core values based on which, the upcoming in-house engine block manufacturing system design was derived from, and about the strengths it would service Wärtsilä's operations. Multiple illustrations detailed information about the overall MTAC project, its scope, the surrounding organization, and the deliverable-schedule, containing the *Flow* EBMOM as a required part of its development. The material also contained visualizations of the planned manufacturing system rendered in 3D, and details of its technical solutions. The visualizations demonstrated the would-be physical manufacturing system area at STH facilities and how the actual Large CM system consisted of various manufacturing system elements. The Portal Machining Center (PMC), washing machine, loading stations, pallet buffers, the robot deburring measuring and component installations cells, and finally the Automated Guided Vehicle (AGV) system. [23]

This presentation gave the author a good overview of the high-level process, structure, and capabilities of the to-be implemented MTAC Large CM system, and the overall development project surrounding it, in relation to the development of the *Flow* EBMOM.

3.1.2 Thesis meeting with company supervisor

The thesis process was started in November 2019. Two meetings were held between the thesis author and the thesis Wärtsilä side supervisor. The received prior investigative material was reviewed, to better explain their concepts and the current interests regarding them. The possible role for the thesis in their development was discussed, and what scope, goals, and resulting schedule constraints could be derived.

The understanding gained from the meetings, was that the motivation for the thesis was the need to develop the so far only preliminary investigated new *Flow* EBMOM, concerning the manufacturing and supply chain of Wärtsilä engine blocks from start of casting, through machining, to delivery for start of assembly, in the upcoming new environment of STH manufacturing strategy, capability, and environment, while pursuing the overall improvement of lead time, total cost, and throughput.

The resulting thesis schedule was agreed to set in-line with starting the processes according to the new EBMOM at STH by June 2021, and therefore to have the EBMOM's main processes clarified by spring 2020. The preliminary milestones for the thesis were therefore set as; Creating a mapping of the current-state operating model by the end of January 2020. An outline of the concept operation model by end of March 2020.

Value Stream Mapping and interviews were at this initial point considered for data collection in the thesis, and to work as a basis for detailed discussion and decision making regarding the EBMOM development. The thesis theoretical contents regarding the operation model areas of interests, was suggested to be dealt with extensively on a general level, but without going too far into the details of the different areas. It was suggested to consider the prior Wärtsilä Delivery Centre Vaasa (DCV) business case analysis as basis for design of the supply chain structure for the new EBMOM. Leverage the DCV Machining Delivery Unit (MDU) resources and knowledge to develop the would-be required new machining model. Refer to ongoing other STH project development streams to gain synergy regarding new technologies and knowledge. Communicate with the Research and Development (R&D) -department about development needs in the areas of product- and engineering data, as implied by the eventual definition of the engine block machining model, while searching for opportunities to drive machining cost down.

It was deemed that further discussions on these initial thoughts should still be held with also the key stakeholders of the to-be developed EBMOM, to make sure that key point of views would get considered before going further with the definition of detailed scope and plan for the thesis process. The thesis author was also at this point introduced to the STH project team in their weekly status meeting.

3.1.3 Thesis meeting with key stakeholders

The third meeting was held at the start of December 2019. In the meeting, key persons participated from the initially relevant deemed main stakeholder functions of, Smart Manufacturing & Innovation, Business Development, Machining Delivery Unit, Supplier Development, and Strategic Purchasing.

The preliminary thoughts on the development of the new *Flow* EBMOM and the aligned preliminary thesis plan, were presented by the thesis author. The thesis supervisor explained the background and motivation and the resulting needs for the thesis work, and the preliminary vision of its deliverable result. Extensive discussion amongst the supervisor, author, and participants proceeded to collect the stakeholders' inputs of first thoughts and questions. As a result, the following main areas of interests, as seen in table 1, where investigation should be carried out in cooperation with stakeholders, could be recognized:

Table 1. *Identified main areas of interests for investigation.*

Main areas of interests:
Supply chain management, information-, and material flow.
Production planning and scheduling.
Research & Development and product data management.
Procurement and purchasing.
Business Development.
The overall development project.

The consensus amongst the stakeholders was, that the thesis should investigate the development needs and potential of the new EBMOM, and to carry the body of the development process towards a common vision. Not necessarily to comment on the detailed implementation of the new operating model solutions, but to find the concrete steps needed to move forward with the definition of the model to be used at STH.

The facilitation of workshops with invitation of participants from key stakeholder departments, was seen as an efficient way to bring up issues to attention and start moving their development forward. Additionally, information produced by mapping the current-state EBMOM was seen as a potential way to gain basis for development and decision making to define the future-state EBMOM. The Agile Scrum Sprint based development framework was also considered to be possibly used at the later development stage of the EBMOM to manage the systematic development of the future-state EBMOM's solutions.

The following initial understanding was gained regarding the definition of this thesis:

Scope:

- Covers the new EBMOM development in its whole various areas of interest.
- Investigates what changes are needed to current ways of operation? What new possible ways of operating can be found? What current issues can be resolved?

Role:

- Helps finding the common state-of-will, development scope and steps, needed to be done regarding the overall supply chain.
- Manages the overall development process around the individual development streams to maintain a clear goal among all participants.
- Explains the steps needed to be done to achieve operation according to the new EBMOM at STH. Does not necessarily comment on the detailed implementation.

Approach:

- Maps the current-state, to use as basis of definition of future-state EBMOM.
- Facilitates group working to surface issues, gain commitment from stakeholders.
- Starts and structures development process to carry it towards the common vision.

Already, many discussion points were surfaced regarding the development of the new EBMOM concept, according to the *Flow* vision of it. The items were written down and stored as meeting notes. At this point, they would guide the author in aligning the thesis plan with the needs of Wärtsilä, but in a later stage in chapter 3.2.4 the qualitatively processed notes would help to form a list of preliminary questions surrounding the development of the EBMOM, in relevant areas of interests. The following main stakeholder functions, seen in table 2, could also be identified from this discussion:

Table 2. *Identified main stakeholders to development.*

Main stakeholders to development:	
Smart Manufacturing & Innovations	New Product Introduction
STH Development Projects	Research & Development
Business Development	Delivery Management
Machining Delivery Unit	Category Management
Strategic & Operational Purchasing	Production Planning
Supplier Development	Material Supply & Development

Ultimately, the meeting discussion produced basis for the author to define the research problem, research questions, and the subsequent thesis research plan for investigation.

3.1.4 Thesis meeting with company and university supervisor

The fourth meeting was held including the thesis supervisors from Wärtsilä and Tampere University, in the beginning of January 2020. The thesis author had drafted a research plan based on the understanding gained so far from the meetings within the company. This included first defining the background, motivation and needs for the thesis, which in turn formulated the research problem. From which, the scope, goals, and research questions for the thesis could be derived, and for answering of which the research strategy and methods could be chosen. The following definition and plan were agreed upon:

Thesis research problem:

- Along with the move of Wärtsilä Finland Oy Vaasa area operations into the new STH, center of product development and production, a new EBMOM regarding the casting and machining supply chain is needed to be developed, to successfully operate in the changing context of the *Flow* vision of manufacturing strategy, MTAC Large CM system manufacturing capability, and the rest of the changing operation environment, while pursuing overall business goals of improved lead time, total cost, and throughput.

Research questions:

1. What is the current engine block manufacturing operating model?
2. How is the common state-of-will found regarding the way of operating in the new EBMOM?
3. What areas of interest and issues to consider are identified regarding the development of the new EBMOM?
4. What is the development scope and the steps to achieve operation according to the new EBMOM?
5. How is supply chain lead time, total cost, and throughput improved in the new EBMOM?

Research goals:

- To investigate, facilitate, and manage the overall development process of defining the new EBMOM, and answering of research questions to the extent feasible in the thesis time constraints.

Research scope:

- Research the development of the new EBMOM concerning the manufacturing and supply chain of Wärtsilä engine blocks, from start of casting, through machining, to delivery for start of assembly in the context of STH environment and set business goals, without the need to comment on detailed solutions or final implementation.

3.2 Development approach activities

At this point of the thesis process, four meetings in total were held, and independent work was carried out in parallel. The had author familiarized himself to the topic, and the more specific matters already raised by the discussions with main stakeholders of the thesis. The research plan for the thesis was agreed upon, and the thesis started officially. A vast overview of the thesis theoretical- and conceptual framework was personally carried out by the author, to ensure a starting point of holistic understanding of the topic.

The following structure will continue to describe the thesis practical process activities.

- Choice of research strategies and methods.
- The definition and redefinition of a group working workshop plan.
- Discussion of *Flow* EBMOM development with the Machining Delivery Unit.
- Introduction to the MTAC Large CM simulation model.
- Facilitation of the *Flow* EBMOM development process planning day workshop.

3.2.1 Choice of thesis research strategies and methods

In the first weeks of January 2020, the author started planning the practical activities of the thesis process. The plan was started by defining the to be used research strategies and methods the author deemed appropriate, for guiding the practical activities, data collection, analysis, and producing of results for the thesis.

The **technical action research** strategy was chosen since the thesis would address the practical problem of the need for development of the new EBMOM, in the environment of Wärtsilä and its internal stakeholders. Also, due to the defined role for the thesis author, to act as a change agent facilitating the data collection, and development activities, while leveraging the knowledge and contributions of key stakeholder participants.

The **descriptive case study** strategy was chosen due to the need to produce descriptions and insight related to the studied instance, the EBMOM and its environment, for further investigation and solution development. Additionally, all the related processes and interdependencies within the instance and its environment would need to be considered. Also, multiple information sources from various points-of-views and data collection methods would likely be needed, due to the vast scope of the researched topic, to bring confidence into the results.

The **focus groups** research method was deemed fitting to serve both research strategies by being an efficient way to access the expert knowledge and vast point-of-views of participants, and to naturally carry the discussion along matters deemed most important by the stakeholders. Additionally, it would enable effective assessment and creativity between participants, while the thesis author could work in parallel in steering, feeding, and documenting the discussion and development process activities. In practice the facilitation of workshops or other group working sessions was seen as a way to realize this. Characteristic of the *interviews* research method could be used in a supporting way.

The research methods **creative techniques**, **data analysis** and **literature review** were also deemed good methods, to produce supporting knowledge of the relevant theoretical framework and supporting material of practical findings. These could support the development activities during the process, by defining the frameworks, techniques, and tools for working, data collection, analysis, presentation, and decision making.

The idea of the using the Agile Scrum Sprint based development framework in the thesis practical process was dropped due to lack of prior experience on the utilization of those methods on behalf of the author, and doubts of their effectiveness at the initial data collection stage of the thesis. The methodology's applicability to the later stages of development, however, was still considered highly appropriate due to its prior usage at other Wärtsilä's development processes, making it likely familiar and easy to utilize in cooperation with stakeholders. Revisiting to consider its potential usage was planned.

3.2.2 Plan for a Value Stream Mapping workshop

To answer the 1st research question of "**What is the current engine block manufacturing model?**". A Value Stream Mapping (VSM) workshop was first decided to be planned. The idea was that with the VSM workshop group working, the knowledge of the invited expert stakeholder participants on their own operations, could be utilized to map the current-state EBMOM, from start of casting, to delivery of the machined engine block to assembly. The motivation for the workshop was to gain an understanding of the current-state EBMOM's material and information flows not only for the author, but for the thesis findings, and for all the participating invited stakeholders. By mapping the systems, stakeholders, functions, information- and material flows and inventories in the current supply chain, the current-state EBMOM could be defined as basis for developing the future-state *Flow* EBMOM.

Additionally, the information potentially provided by the VSM was considered to eventually help in answering the 5th research question "**How is supply chain lead time, total cost, and throughput improved in the new EBMOM?**". By collecting descriptive base data on the performance of the current EBMOM's supply chain value streams, it would be possible to set measurable comparison points for later discussions comparing those to the future-state EBMOM's value streams. The overall fulfilment of performance and business goals could be analysed, and basis provided for subsequent decision making regarding the final definition of the *Flow* EBMOM.

The planned to be mapped information could also serve as basis to at least discuss the 3rd research question **"What areas of interest and issues to consider are identified regarding the development of the new EBMOM?"** by potentially helping to recognize points of issues, development areas, and the wasteful non-value-adding elements that could be improved in the current EBMOM.

It was planned that if the workshop was held, the author would interview the participants first to create a draft VSM containing the basics and obvious items of the map before carrying out the actual workshop, to ensure the time of group working would not be wasted on mapping trivial matters. The workshop facilities would also be prepared in advance with all office supplies needed to physically carry out the mapping process.

Regarding the participants preparation in case the workshop was held, it was planned that as a pre-task, VSM method introducing material would be shared and recommended to be read, and therefore prepare the participant to the Value Stream Mapping process. In the would-be invitation, they would also be challenged to start thinking about their own area of operation in the VSM context and if possible, to bring useful pre-existing material to the workshop to support the effectiveness of the mapping process.

Regarding documenting the results of the potential workshop; The physically created material would be collected, and afterwards digitized and refined by the author. Independently further investigating still unknown or unclear areas via separate interviews and data collection. To fill in missing information and complete the map. The final processed results from the workshop would be then have been reviewed with the participants in further group working sessions, to identify the key issues or areas of interest needing change regarding the development of the *Flow* EBMOM and its future-state map.

According to the preliminary plan, these would-be identified items brought up by the potential workshop mapping process regarding the future-state EBMOM, would then have also been set as focus points for analysis with comparison to established theory. Development streams would have been started to go forward to creating solutions for them. Also, any identified key comparison points between the current- and future-state EBMOM VSM's would have also been at this point defined and documented for later use.

3.2.3 Redefining the planned workshop's focus and contents

In the middle of January 2020, the previous plan and further defined details for the VSM workshop were presented in a meeting to the thesis supervisor to collect their input and refine the plan accordingly.

It was concluded that while the VSM workshop plan would likely be a good way to carry out base data collection on the current EBMOM, for the reasons established in the previous chapter. Concerns were raised, if the VSM workshop would truly be an effective way to efficiently put the *Flow* EBMOM development process into motion, which was seen as the priority. Doubts were also raised, about the VSM process likely require extensive data collection via go-and-see activities, to produce valid results. Which would not be practical upstream from Wärtsilä DCV.

It was agreed that the workshop's focus and contents should somehow be changed. Discussing the essential items needed to be investigated, changed, or solved, to achieve successful operation with new EBMOM, according to the preliminary *Flow* manufacturing strategy vision, and in the context of any already defined aspects of it.

The VSM workshop plan was decided to be kept available to proceed with, but set aside for now. The 1st research question **"What is the current EBMOM?"** was at this point chosen not to be attempted to directly answer anymore, as it would not be possible without the VSM workshop or some other equivalent data collection and analysis process.

The redefining of the workshop's content and structure was left to the thesis author as an individual task. A method that could more effectively channel the group working towards the prioritized matters would need to be found. Alternative group working techniques were started to be researched.

It was also understood that participants would need to be introduced to the background and motivational contexts of the workshop. What are the drivers for the new EBMOM development? What is the role of this thesis regarding development? What are the themes of discussion to focus on? The introductions and themes were considered key for orienting the participants to think about the workshop activities in the appropriate point of view, to ensure group working produced results that the workshop was structured for.

The need was also noted to make calendar and workspace reservations early in advance for the first workshop and for any potential further workshops. This was due to the need of avoiding scheduling conflicts that would likely appear amongst the large number of needed participants and the availability of suitable workspaces.

The necessary deemed introductions for the beginning of the workshop were planned. The presentation materials were arranged or created regarding the *Flow* manufacturing strategy vision for the new EBMOM, regarding the MTAC Large CM system, and regarding the role of the thesis work in the overall development. The definition of the workshop group working activity steering discussion themes were also started to be drafted.

The presentation about the Large CM system plans, was agreed to be held by the thesis supervisor as it was his expertise. The presentation would help provide context by explaining the manufacturing process, main resources, and the overall system concept, helping participants evaluate its effects on the development of the *Flow* EBMOM.

The *Flow* vision of manufacturing strategy regarding to new EBMOM would be presented by the thesis author. It would help explain the needs set for the thesis and the development of the *Flow* EBMOM, which in turn would help explain the purpose of the workshop.

Further advice on facilitating and the existence of any official best practices was asked from colleagues who had previous facilitating experience regarding other development projects at Wärtsilä. The advice regarded general level matters such as finding a suitable workspace, procuring potentially needed tools and materials, defining appropriate group sizes, scheduling, and structure for the workshop. Some advice was received, but the detailed plan to carry out the workshop was done by the thesis author.

The date of 18.02.2020 was set for the workshop and a 4-hour schedule for the day was preliminary defined, however still waiting for the detailed structure of the to-be chosen group working technique. The participant list was defined with the help of the thesis supervisor. It was attempted to ensure that the right persons from all areas of the *Flow* EBMOM would be present at the workshop. Also, that they would be from the right level of leadership, to execute the potential changes during development. The needed workspace for the workshop was booked and the invites sent for the participants. The invites at this point, were only to reserve the time for the workshop. All additional information to prepare the participants for the workshop, would be sent once the plan was finalized.

3.2.4 Discussion with MDU and listing of so far findings

At the end of January 2020, it was agreed with the thesis supervisor, that in the remaining few weeks leading to the workshop, the time should be utilized effectively. Discussions should be started with the Machining Delivery Unit, regarding aspects relevant to their expertise in the development of the *Flow* EBMOM.

A meeting was held, where discussions ranged from; How a new engine block machining model phasing could be defined in a way that would best support the future *Flow* manufacturing strategy vision, while taking into consideration the known capabilities and production environment of the MTAC Large CM -system and the rest of the engine block machining supply chain? What machining model would enable successful operation at STH as part of the to-be developed *Flow* EBMOM?

Similarly, to the first discussion with stakeholders in chapter 3.1.3, many discussion points were again identified in various areas of interests. The items were again written down and stored. However, this time the notes from both meetings were processed by Qualitative Data Analysis, to form a list of questions separated to areas of interests needed to be considered as part of the *Flow* EBMOM development.

The findings from the so far two meetings held with the key stakeholders of the thesis topic, are listed in table 3. The written down findings were processed to a form where the identified main areas of interest were combined into a similar abstraction level and listed in rows with bolded text. The discussion points as questions within these areas of interest were listed in the rows below them, formed according to the understanding made by the thesis author.

Table 3. *Identified areas of interest and discussion points regarding thesis topic, as identified in the so far meetings with thesis topic stakeholders.*

The manufacturing strategy and operations:
What are the manufacturing scenarios, product range, and volume planned to fill capacity of the STH MTAC Large CM system?
What is the desired level of manufacture of engine blocks arriving at STH?
What are the feasible possibilities to design the new machining model phasing?
What machining model scenario enables best overall performance and cost?
What is the scope of primary and secondary manufacturing operations in the external supply chain manufacturing, storage, and transportation, as derived from the new machining model?
What is the scope of manufacturing operations in the internal Large CM system, as derived from the new machining model?
How can service flexibility, backup capability, resource and flow efficiency be ensured?
How will personnel operate within the in-house manufacturing processes?
Supply chain management, information-, and material flow:
What inputs and outputs of production information are needed between actors?
What changes are needed in the control systems?
What kind of buffers should be utilized in the supply chain and near STH?
What are the new effects and potential in transport routings, set by the new Antwerpen-Vaasa shipping line?
What protection needs will the engine blocks machined to various levels of manufacture require at different stages?
What are the requirements for each main manufacturing stage in the supply chain to be able to operate?
How can the indirect needs of quality assurance, protection, blasting, painting, marking, etc. be arranged in different points of supply chain?
Production planning and scheduling:
What changes are needed in production planning and scheduling?
How is the transparency and traceability of engine blocks arranged between manufacturing operations and transports until designation to specific project?
What will be the control points to enable locking of production schedule?
How can recent development knowledge regarding cylinder head manufacturing be applied to engine blocks?
Research & Development and product data management:
What changes are needed for component design, manufacturing documents, product data management, and machining process method planning?
What possibilities exists on standardizing of castings, and pre-machining of engine blocks, to achieve late variation?
Procurement and purchasing:
What changes are needed regarding casting and machining procurement, and operational purchasing processes?
Business development:
How can lead time be shortened, total cost reduced, inventory amount and obsolescence risk minimized?
How will the direct and indirect manufacturing, transportation, and inventory costs change?
Overall development project:
How can all relevant stakeholders be consulted to discuss and decide on a common vision and development plan?
How to achieve development process where responsibilities are shared, and resources committed to development?
What is a realistic timeframe to achieve development and definition of the *Flow* EBMOM?

From the findings in table 3. a few key points of discussion could be noted that needed to be considered in the next steps of the development of the *Flow* EBMOM:

- The appropriate definition of the engine block machining model phasing would heavily depend on, what kind of production scenarios would first be defined to best utilize the capability characteristics of the Large CM system, and how to secure performance in-house.
- In parallel to designing the engine block machining model to best suit the Wärtsilä in-house manufacturing operations, the secondary manufacturing operations at suppliers and the needs regarding storage and transportation in the supply chain, were important to consider, to not cause significant development issues there.
- The development of new manufacturing documents such as the engine block machining drawings to support the changing machining model would be needed, and the process should be started early due to the likely long timeframe needed.
- All relevant stakeholders should be gathered to discuss and start making decisions together, to avoid conflicting plans in different areas of the *Flow* EBMOM. A development process should be arranged where responsibilities regarding the development areas are shared, and resources would be officially secured.

Overall, the meeting helped to gain awareness amongst the MDU stakeholders about the need to start the development of the *Flow* EBMOM. Also, key questions, considerations, and dependencies regarding development were immediately identified.

3.2.5 Familiarization with MTAC Large CM simulation model

As was noted from the previous meeting discussion with the MDU stakeholders. The need was identified to somehow analyze the performance of the MTAC Large CM manufacturing system, with the different possible production scenarios and machining model scenarios that could be developed. The thesis author and thesis supervisor agreed that this would in theory best achieved by running simulations on the production process of the Large CM system.

An existing Visual Components and Excel -based simulation model had already been developed for Wärtsilä, that could be used for this. This model however was not up-to-date, according to the present plans for the Large CM system. It was decided that time would be taken for the thesis author to familiarize with the simulation model, and to consider its utilization possibilities at supporting the development of the *Flow* EBMOM.

Since the simulation model did not match with the actual plans of the manufacturing system it supposed to represent, it would need to be updated by the company who had originally developed it for Wärtsilä. The investigation of needed changes was also to be started by the author, and once identified, to communicate the needs to the developer to produce the needed updates.

It was also agreed with the thesis supervisor that the author would run and present some preliminary simulation results at the upcoming workshop, even though the simulation model was not up-to-date. The simulation runs and subsequent results presented in the workshop, would of course at this point only serve as purely crude examples, to bring forth awareness of the availability and potential benefits of the simulation tool for decision making. A few slides would be presented by the thesis author, about the simulation model, the simulation runs, and their results.

Base data used for the simulation at this point could only be old manufacturing data provided by the thesis supervisor, which had some time ago already been collected from the existing DCV current-state EBMOM production system. The results from using this base data for a few simulation runs to show in the upcoming workshop, would therefore only likely point to the inapplicability of the traditional machining model phasing and production scenarios with the future Large CM -system. However, it could evoke motivation among the workshop participants to start developing the *Flow* vision based new machining model, production scenarios, and other related areas of the operating model.

The familiarization with the MTAC Large CM system Visual Components simulation model was at this point started by the author, to produce the few simulation runs, and to also start defining the needed changes to having it updated.

3.2.6 Final definition of the workshop plan

In the last weeks approaching the date of the planned workshop, it was agreed with the supervisor to finally define and lock the workshop plan. Based on the observations made in the discussions so far and with the recent discussions with MDU stakeholders, it was generally felt that with the large number of interdependencies and concerned stakeholders in the development of the new *Flow* EBMOM, it was difficult to visualize independent development plans and carry them forward in contained information silos. Therefore, the development process should be discussed and started with all the relevant stakeholders simultaneously. Subsequently a new plan was made, shifting the focus fully into carrying out a planning day for the start of the practical development of the *Flow* EBMOM instead.

The creative ideation technique called *Cumulative Group* was chosen to be used as reference for the structure of the workshop. With the replacing technique, the author thought it could be argued that the workshop would still efficiently leverage the participants knowledge on their areas of expertise as is typical for *Technical Action Research -strategy*. However, the results of the workshop would be more effective at speeding up the start of the actual development of the *Flow* EBMOM. This would realize by using the method to map the participants independent and combined views, on any prioritized questions or points of discussion defined by the author for the workshop.

Structuring the workshop plan using the Cumulative Group -technique as a basis, would effectively enable interaction between all the invited key stakeholder participants at the same time, and the resulting discussions and observations considering the workshop themes and questions would be taken in simultaneously in multiple point of views. The synergy between participants could produce better results faster, than individual interviews or discussions with the participants separately, by allowing the opportunity to present questions, align views, and come to conclusions as a group. The group working way would also enable the author to act in the role of, guiding the discussion by the predefined themes and questions regarding the topic, to keep the group working on track, to concern relevant matters, and reveal and document the results desired to gain from the workshop.

The author also evaluated that the usage of the research methodology *Focus groups* and *Interviews,* would be also more emphasized by using this group working technique. Even though in the point-of-view of the *Interview* research method, the group working would not be able to produce complex information. Due to its semi-structured nature, it could produce information on a vast scope of issues, and from unexpected point-of-views. Views not realized to set as direct questions to originally guide the discussion.

The author argued that this kind of workshop could provide answer to the 3rd research question of: **”What areas of interest and issues to consider are identified regarding the development of the new EBMOM?”**, and it could potentially provide basis to start answering the 2nd and 4th research questions of: **”How is the common state-of-will found regarding the way of operating in the new EBMOM?”**, and **” What is the development scope and the steps to achieve operation according to the new EBMOM?”**. Also, the change of the group working method would fortunately not have any effect on the list of needed participants already invited to the workshop, or the workspace that was already booked.

3.2.7 *Flow* EBMOM development planning day workshop

The workshop as defined according to the new plan in the previous chapter, was finally carried out on the date of 18.02.2020 with the title of *STH Flow Planning Day*.

Once the 14 participants out of 15 invited had arrived, the workshop was started by the author acting as the facilitator. The progress of the workshop was structured and controlled by displaying a presentation on a large screen in front of the conference room, where all relevant information were presented to the participants. Information regarding, the goals for the day, introductions to the topic, the day's schedule, discussion themes, group working instructions, and so on.

The day's goals:

The first thing that was done, was to present the participants with what were set as the day's goals for the workshop. As can be seen in figure 9, three self-explanatory goals were set:

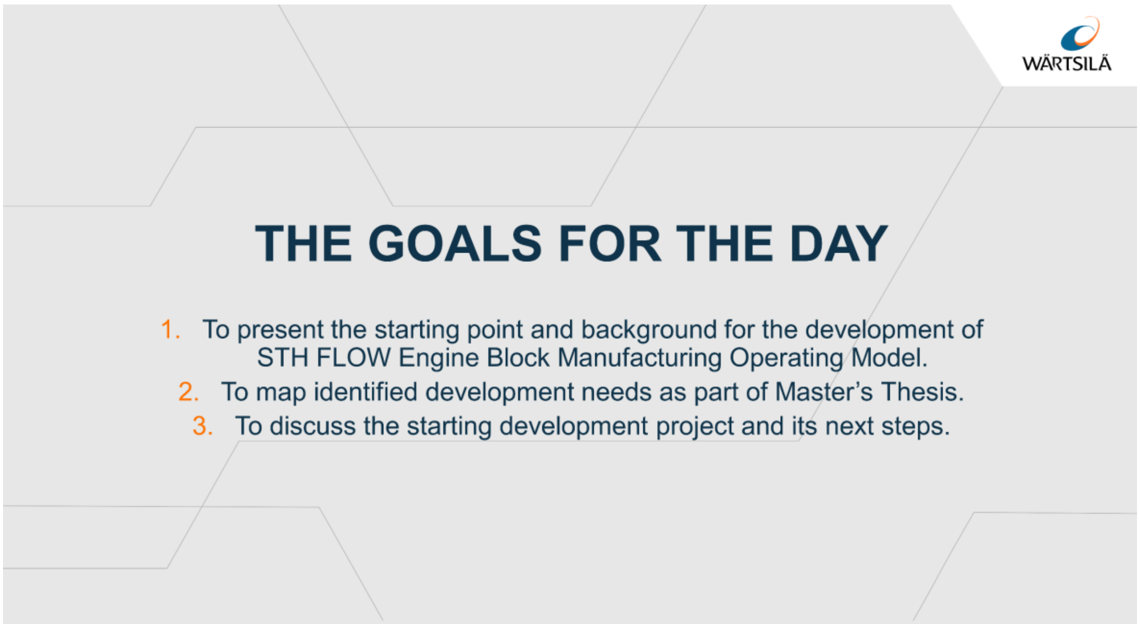

Figure 9. *The goals for the day as presented to the workshop participants.*

The day's schedule:

As the next step, the author continued to present the planned schedule for the day as shown in figure 10. It first contained reserved time for the introductions presented by the author and thesis supervisor, about the related background for the workshop discussion and group working topics. A small timeframe was also reserved after this for any questions that might raise about the workshop at this point. The schedule continued with time reserved for the main part of the workshop consisting of; Explaining the following group working activities. Carrying out the multiple steps of the group work. Continuing the group work, by reviewing the group working results. Lastly, the schedule continued with time reserved for discussion, about the authors and the participants thoughts about the next steps of the *Flow* EBMOM development, and free discussion concluding the workshop.

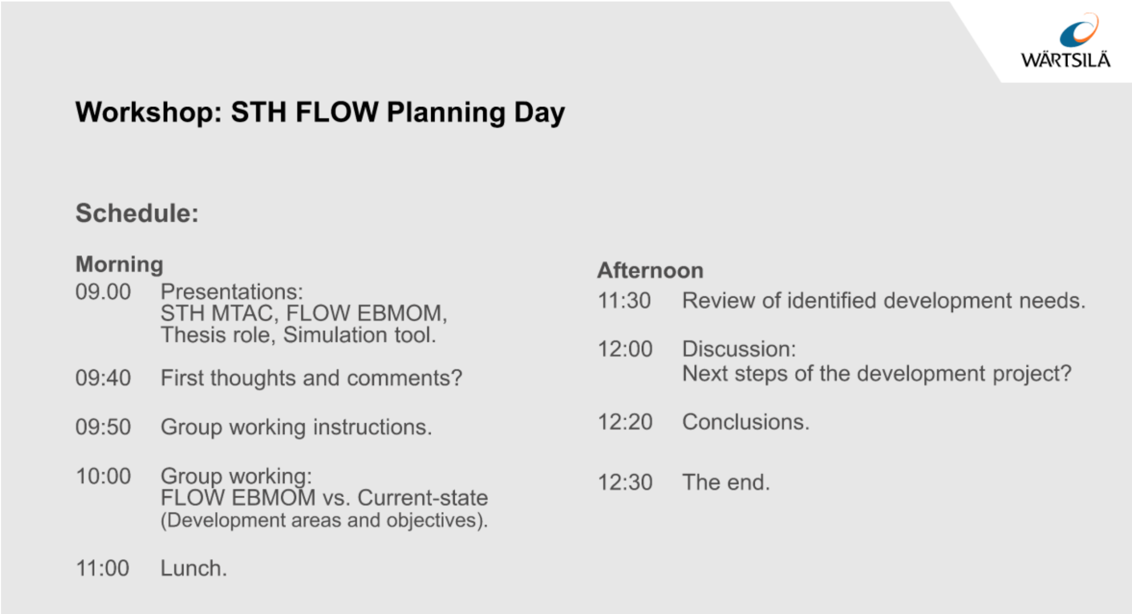

Figure 10. *Presentation slide defining the day's schedule for the workshop.*

Recommendation to take notes

At this point the next slide was presented, where it was simply recommended to start writing down any questions or comments, that would come to mind during the introductory presentations that would follow in the next step. The author had prepared for this by arranging pens and A4 papers available in the workshop room for each participant.

Introductory presentations

As the next step the introductory part of the workshop began. As it was arranged, the thesis supervisor showed the participants a similar presentation about the plans for the future STH in-house engine block manufacturing system, the MTAC Large CM, as was provided to the thesis author at the beginning of the thesis in chapter 3.1.1. However additionally, this time the presentation also contained a short video captured from the simulation model, which provided a 3D recreation of the manufacturing system demonstrating the generic manufacturing process workflow. This time the presentation also detailed the at this point known Work Breakdown Structure and high-level work packages for the development of the Large CM system, containing the *Flow* EBMOM as being one required part of it.

The second introduction was made by the thesis author. The main purpose of the presentation was to explain to the participants, the at that point understanding of the needs for the development of the *Flow* EBMOM, in the context of the previously presented new Large CM system, and the changing *Flow* vision of manufacturing strategy at STH. Also, the role, scope, and timeframe of this thesis in the overall picture and what work had been done at this point.

The third introduction was also held by the thesis author about the Visual Components and Excel based MTAC Large CM simulation model, that the author and thesis supervisor had previously considered might prove to be a useful tool at some stage of the *Flow* EBMOM development. The simulation model was presented to the participant in the point-of-views of; What are the simulated resources in the Visual Components model? What base data is needed to be input into the Excel portion of the simulation model? What output data is available for analysis after running the simulation? As planned a few preliminary simulation runs were presented in the workshop. The purpose of them was to roughly demonstrate the effect on overall system throughput, by changing the process times needed in different machining model phasing scenarios. Basically, testing the current EBMOM machining model phasing with the new Large CM system capabilities, and comparing the results, to a very preliminary idea of the *Flow* EBMOM machining model phasing and its results with the Large CM system capabilities. The details of the simulation runs are irrelevant to go through in this thesis, since the runs were done with the simulation model that was still not up-to-date and the starting data was highly inaccurate, but they demonstrated to the participants that the old machining model phasing was not appropriate to go forward with in the future and development was indeed needed.

The aim of these presentations was to bring clarity for the participants about the context this workshop was held in. To emphasize the immediate need for development of the *Flow* EBMOM, and the fact that it had already been started indirectly through this thesis, and that the EBMOM's next development steps would be largely defined based on the information gained from the group working activities of this workshop. They were also held to emphasize the importance of developing the *Flow* EBMOM, due to the incompatibility of the current EBMOM machining model phasing with the new Large CM system, as shown by the simulation model. The carrying out of these presentations was also considered to be in line, with what was identified as good practice in the *Cumulative Group* technique on basis of which the workshop was loosely designed on.

Workshop discussion framework

After the introductions, the workshop presentation slides continued in figure 11. This presented the themes that would act as a supporting conversation steering framework, to guide the discussion in the actual main item of the workshop, the group working stage. The slide contained the initially prioritized so far identified main questions, sub questions, and discussion points regarding the to be developed *Flow* EBMOM. It would define the point-of-views in which the group working tasks could be thought about by the participants and provides basis for drawing inspiration during the process.

The items on the slide represented the thesis authors so far understanding of the key matters that should be focused on, in the starting of development of the *Flow* EBMOM. Therefore, it might have not been all inclusive at that point. The author thought it was good that his understanding on the matters was up for criticism at this point. In case any essential matters were missing from the slide in the opinions of the workshop participants, it would likely encourage the discussion that was pursued. More relevant matters would be identified to add to the list, in the workshop group working process.

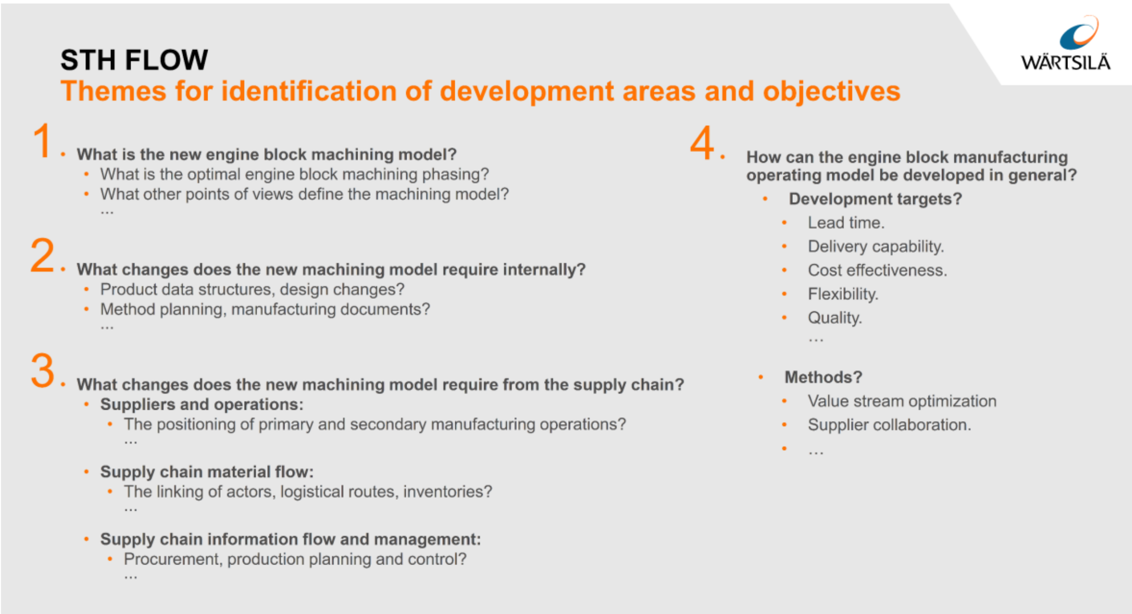

Figure 11. *Presentation slide defining the themes guiding the workshop group working activities.*

The themes mostly concerned the structural development of the rest of the *Flow* EBMOM according to the initial definition of the to-be developed new machining model. Also, they concerned the general EBMOM performance development point-of-view. Since the main goal for the workshop was to efficiently get started with the development of the *Flow* EBMOM, the steering of discussion to identify these practical matters and their interdependencies needing development, was seen as the most effective way gain substance.

This presentation slide was also printed as physical material and multiple instances of it were positioned around the workshop workspace for participants to easily reference it.

Stage 1 of the group working process

The next step going forward from presenting the workshop discussion framework, was to start the actual group working process. Stages were planned loosely according to the chosen *Cumulative Group* techniques principles, attempting to leverage the methods strengths, while applying into the specific needs of the workshop. The instructional slide for the stage 1 is seen in figure 12.

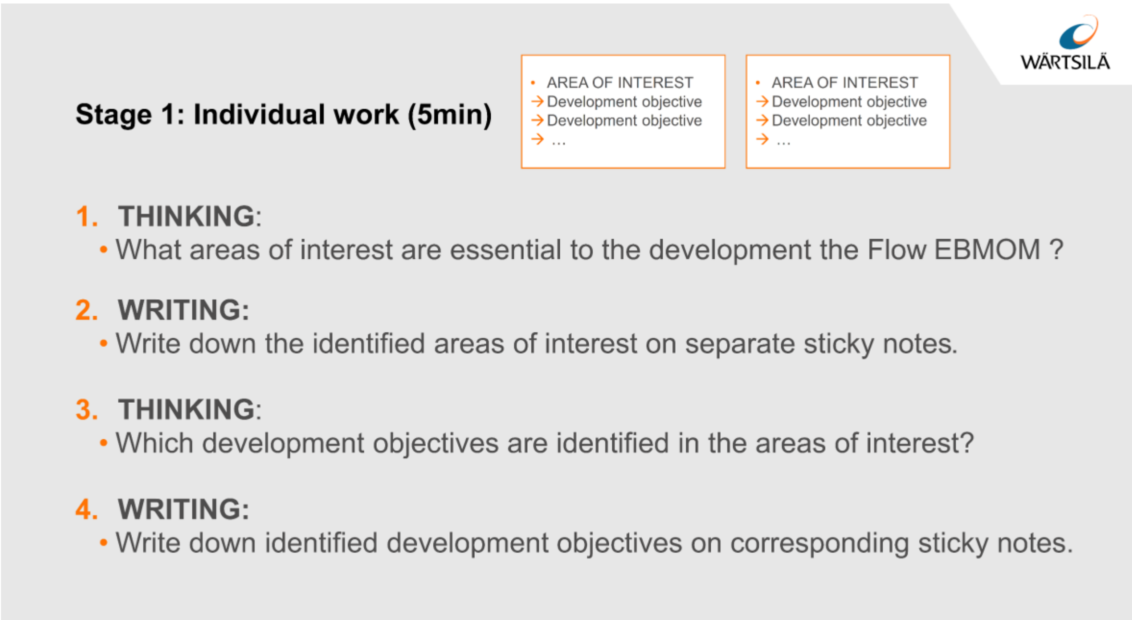

Figure 12. *Presentation slide explaining stage 1 of group working process.*

The 1st stage of this group working process consisted of individual work. The participants were instructed to, grab a pen and sticky notes and during 5 minutes to:

1. Think about, what areas of interest are essential to the development the Flow EBMOM in the participants point of view.
2. Write down the identified areas of interest on separate sticky notes.
3. Think about which development objectives can be identified under the previously identified areas of interest.
4. Write down the identified development objectives on corresponding sticky notes.

The first stage of the group working process was planned this way, to ensure the possibility to work individually, without social barriers and to promote divergent thinking. It also would be beneficial in the case that individual working suited some participants better than group working. The author monitored the individual working process in case the participants were confused or came up with any clarifying questions to ask.

Grouping of participants

After the 1st stage of the group working process was completed, the groups for the remaining stages were defined for the participants. The groups were defined in advance as the list of participants available to join was confirmed. The groups were defined in a way, that the group would consist of members from a wide range of expertise, to bring multiple points of views to support the following group working discussion. In total 4 groups of 3 members each was formed prior to the workshop, but in the end one participant did not arrive, and two not considered extra participants without predefined groups then joined groups one and two, resulting in four groups of 4, 3, 3 and 3 participants.

Stage 2 of the group working process

After revealing the participants groups, the instructions for the 2nd stage of the group working process were explained as is shown in figure 13. Continuing with the principles of the Cumulative Group method, the participants were instructed during 15 minutes to:

1. Gather into the defined groups in front of the designated papers on the wall.
2. Present each other the identification results from the individual work.
3. Attach all the so far created sticky notes to the paper designated for the group.
4. Discuss and define in group, more areas of interest and development objectives.

The thesis author as the facilitator of the workshop had prepared the A1 sized flipchart papers to the walls ready for utilization in the group working process. The process was observed by walking around the workspace, listening to the discussions and occasionally steering the discussions to relevant matters, and ensuring the matters were noted down.

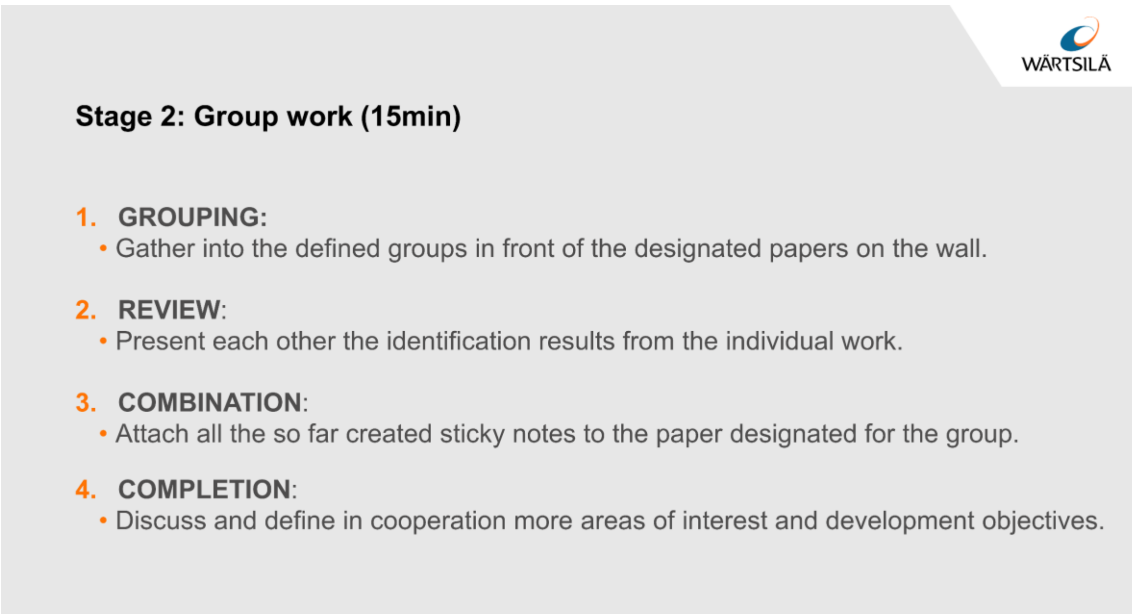

Figure 13. *Presentation slide explaining stage 2 of group working process.*

Lunch

At this point it was scheduled to take a break from the workshop and go to lunch. Obviously, it was a necessity to fulfil during the workday of all participants, but timing it to happen at this point of the workshop gave participants time to potentially process the so far activities and help continue the group working process with new energy.

Stage 3 of the group working process

After lunch, the group working process was continued to stage 3 as seen in figure 14. This stage was split in to three steps, to be carried out group by group in rotations, until all had carried out the steps. The groups were instructed to:

1. Present their definitions of areas of interest and development objective to the other groups.
2. The other groups should comment on the defined areas and objectives, and suggest further objective additions which would be also noted.
3. The process is rotated and the 1st and 2nd steps should be repeated in turn by the other groups.

Time of 10 minutes were reserved for each group and 40 minutes in total. The thesis author listened to the discussion to ensure that all additions would be noted. This stage and the previous stage enabled for further consideration and elaboration of the identified matters in different point-of-views of other groups and their participants.

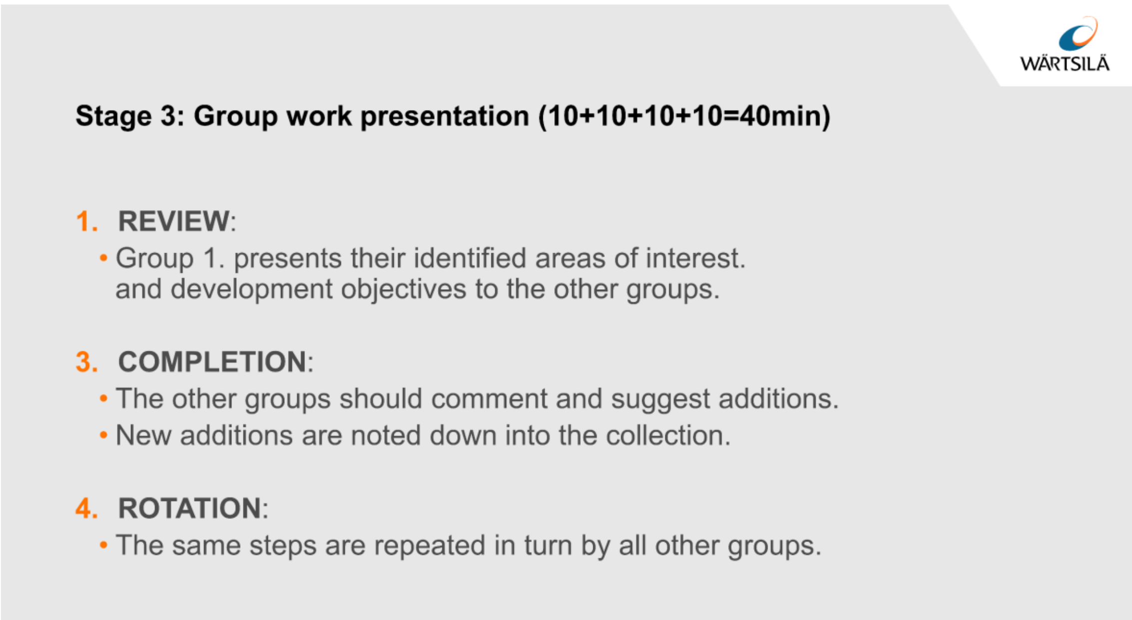

Figure 14. *Presentation slide explaining stage 3 of group working process.*

Stage 4 of the group working process.

For the final stage of the group working process as presented in figure 15, the participants were instructed to:

1. Spend 10 minutes freely reviewing the results created so far.
2. To input any additions that come to mind.
3. Gather together for discussion.

The next 20 minutes were reserved to discuss the participants opinions on the questions:

- Were the areas of interest and development objects identified compherensively?
- Was the workshop group working technique appropriate?
- Hw should the to-be-started Flow EBMOM development process be carried out, in relation to these workshop findings?

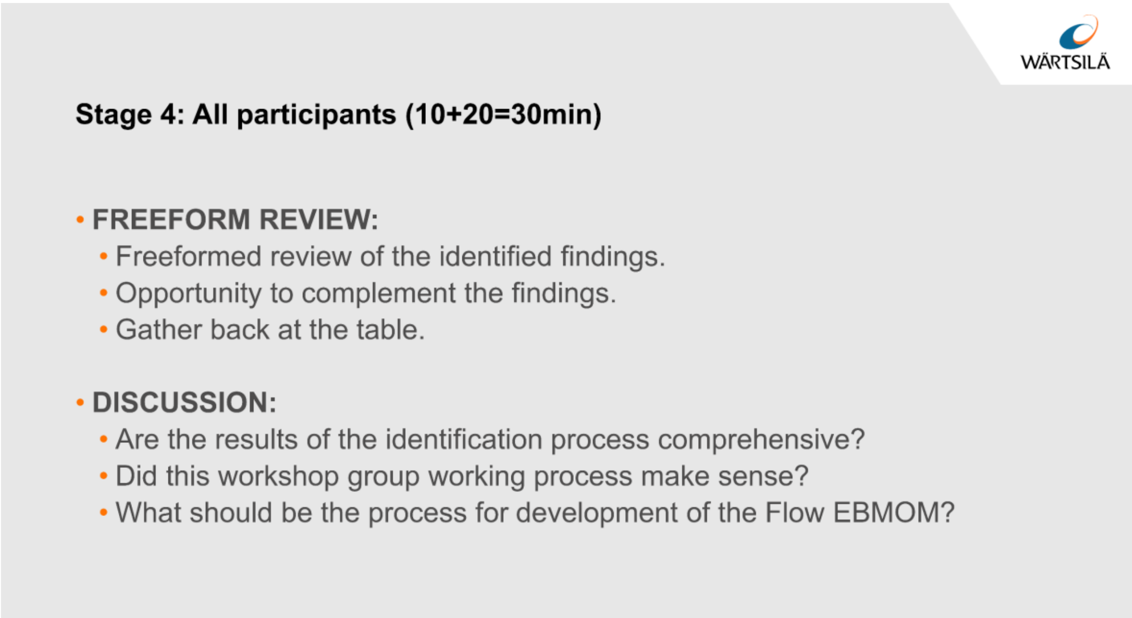

Figure 15. *Presentation slide explaining stage 4 of group working process.*

Conclusions of the workshop and the next steps of development

The consensus identified in stage 4, was that the amount and scope of identified items was a great basis to start going forward with the development process of the *Flow* EBMOM. It would help define the concrete items to discuss in the future stages of the development. The participants felt that the workshop was well planned and appropriate for its purpose. The next steps were difficult to efficiently discuss or agree in detail, but what was clear that on the basis of the mapped items, structured development with committed resources should ensue, in which no decisions should be hastily made regarding the definition of the *Flow* EBMOM.

The thesis author followed this conversation by presenting his own suggestions in figure 16, for the plan of the next steps of development following the workshop. The plan was:

1. Organize and refine the results of the workshop, the development objectives, and areas of interest, to a presentable form. Define a development plan on the basis of the results and other so far findings made during the thesis process.
2. Arrange a development meeting area by area, where the documented items and the development plan are reviewed and refined. Define the next steps considering priority, sequence, and timeframes. Consider if development can start on the specific area.
3. Arrange regular development meetings where tasks are shared, development work is carried out and the project is managed.
4. Plan and arrange further workshop if deemed necessary or useful.

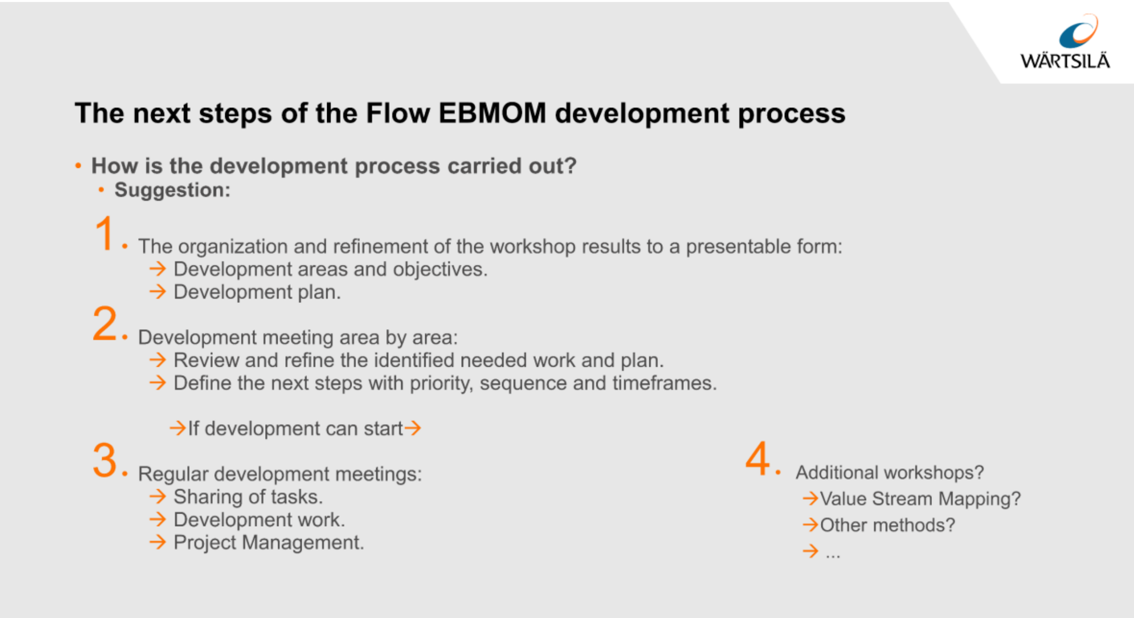

Figure 16. *Presentation slide explaining the authors plan for next steps.*

The authors plan of the next steps was seen by the participants as a good way to push forward the start of the development of the *Flow* EBMOM. However, concerns were raised that it did not yet fully define the solutions for structuring and resourcing needs for the full development process of the *Flow* EBMOM. At this point no further detailed plans regarding the next steps of the development process could be agreed upon.

Finally, the workshop was concluded after the roughly 4-hour session and the participants were thanked for their work efforts in the workshop. To document the findings gained from the workshop group working process, the results were photographed, and also physically collected for backup.

3.3 Development process definition activities

At this point of the thesis process, the activities related to finding an appropriate way to approach starting the development of the *Flow* EBMOM were now carried out. Stakeholders had now been introduced to the situation, and their initial point-of-views were documented. Their views were considered while defining the framework of themes for a structured data collection process, in the arranged workshop. Results had been gained that would now further provide basis for defining the actual scope of needed development work, and the steps to achieve detailed development of the *Flow* EBMOM in a defined development process.

The following structure will continue to describe the thesis practical process activities.

- Processing of findings from the workshop group working results.
- The definition of needed development work as a Work Breakdown Structure.
- The identification of Project Management related items to support development.
- The definition of needed development process as an Activity Network Diagram.

3.3.1 Processing of workshop findings results

In the results from the workshop as-is findings in figure 17, many areas of interest and development objectives and open questions for development were identified. After the workshop, all the collected results were approached with the *Qualitative Data Analysis* research method point-of-view. According to the *preparation* phase of the method, the findings were first digitized by typing them out group by group, one sticky note at a time, in a word document. This was done, so the author could go back and see which group and its participants had originally identified which matters, in case the notes would need to be clarified further by them.

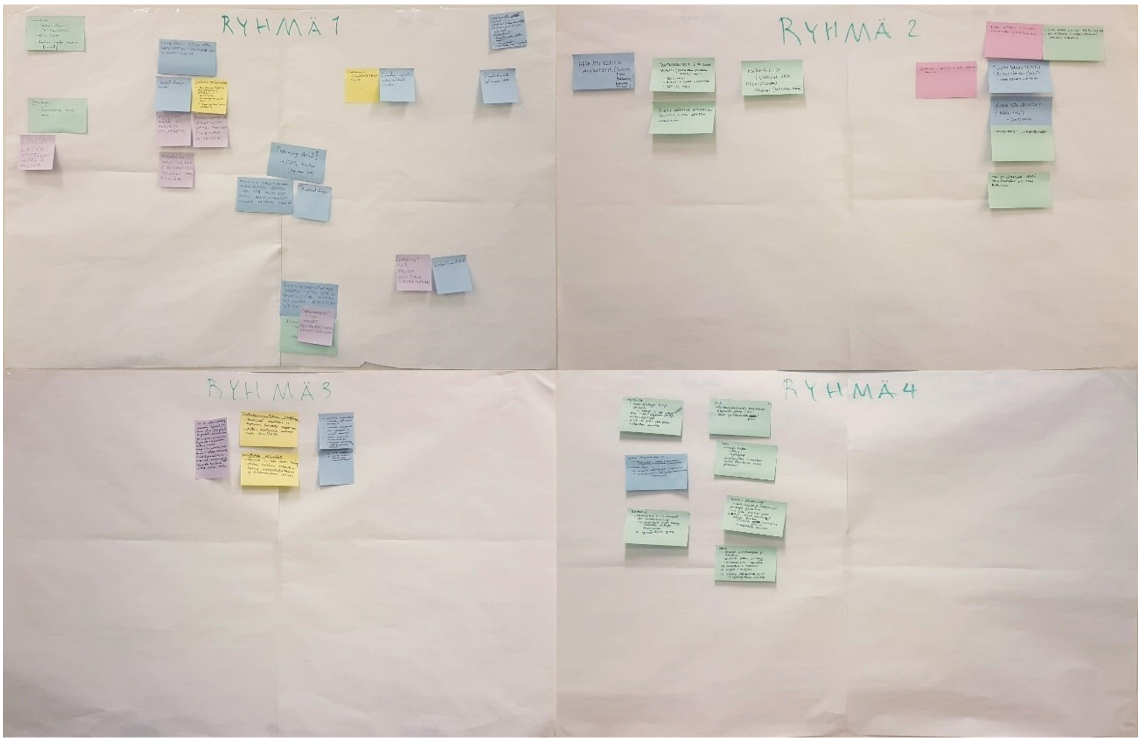

Figure 17. *The as-is results of the workshop group working activities findings.*

As the next step, the author continued in a separate document. Sorting the now digitized but still as-is findings into appropriate categories, regarding the *Flow* EBMOM development according to the relevant conceptual framework identified by the author. As the original findings made by the participants were noted down on different levels of abstraction, organizing them to similar levels would make it easier to further understand the results as a whole. Which of the findings regarding, identified development areas of interest and the identified development objectives inside them, were relevant to which structural aspects of the *Flow* EBMOM? Additionally at this point, any notes identified as duplicates were also discarded.

As the third step, the author started processing the original findings to combine and extrapolate the simple few-words-based notes, into a more understandable and meaningful phrases of statement in a separate word document. As in the *interpretation* and *analysis* phases of the research method. This transformed the findings, into a more appropriate form which supported better what was expected to gain from the workshop group working activities. To answer the research question of ”**What areas of interest and issues to consider are identified regarding the development of the new EBMOM?**”.

Finally, the author transferred the now organized, cleaned, and processed findings into a mind map document, in a more visually convenient way of presenting the results of the workshop. The high-level public version of the mind map can be seen in figure 18, and the detailed-level internal version for Wärtsilä can be seen in the detached appendix B.

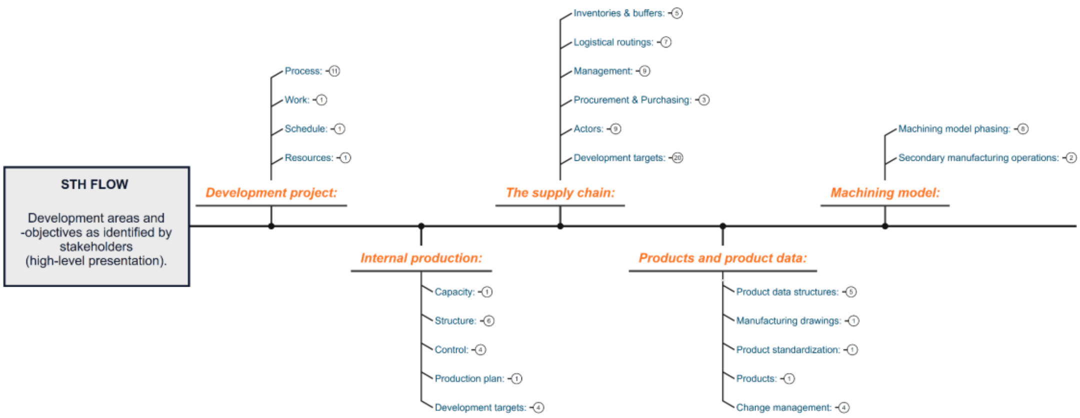

Figure 18. *Workshop results processed into a mind map (public version).*

As can be seen in the high-level public version of the mind map, 5 main structural areas of the *Flow* EBMOM were categorized by the author. Under those categories 22 listed sub-categories or development areas of interests were identified through the workshop findings. Continuing, the following numbers of 105 in total, represent the next levels of the hierarchy of identified areas of interests or development objectives within them.

Some of the text wrote down by the participants in the as-is findings could not be successfully collected through the analysis process into the final results, due to not understanding the ambiguity of the notes and what was originally meant by them. It could be argued that some important identified matters might have been ignored at this point due to this. The author acknowledges that they should have been clarified further as originally prepared for, but in the end they were not, due to lack of available time to carry it out.

3.3.2 Work Breakdown Structure definition

The created mind map of identified areas of interest, and development objectives within them, along with all other knowledge gained at this point of the thesis, was now to be utilized to define the needed development work for the *Flow* EBMOM.

The author considered that before being able to structure the needed development process for the *Flow* EBMOM. The project management *creative technique Work Breakdown Structure* (WBS) should be used to visualize the recognized needs for its development activities in a hierarchical form, arranging larger activities to smaller components, as packages of work. The packages would be formed based on the so far understanding gained from prior meetings and other discussions, but mainly from the processed workshop group working activities resulting findings.

Inspiration was derived from the presentation material given by the thesis supervisor about the STH MTAC Large CM project, where the supervisor had already visualized its development in a WBS, in a systems and subsystems point-of-view. There the *Flow* EBMOM was set as one of its high-level development activities under the *Large Component Manufacturing Process & Supply Chain*. Now, as if to expand the Large CM WBS, the thesis author drafted the WBS for the needed development activities for the *Flow* EBMOM. The chart can be seen in figure 19, and more clearly in appendix C.

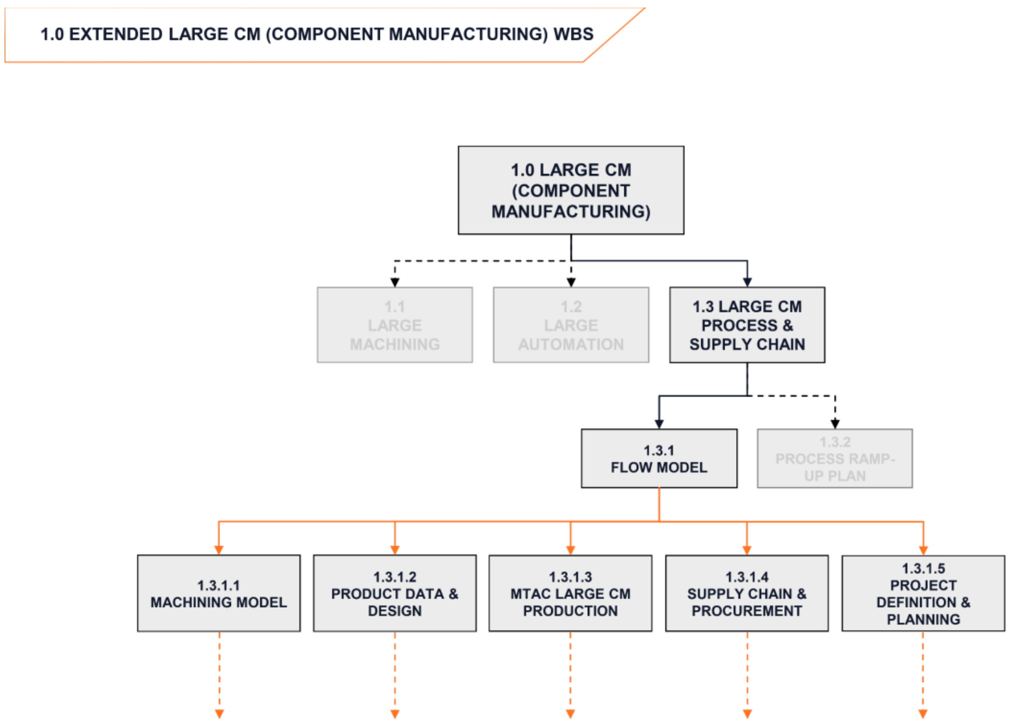

Figure 19. *The extended LARGE CM system WBS, with FLOW MODEL as its high-level subsystem, and the five major development activities as its extensions.*

The first level of the WBS regarding the extension 1.3.1, was of course the development of the new EBMOM or in short, the "*FLOW MODEL*", as it was commonly called at this point. For the next level in the hierarchy, five major areas were defined: *"MACHINING MODEL"*, *"PRODUCT DATA & DESIGN"*, *"MTAC LARGE CM PRODUCTION"*, *"SUPPLY CHAIN & PROCUREMENT"*, and *"PROJECT DEFINITION & PLANNING"*. These 5 major activities were defined also with a systems and subsystems point-of-view in mind.

In project management activities in general, the WBS usually contains defined deliverables and milestones to achieve, and the defined work packages would be formed so that at least the sequence, specific deliverable and monitorable time estimate could be defined for them. However, at this point the WBS was made only to the stage that it could be used as reference. The idea was to continue defining the work packages and elaborating the WBS gradually through the development process, to a more detailed form in cooperation with the development stakeholders, who had the needed expertise and authority to define them realistically, and to ultimately commit resources to carry them out.

This detailed definition was initially attempted by the thesis author, but it was quickly deemed too arbitrary and difficult to individually define exact work packages with limited expertise on the specific areas. The items possible to define at this point were on a quite high-level of abstraction, so the chart took a more freestyle form at first. A more defined official WBS style chart could be defined as development continued, and when needs for specific work packages and their relations in sequence and time got more clarified.

The way the author decided to draft the WBS was by first having the needed development work for the *FLOW MODEL* divided into 5 major activities with each section having 2 sub sections. The grey-coloured section titled "OBJECTIVES" contained the clearest needs for development as bullet pointed phrases, clearly indicating the need to carry out development work on a specific subject. These were items, which could be considered as quite clear development activities which could be narrowed down and specified as detailed work packages later. The blue-coloured sections "TO CONSIDER" contained open-ended questions and discussion points, that should be considered while further defining and performing the specific development work defined in the grey section. Additional development activities or specific work packages could also be directly derived from them.

Not all needed development work could be formed in the chart at this stage, but the author thought it could be argued that it was a good starting point to go forward into the development process. By defining the WBS, the participants to the development of the *Flow* EBMOM, would know what work is needed in the project. The public version demonstrating the drafted WBS format without details, can be seen in figure 20, and the detailed internal version for Wärtsilä, can be seen in the detached appendix D.

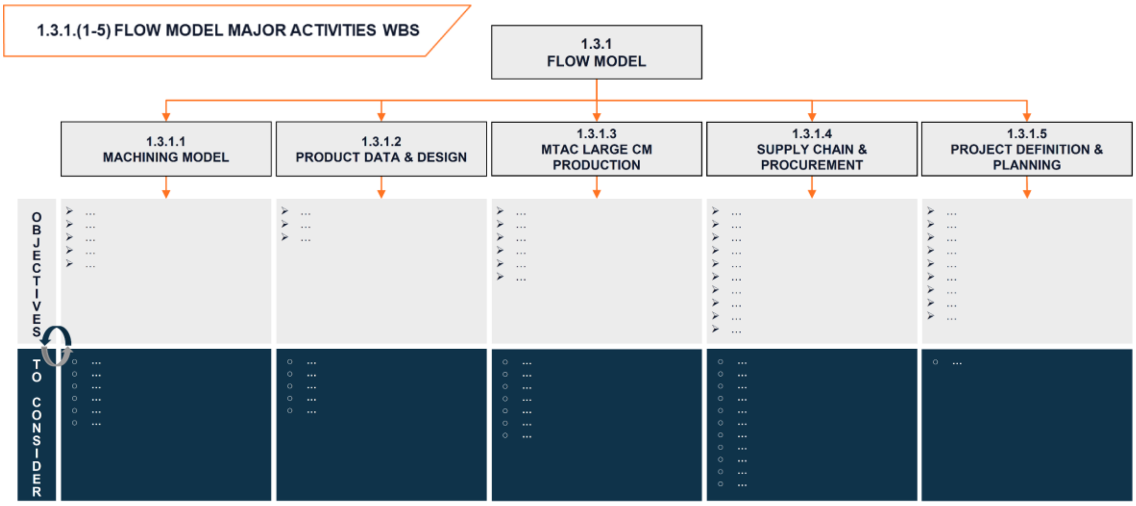

Figure 20. *Work Breakdown Structure for the FLOW MODEL (public version).*

The author drafted a complementary presentation chart as seen in figure 21. This would help instruct on the further definition of the WBS hierarchical levels of work packages, deliverables and milestones, during the future stages of the development process.

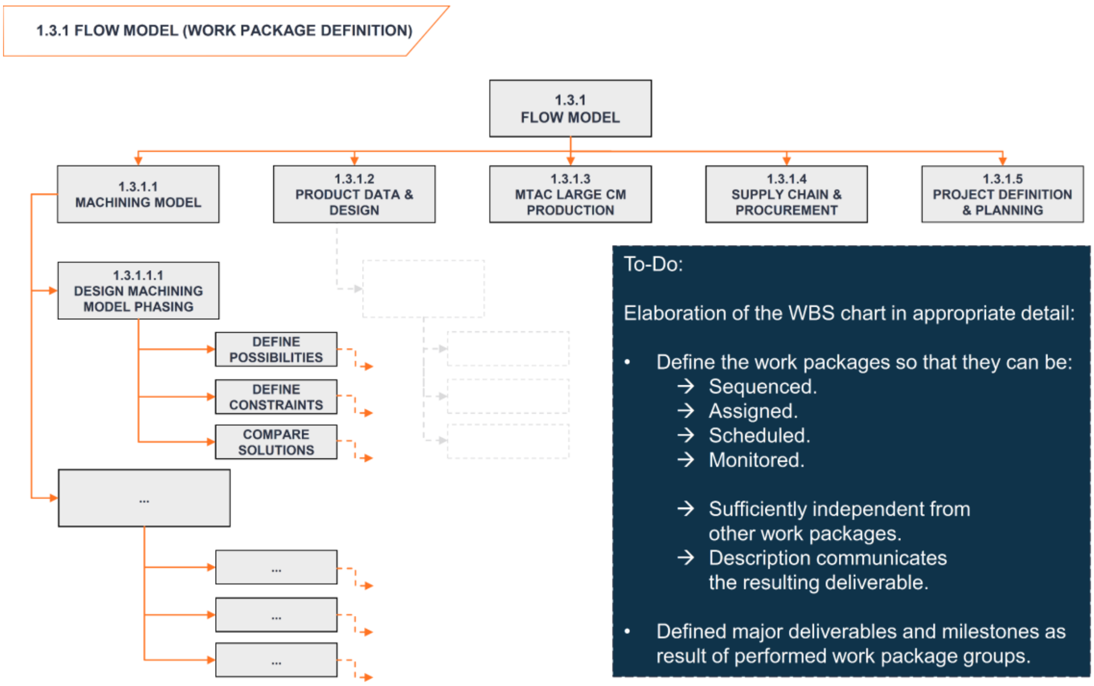

Figure 21. *Instructions for further definition of the Work Breakdown Structure.*

3.3.3 Project management of development process

After processing the so far findings and drafting of the *FLOW MODEL* WBS based on them. The already initially expected vastness and complexity of the thesis topic was realized in writing. As was already discussed at the end of the workshop, the definition of a structured development process and securing of resources was seen as the next most important items. The logical plan as seen by the author was to now in a **Project Management** approach, start the detailed development process of the *Flow* EBMOM. The author considered this now on a high level and argued that at least some of the following items were key to arrange:

- A **Project Charter** should clarify what is pursued by the project.
- **Stakeholder analysis** should secure communication in the project.
- **Risk breakdown structure** should map the potential risks to consider.
- **Activity Network Diagram** should define the project's development process.
- **Gantt chart** should define the schedule for the whole project.
- **Teams** should define the secured participants from different stakeholder areas.
- Teams should have **team leaders** that were aware of other teams' proceedings.
- Teams should contain a **manager** to support decision making.
- A **Development Framework** should be chosen and systematically utilized.

Out of these project management supporting items, the **Activity Network Diagram** was deemed as the next priority step to define by the author. It would provide understanding about the sequence of the development objectives that need to be carried out in the project to achieve its milestones or end goals. It would help organizing the development work in the correct logical order taking into consideration the dependencies between the work packages defined in the already drafted WBS. Also, it would help identifying the needed inputs and timing for decision making in the development project.

The other listed Project Management related items would eventually be scoped out of the thesis due to time constraints, but should be considered outside the thesis scope.

3.3.4 Activity Network Diagram definition

Having identified the development areas and development objectives now mapped in the WBS by the author. The Activity Network Diagram was deemed as a good method to help give structure to the complex development process. As one of the next logical steps defined in the previous chapter, it was attempted to now define the sequence in which the development work of the WBS should be carried out, in order to support the development process of *Flow* EBMOM.

In general, the way forward as seen by the thesis author and also the thesis supervisor, was to start first by defining and developing the needed new machining model, and on basis of its findings and defined aspects, further development could be then carried out in other areas of interest in the *Flow* EBMOM. The author agreed with this, and the Activity Network Diagram was defined mainly in this point of view. But it attempted to take into consideration the whole of the development process' dependencies. The defined Activity Network Diagram can be seen in figure 22, and in more detail in appendix E

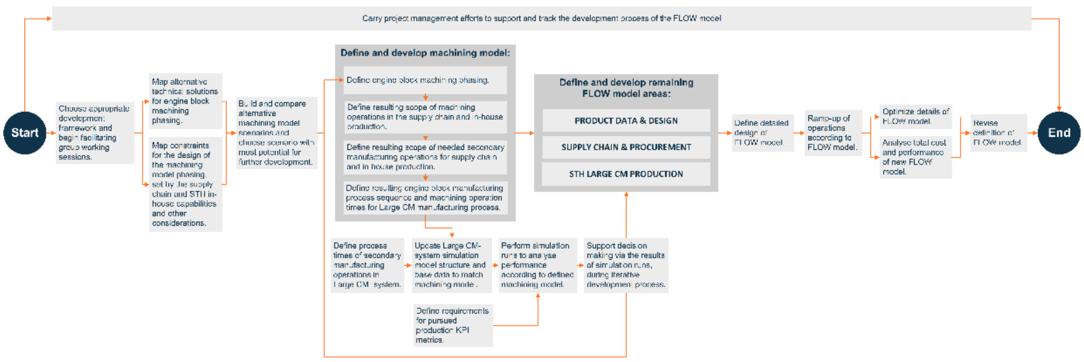

Figure 22. *The Activity Network Diagram for the development process of the FLOW Engine Block Manufacturing Operating Model*

The author considered that first the *Flow* EBMOM development process would start by choosing an appropriate development framework and starting to facilitate it until its end.

Next the possibilities, constraints, and other considerations for the design of the new machining model phasing in the point-of-views of the MTAC Large CM and rest of the supply chain should be mapped and alternative scenarios defined, from which the most potential should be chosen for further development.

To define the actual machining model, the phasing, and resulting machining- and secondary manufacturing operations should be determined, and the resulting process sequence and operation times estimated, at least for the Large CM production.

As the next step this information about the machining model in addition to other collected information, would be utilized to allow the updating of the existing MTAC Large CM simulation model structure and base data.

This in turn would enable to perform relevant simulation runs and through their results provide basis for decision making regarding the machining models feasibility and its performance's acceptability, and provide early reasoning if the model should be altered.

After this, the definition of the developed feasible machining model would provide basis for the definition and development of the remaining *Flow* EBMOM areas of interest.

However, since the design of the new machining model would inevitably have dependencies on the other areas of the *Flow* EBMOM, this described process would likely have to be performed in an iterative manner.

Finally, once the machining model all other areas of the *Flow* EBMOM would be defined and developed, the detailed definition and ramp-up phases could be continued with.

At this point the analysis and subsequent revision phases could also be carried out regarding the realized total costs and performance of the *Flow* model, which was set as a research question for this thesis at the beginning in the form of: "***How is supply chain lead time, total cost, and throughput improved in the new EBMOM?***"

3.4 Development stream activities

At this point of the thesis process, the needed development project for the *Flow* EBMOM was preliminary defined by the thesis author. Having processed the workshop findings and formed the Work Breakdown Structure, to define the needed development work, and drafting the Activity Network Diagram, to define the needed development process. Also, considering what would be the other key Project Management related supporting items to help carry out the *Flow* EBMOM development process in a structured way. The development streams were now possible to be started.

The following structure will continue to describe the thesis practical process activities.

- The need to narrow the development focus of this thesis.
- Start of the machining model development stream.
- Preliminary new machining model scenario definition.
- Large CM manufacturing process sequence definition.
- Simulation model development.

The initial plan was to during the first weeks of March 2020, to draft the important deemed Project Management supporting items as the next step. However, the thesis author unexpectedly lost a few weeks of time, due to data corruption that happened to the thesis data which was momentarily stored on an external drive. The author was fortunately able to successfully recover the files, but the process took a substantial amount of time. At the same time the COVID-19 pandemic had resulted in a remote work recommendation, which would now change the possibilities for practical group working.

After the time needed to recover the thesis data, reorientate into start working again on the actual thesis process, and to consider the changed circumstances by the pandemic. It became clear that for the rest of the thesis process, the author would have to limit the research scope of the thesis, to able to finish it by the timeframe left for practical work.

It was agreed with the thesis supervisor to set aside everything else, and go forward with starting the first detailed development streams regarding the *Flow* EBMOM development project. It was decided to primarily focus on the machining model development stream, and the related simulation model development stream. The rest would be left to be continued by other internal processes at Wärtsilä.

3.4.1 Start of machining model development stream

One of the primary development streams that was now decided to go immediately forward with, was the development of the machining model for the *Flow* EBMOM. The research method of *Focus Groups* was again utilized. For carrying out this part of the thesis practical process of development, it was essential to leverage the expertise of the stakeholders in meetings facilitated by the author. Participants would be joining from the MDU, R&D, and the Smart Manufacturing & Innovations unit.

In the first facilitated meeting held in the end of March 2020, the objective of now starting the detailed development stream of the new *Flow* EBMOM machining model, through this and further regular meetings, was explained to the participants. Discussion about the participants views on a suitable development approach was carried out. Similarly, the authors view on the approach to the development was first presented through the previously drafted Work Breakdown Structure and Activity Network Diagram.

After the discussion of the approach, another agenda was set by the author for the first meeting. To try to further divide into smaller work packages, the preliminary objectives regarding the definition and development of the machining model, as were identified in the drafted Work Breakdown Structure, and Activity Network Diagrams. Then begin assigning tasks for the participants to carry out.

However, at this point there was no official resourcing made, since this, among the other planned project management supporting items defined by the author, were had to be scoped out due to the time constraints and prioritization of just starting this first development stream.

Therefore, having no official working time reserved for these potential development tasks, the meeting participants were understandably hesitant in defining an exact process and its tasks and assignments between them. However, the development of the machining model was agreed to be started to be discussed on a general level regarding how it could be approached and defined during following meetings.

Author's suggested approach to the machining model definition

The authors idea presented to the participants, was the one drafted in the Activity Network Diagram. In this systematic approach, the definition of the new machining model could be started by the mapping of its possibilities for technical solutions, by looking at the current machining model phasing, and the phases specific machining operations.

The author argued for a systematic process for the definition of the machining model:

1. What operations must be or cannot be machined at certain phases of machining?
2. What operations were considered as critical to the products quality, or which machining expertise was wanted to secure in Wärtsilä's own operations according to the *Flow* manufacturing strategy, and which phases would they then fit in?
3. What operations were such that would be wanted to be avoided in the in-house production according to the changing *Flow* manufacturing strategy, and to which phases could they be contained in?
4. What features would be convenient to machine in the so far defined phases?

Through this sorting of operations, the form of the machining model phasing, and scope of internal final-machining, and external pre-machining, would be step-by-step defined.

It was also thought by the author, that additionally the constraints and other guiding factors that were set by the external supply chain, the internal STH MTAC Large CM system, and other operating model areas, should be systematically mapped as well in addition to those already in the drafted WBS. They should be then considered while defining the alternative scenarios for the machining model, and when finally choosing the most potential to go forward with.

In the end, this systematic process suggested by the author for the definition and detail development of the machining model was commonly deemed not the preferred way of going forward at this initial point. The author admitted that since it was not his strong suit, the approach to the machining model development was better left to the responsibility of the MDU participants expertise. Following this, their vision of the approach was further clarified and prioritized going forward in the next meetings.

The MDU expert's approach to the machining model definition

In the following regular machining model development meetings facilitated by the author, the preferred way of approaching the development of the new machining model, and its preliminary definition was gradually clarified.

The state of will agreed on by the MDU stakeholders at this point, was to have the engine blocks that would arrive at STH MTAC Large CM production to be pre-machined to such a state, that the to-be processed surfaces were already machined to a varying few millimetres of machining allowance. So that preferably only finishing machining operations and drillings and thread tappings, but not roughing machining operations, would need to be carried out in the in-house machining process. This preliminary preference for the 1st scenario was deemed as something which of course would need to be assessed in terms of feasibility, but it could be used as the first basis of approach towards the final definition.

The MDU expert's suggested approach to the machining model definition

The experts having now had more time to think about their preferred development approach, suggested a suitable process for defining the new 1st machining model scenario in further detail. It was agreed that:

1. An MDU engine block expert would create a machining model visualization, according to the priorly described state-of-will for one Wärtsilä engine block model.
2. This first vision of the machining model would be based on an old pre-machining model once created for another Wärtsilä engine block model, but this time it would be altered by attempting to avoid some of the wasteful aspects of it. Aspects such as required multiple passes of machining of certain features, which was deemed as a definite cost and processing time increasing aspect of the old pre-machining model thinking. Now some surfaces were thought to be possible to be finish-machined already in the pre-machining phases and then blasted and painted before the in-house finish-machining phases without it causing problems.
3. To visualize the machining model, the expert suggested that all in some way processed surfaces would be coloured in a 3D CAD model of the engine block in various colours. Their meaning regarding the specific machining allowances or surface type would be determined in an accompanying word document. This would explain, how the specific-coloured surfaces were to be machined or otherwise processed according to the machining model at different stages of phasing. In this way, the description of the desired processed state of the engine block in different phases of the machining model could be compiled in detail.

3.4.2 Machining model 1st scenario definition

It was agreed that the previously explained visualisation would work as a good basis for further detailed discussions of the direction the machining model definition would be taken. It would bring concrete visual substance to the discussion and enable easier assessment. It would also be an effective way to clearly describe the defined machining model once ready. The previous approach suggested by the thesis author, could also be utilized more conveniently in conjunction with this, at a later more fitting stage.

The development of the 1st scenario machining model was now started after the first visualization model was created by the MDU expert. The coloured engine block 3D CAD models were analysed in a few weekly meetings and the definition of the machining phasing was developed incrementally further. The preliminary definition of the new machining model was eventually reached by the MDU experts, and its resulting scope of a specific number of pre-machining phases and final-machining phases were defined utilizing the visualization method.

After the preliminary definition of the new 1st scenario machining model, it was agreed that another MDU expert would modify the existing CAM programs according to the new machining model for the specific engine block model used previously in the visualization. Through this process time estimations would be derived for the changing operation times for this single engine block model. The changed machining process times could then be compared to the current EBMOM known measured machining model times, to assess the relative change in process times. The times for the *Flow* EBMOM new 1st scenario machining model's multiple other engine block models could be extrapolated as estimations based on this relation.

Machining model base data for the MTAC Large CM simulation model

Machining times estimations according to the new 1st scenario machining model were received from the MDU experts for two different Wärtsilä engine block models.

These time estimations and their extrapolations for other engine block models could now be potentially used as the missing base data for the Large CM simulation model, to partially enable carrying out of simulation runs and giving clarity to the performance of production with the new 1st machining model scenario.

These machining times only represented two models of a large number of engine blocks that were to be eventually manufactured at the MTAC Large CM, but the information about the relative effects on machining time could be extrapolated to other engine block models also when needed.

The availability of the updated machining times base data, although useful, were only one thing to update regarding the simulation model. Additional processing times would be needed for the secondary manufacturing operations, such as setups, washing, deburring, component installation, and testing operations' times. These however, were deemed too early to estimate at this point of the Large CM system detailed development.

Also, to have any benefit of using the estimated *Flow* EBMOM 1st scenario machining model processing times, or other collected operation times in the simulation runs, the simulation model process structure and functionality would also be needed to match the reality of the actual designed Large CM system.

Therefore at this point, the development stream of defining the needs for updating the simulation model structure and functionality was deemed as the next priority. It was started in parallel to the machining model development stream.

The collecting and definition of simulation base data was left to a later stage of development of the *Flow* EBMOM, where they would be feasible to estimate, and the simulation model was up-to-date. Subsequently no useful simulation runs were made at this point, even though the machining model scenario was now preliminarily defined.

Needed inputs for further definition of machining model scenarios

After the preliminary definition of the 1st scenario machining model, the development could not end there. It was agreed that possibilities for alternative scenarios should also be investigated in the continuing weekly development meetings facilitated by the author.

However it was quickly determined, that first the capability of the MTAC Large CM system robot cell would be needed to be discussed, to determine if potential existed in offloading machining operations to the robot cell, which main use-case was mainly deburring, but which was thought might be able to carry out drilling and tapping operations for the engine blocks also. This was a difficult topic of discussion since the design of the robot cell was not locked in and it was unclear what features were feasible to machine with it, or what features were actually desired to be offloaded from the Portal Machining Centre to it. The sensibility of offloading these types of operations to the robot cell would also ultimately depend on the whole manufacturing systems resulting balance of loading.

It was noted that in-case the deburring cell was attempted to be utilized for also drilling and tapping, its overall effect on production could be negative, by reducing the deburring performance of the cell, due to having to use a more heavy-duty larger spindle, and therefore losing its agility for movement around the engine block in the cell. It was also noted that the sufficiency of the accuracy and stiffness of the deburring cell robots would need to be considered if they were enough for the demands of drilling and tapping needs.

Ultimately at this point of development, it was decided to continue defining the machining independently from the robot cell. If the need would arise later, the possibilities would be considered again according to the following questions: *What features might be possible to be machined in the deburring cell? What kind of capability do the features to be worked on require?* For example, one identified possibility were such holes, which in the current EBMOM machining model's manufacturing process were drilled in a time-consuming process by hand due to their difficult location, but which a robot might as well reach.

As the next steps, it was agreed that similar discussions should be held about the Large CM measuring cells capabilities, the engine block fixturing methods, and the external manufacturing process in the *Flow* EBMOM supply chain in general. To map the constraints and possibilities set by them, such as the utilization of 3D scanning or zero-point clamping, and so on, to improve the efficiency of component machining operation setups.

However, at this point the thesis author would not actively facilitate this development stream further and would shift focus to the MTAC Large CM Simulation Model development instead. The MDU stakeholders would independently continue with the further definition and development of the machining model scenario.

3.4.3 MTAC Large CM Process Sequence definition

Based on the reasoning in the previous chapter, the simulation model development stream was started in parallel to the machining model development stream. The author utilized the research method of *Focus groups* and *Qualitative Data Analysis* to carry out data collection on needed information, and the *Creative Techniques workflow modelling* to produce the needed descriptive material for this section of the development.

As-is out-of-date manufacturing process sequence

To update the structure of the simulation model to match the reality of the MTAC Large CM system, a swimming lane style Process Sequence Structure chart was thought to be useful. The chart was first drawn of the existing process sequence that structured the operation of the out-of-date simulation model. The public version demonstrating the chart format without details, can be seen in figure 23, and the detailed internal version for Wärtsilä, can be seen in the detached appendix F.

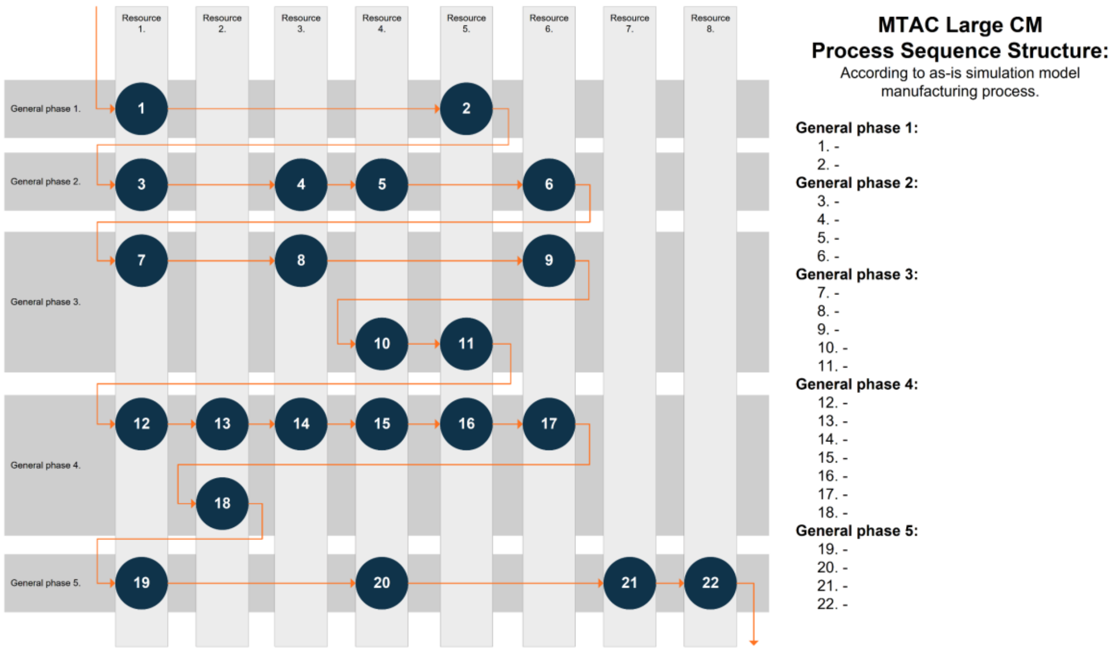

Figure 23. *The as-is simulation model process sequence structure (public version).*

The information needed to draft this baseline chart was collected from the Visual Components and Excel based simulation model's files, where the existing process sequence could be observed in written form in the Excel file's sheets as described operations, divided into phases. The information could also be checked visually by running the 3D based simulation model of the Large CM system in the Visual Components application, where the process sequence could be seen in practice in a 3D environment.

In the first swim-lane chart of the as-is simulation model process sequence, the author drew vertical columns to represent the various manufacturing resources in the MTAC Large CM system through which the process' operations were carried out to manufacture the engine block. Horizontal bars were drawn to represent the main phases of the manufacturing process, and the numbered circles were drawn to represent specific operations carried out in these phases with the specific resources and in the specific order of number, hence the arrows connecting them in sequence. On the right-hand side next to the chart is first the title, which in this case described how this chart represented the starting point process sequence for the as-is simulation model. Under this title, the main phases of the manufacturing process were written in bold, and beneath each phase the actual operations belonging to these phases were listed.

In this process sequence chart of the as-is simulation model, the machining model was roughly the one according to which Wärtsilä operated under the current EBMOM. This defined as-is simulation model process sequence clearly shows how the manufacturing process of the engine blocks is not as simple as is often commonly thought. It is easy to think that only a few main machining phases would result in the finished engine block. However, at minimum of 22 operations are for example needed to perform in a specific order in this representation of the manufacturing process, which still likely does not contain all the truly needed minor operations that were deemed not worth to simulate.

This chart was thought by the author to work well as basis to discuss and determine the up-to-date real process sequence matching the developed 1st scenario machining model that would be potentially used in the Large CM system in the future.

Updated manufacturing process sequence of the 1st scenario machining model

The drafted as-is process sequence chart was at this point presented to the MDU experts who also participated in the previous chapters machining model's development stream to define the 1st scenario machining model. The experts deemed the creation of this chart as a very useful way to represent the process, and it was thought that this way the process sequence for the *Flow* EBMOM machining model should be described as well. It would help defining the needed updates for the simulation model as the author planned, but also to support the experts understanding around the matter. The author and the MDU experts reviewed the chart together in a meeting and started going through the process while thinking about how its structure would now change step-by-step and would need to be corrected accordingly.

According to the vision of the *Flow* EBMOM 1st scenario machining model. Now instead of the few main machining phases that fully completed the internal machining process of the engine block according to the old EBMOM machining model. There would now be a few phases that complete the internal machining process of the engine blocks, but as an extension to a few pre-machining phases that would be ideally carried out by suppliers.

Eventually a few needs for added operations and many changes in the sequence of the process and the details of what would be actually done inside the operations could be identified. A new process sequence structure chart was then drafted to match the 1st scenario machining model true process sequence structure. The public version demonstrating the chart format without details, can be seen in figure 24, and the detailed internal version for Wärtsilä can be seen in the detached appendix G.

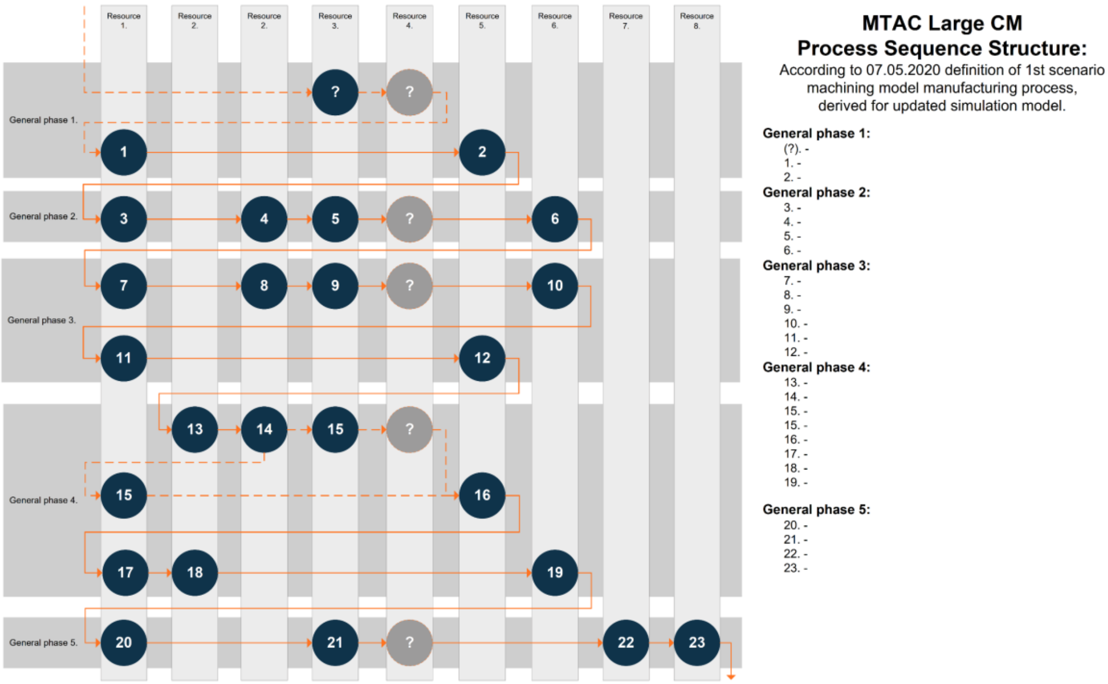

Figure 24. *The updated process sequence structure (public version).*

While the second process sequence chart was modelled according to the same principles as the first one, this time it additionally contained items like the dashed arrows and circles containing a question mark instead of a number. These items now depicted optional operations or alternative routes which necessity could not at this point still be fully confirmed, and which might change for the final true process sequence along with the further development of the machining model scenario.

This updated process sequence according to the 1st scenario machining model would now again partially enable the further definition of needed updates for the Large CM system simulation model.

3.4.4 Simulation model development

As it had become apparent in the previous chapters, the Visual Components and Excel based simulation model of the MTAC Large CM system was available as a tool to be used alongside the development of the *Flow* EBMOM, and particularly its new machining model, which firstly would determine the engine block machining phasing, and its needs for secondary manufacturing operations, and finally the Large CM process sequence, and operation times. The simulation model could potentially help with being able to test the resulting production performance with alternative designs of the new machining model, and provide basis for decision making regarding in what direction the development of the machining model should be taken, in the point-of-view of whatever scope of production was simulated in the model.

A simulation models usefulness of course depends on the accuracy of the base data fed into the simulation, and the validity of the model's structure, functionality, and behaviour in representing the system it is supposed to simulate. Therefore, it was essential that before this development tool could be leveraged, it needed to be updated and validated and continued to be doing so, in parallel as the development of the machining model and the development of the whole *Flow* EBMOM progressed and got more defined. At the starting point of this thesis the simulation model had not been updated for a long time.

The process sequence in the model represented the traditional DCV engine block machining model that was fit into an early vision of the STH MTAC Large CM system structure of resources and operating logic, and subsequently did not reflect the up-to-date plans for the physical manufacturing system or the now preliminarily defined 1st scenario machining model. The simulation model therefore needed to be updated for its structure and functionality and behaviour, to ensure the validity of future simulation runs and their results, upon which decisions could made regarding the further development of the machining model and the whole *Flow* EBMOM.

The simulation model was developed by an external company for which Wärtsilä was a customer to, so changes to the structure and functionality of the simulation model process could not be made directly by the author itself. Therefore, the needed modifications to update the simulation model needed to be identified, defined, communicated, and procured by the author from the supplier of the model. As fitting with the research methods of *Qualitative data analysis* and *Creative Techniques* the author would now carry out these activities for the simulation model development.

The Visual Components based simulation model functioned in combination of an 3D simulation model which can be seen in figure 25, and Excel document, and various intermediary text files holding the input and output information. As to control when they were to be read as base data in the simulation model or read back to display as results in the Excel file. The input data for the simulation would be first inserted into the Excel file, from which the data was saved via a macro button to the intermediary text files at the user's request. From the intermediary files, the simulation model automatically would then read them for the simulation model to be run. The simulation model also would automatically output the resulting data once finished to these intermediary text files, but from which the results would again be read to the Excel file only at the users request via a similar macro button, to not overwrite the previous simulation run results data.

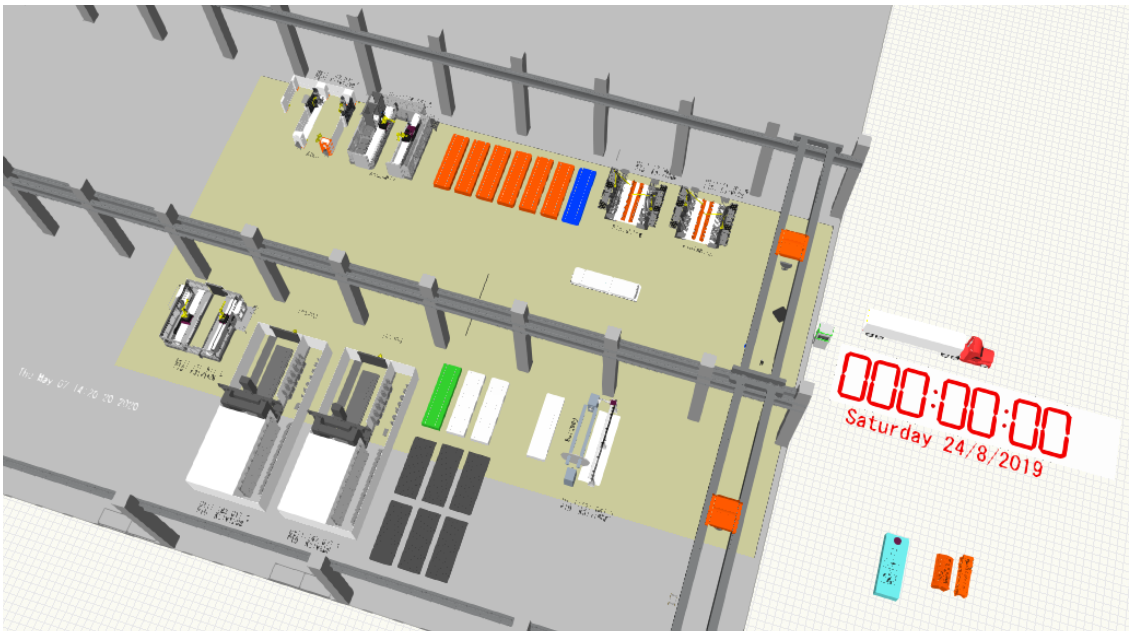

Figure 25. *3D portion of the Visual Components and Excel simulation model.*

The Excel file containing the input and output data was divided into nine sheets focusing on different areas of the simulation. The sheets contained the following information as described in table 4.

Table 4. *Structure of the simulation model data input and output Excel document.*

“Start”:
Contains the buttons for control the data transfer of the input and output data. Additionally, some basic information to identify for which simulation model the Excel file was for.
“Flow”:
Contains the list of operations possible to use in the simulation model and their respective operation sequence numbers in intervals of 10 and phase numbers in intervals of 1 for the user’s reference. These could not be modified by the user.
“Lineup”:
Contains the production plan for the simulation model as input by the user. Here the user could add the desired list of to-be manufactured products with their specific sequence in the simulation run.
“Products”:
Contains the base data for what are the needed operations for each specific product and the specific process times that each operation for each product would then take.
“Parameters”:
Contains the parameters through which the user could adjust the movement speeds and other characteristics for the AGV system that transports the manufactured products between the resources in the simulation model manufacturing system.
“AGV Operations”
Contains information about the operative tasks of the AGV system during the simulation run, from which the user can identify the reasons for the AGV system’s utilization at different points in time.
“AGV”:
Contains information about the AGV systems physical movements and its usage time during the simulation run divided to different statuses during the simulation of being busy, idle, etc.
“Stations”:
Contains information about the manufacturing system resources utilization during the simulation run regarding completed works and time spent in different statuses of busy, idle etc.
“Throughput”:
Contains information about the simulation model run in the point-of-view of the products, detailing their throughput time, timestamps, and resulting general production tack-time.

Having defined the manufacturing process sequence for the simulation model according to the 1st scenario machining model in the previous chapter. Missing information still needed to be collected from the thesis supervisor, who had detailed expert knowledge on the properties of resources and operating logic of the MTAC Large CM system.

As noted in the previous chapters, the collecting and forming of up-to-date simulation base data would also be needed before being able to utilize the simulation model for any useful results from simulation runs. However, this had to be at this point scoped out of the thesis and left to a later stage of the *Flow* EBMOM development, where they would be feasible to collect or estimate and then fed to the updated simulation model for use.

The needed changes for the simulation model were identified by the author through; Observing and studying the operation of the simulation model by carrying out trial simulation runs. Comparing the as-is modelled and desired operation through the visualized process sequence structures in the previous chapter. Interviewing the thesis supervisor who was an expert on the design of the simulated manufacturing system and about the system’s true behaviour.

After gathering the needed information and defining the changes through the utilization of research methods of *Interviews* and *Qualitative Data Analysis*, they were documented.

The needed changes that were identified regarded in general:

- The additions, removals and reordering of the process sequence operations.
- The number of resources, their functionality and usage logic.
- The addition of extra information to the output of simulation results.
- The changes to the functionality of the model.
- The solutions to general issues or unexpected behaviour found during usage.

The public version demonstrating the list of procured changes without details, can be seen in table 5, and the detailed internal version for Wärtsilä, can be seen in the detached appendix H.

Table 5. *Changes to the structure and functionality of the Visual Components 3D simulation model and Excel data input & output documents.*

The changes to the process sequence structure:
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Number of resources:
…
…
Changes to functionality and usage logic:
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…
Addition of extra information to simulation results output:
…
…
Solutions to general issues:
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…

To communicate and procure the needed changes, the author prepared the findings also in a visual presentation format, and then facilitated the necessary meetings to communicate the development efforts to the supplier. Which in turn provided the updated model.

4. RESULTS OF DEVELOPMENT ACTIVITIES

Throughout this thesis process, results were gained via a multiple-methods approach to utilization of research strategies and methods during the practical development activities. The complete thesis offers reviewed theory, documented knowledge and produced useful descriptions and further development supporting material as results.

The results do not suffice to fully answer the originally defined research problem. However, they do answer at least to some extent all the research questions derived for this thesis scope, while providing supporting basis for any further attempts at answering them. An overview of the thesis research questions and results is presented in table 6.

Table 6. *Overview of the thesis research questions and gained results.*

Research question:	Result:
What is the current Engine Block Manufacturing Operating Model (EBMOM)?	Answering this was eventually excluded from thesis scope, and no direct results were gained. A VSM workshop plan was drafted for this purpose and described to potentially support any future attempts at answering this.
How is the common state-of-will found regarding the way of operating in the new EBMOM?	Through facilitation of group working activities with stakeholders, where findings of discussion points, development needs, and their interdependencies are identified. Continuing with usage of established development frameworks enabling structured cooperative solution definition, development, and evaluation.
What areas of interest and issues to consider are identified regarding the development of the new EBMOM?	Numerous issues were identified from discussion notes made in meetings with stakeholders, and further categorized into 7 operational areas of interests in table 3. Further extensive identification was made through a structured workshop, which findings were processed into a mind-map hierarchy of 5 main structural categories and numerous sub-items in figure 18.
What is the development scope and the steps to achieve operation according to the new EBMOM?	Preliminary definitions of the identified development project scope and -process, were drafted into a Work Breakdown Structure in figure 20, and the Activity Network Diagram in figure 22 for basis of further elaboration.
How is supply chain lead time, total cost, and throughput improved in the new EBMOM?	Answering this directly was not possible at this stage of development, and no direct results were gained. The updated simulation model, draft VSM workshop plan, and the reviewed theory in chapters 2.5 - 2.7 may support any future attempts at answering this.

4.1 What is the current engine block manufacturing operating model (EBMOM)?

To work as basis for answering the 1st research question, an approach was outlined in chapter 3.2.2 for arranging a *Value Stream Mapping workshop*. However, other areas of the thesis were eventually chosen to be prioritized before the plan had an opportunity to be carried out in detail. As the written description and reasoning for the approach was considered by the author to be potentially useful results, its included in the written thesis.

The contents of this result can provide the reader with vision on how to still answer this particular research question or similar research needs outside the thesis scope, which at some later point of the *Flow* EBMOM development might become relevant to investigate. It includes high-level suggestions on how such a VSM workshop could be efficiently facilitated in practice, what kind of useful information could be gained from it, and how its results could be refined further.

4.2 How is the common state-of-will found regarding the way of operating in the new EBMOM?

The successful thesis practical process itself is an answer to the 2nd research question.

Firstly, introductory meetings were facilitated, to gather key stakeholders together to discuss the starting point and the preferred approach to the overall *Flow* EBMOM development. As the sub-result of this, a list of identified discussion points regarding the development and definition of the *Flow* EBMOM was documented in table 3 at page 44. These findings along with the understanding gained from the meetings in chapter 3.1.3 and 3.2.4, were then utilized to ensure alignment in the planning of subsequent practical development activities by the author.

Continuing, the *STH Flow Planning Day Workshop* was facilitated where key stakeholders again participated. The content, structure, and utilized group working technique, were planned to best gain synergy between the participants, and therefore to effectively collect data on their combined inputs regarding the set focus of the workshop. As the sub-result of this, findings were made defining the relevant deemed development areas, -objectives, and open questions regarding the *Flow* EBMOM.

Further continuing, development meetings were continued to be facilitated in the later parts of the thesis, now regarding the Machining Model development stream. Here as sub-results, the participant stakeholders' expertise was leveraged to gain definition on the preliminary machining model scenario for the *Flow* EBMOM, and the derived manufacturing process sequence structure.

The significance of the previously described thesis practical process and its sub-results is that: Through this kind of approach basing extensively in the *Focus Groups* research strategy, leveraging the stakeholders' contributions and perspectives, the common view of the stakeholders was able to be 1st: *Considered in the appropriate approach and focus of subsequent development.* 2nd: C*ollectively combined in the identifying of needed development work and process*. And 3rd: *Realized in the initial development and definition of the new machining model and the derived manufacturing process sequence structure*.

The results of this thesis could not answer what is the common state-of-will regarding the complete way of operating with the *Flow* EBMOM, but they give indication on matters where the solutions need to be defined, and the process demonstrates how this kind of approach is an effective solution in answering how the state-of-will is gradually found.

4.3 What areas of interest and issues to consider are identified regarding the development of the new EBMOM?

To answer the 3rd research question, the *STH Flow Planning Day Workshop* was facilitated. Whereby emphasizing on the structure, contents, predefined themes of discussion, and focused use of the group working technique *Cumulative Group*, the results described in more detail in chapter 3.3.1 were gained.

The significance of these results lay in the fact, that they represent the development areas, and development objectives, where development work should be carried regarding various issues to consider. They were identified by the participating key stakeholders of the *Flow* EBMOM development and processed by the author. Therefore, they provide the direct answer to the research question, but also provide basis for the actual further definition of the needed development project after the thesis scope.

4.4 What is the development scope and the steps to achieve operation according to the new EBMOM?

To answer the 4th research question, first the processed findings from the *STH Flow Planning Day Workshop*, in combination with the personal understanding gained so far by the author in the thesis process, were synthesized into the *Flow EBMOM Work Breakdown Structure*. The WBS format was created through the usage of *Qualitative Data Analysis* and *Creative Techniques* research methods. The FLOW MODEL WBS as part of the LARGE CM WBS is described in more detail in chapter 3.3.2.

The significance of this result is in the definition gained for stakeholders, regarding what identified scope of work needs to be done and what issues need to be considered in the

Flow EBMOM development project. Instead of forming specific work packages, at this point only high-level development objectives and the accompanying issues to consider could be defined and categorized.

To continue answering the research question, the author drafted the *Flow EBMOM Activity Network Diagram*. The diagram was created again through the usage of *Qualitative Data Analysis* and *Creative Techniques* research methods. The previously described FLOW MODEL WBS was utilized for the definition of development objectives, and the author's own logical reasoning and understanding on the topic was used as a basis for their sequencing. The diagram describes the authors vision of the development steps and sequence to carry out the development process towards the definition of the *Flow* EBMOM, starting from the machining model development stream point-of-view. The diagram is described in more detail in chapter 3.3.4.

The significance of this result is in the definition gained for stakeholders, regarding the structure of how the development process of the *Flow* EBMOM development project could be carried out. The resulting Work Breakdown Structure and Activity Network Diagram work as a basis from which the *Flow* EBMOM development project could be started from, and be continued to be elaborated, extended, supplemented with information, and revised gradually.

4.5 How is supply chain lead time, total cost, and throughput improved in the new EBMOM?

The 5th research question could not directly be answered during the practical scope of this thesis. This was due to the still early stage of development of the *Flow* EBMOM.

The mentioned draft of the *Value Steam Mapping workshop* plan could be utilized for approaching the answering of this research question. If the plan was carried out regarding the current-state EBMOM and future-state *Flow* EBMOM, it would provide base information to use as comparison points needed for performance change evaluations.

The MTAC Large CM simulation model was updated to be a valid representation of the internal manufacturing system, and the preliminarily defined new machining model's manufacturing process sequence. It could be used for assessing at least the throughput and lead times of internal production, in operation according to the *Flow* EBMOM.

The literature review carried out regarding the design of manufacturing systems, pursued manufacturing process characteristics, relationships of process laws and factors, and approaches to process improvement, can also provide theoretical basis for analysis, development, and decision-making activities, that pursue these kinds of improvements.

5. ANALYSIS AND DISCUSSION

5.1 Assessing this research

The thesis research and development activities were challenging. This was primarily due to the vast scope of the thesis topic, which needed to be considered throughout the thesis process in many points-of-views. Those views important to its various stakeholders, and those views implied by the defined role for the thesis. This vast scope originated from the thesis research problem, which regarded the need for development of the *Flow* Engine Block Manufacturing Operating Model. The operation model itself spanned a vast scope of Wärtsilä's internal departments, functions, and expertise, but also the external supply chain's operations and management. Additionally, another layer was the *Flow* vision of manufacturing strategy, which consisted of its own scope of discussion points.

The vast scope required an extensive familiarization with the theoretical and conceptual framework that surrounded the topic and the used research approach. This was due to the need to understand, discuss, and consider, the effects of constantly increasing number of matters that were faced daily in various development activities. At the same time this vast scope however limited the possible time and efforts available for the author to spend on in-depth consideration, analysis, and conclusions regarding specific items. This likely lead to initial disregard of some key matters, and instead into unnecessary analysis of not relevant matters, which ultimately did not fit into the scope of this thesis.

The research spent a long time in the beginning of the thesis looking for its critical path, taking steps into multiple directions of development. This consequence shows in the written thesis as the carrying out of an extensive collection of practical investigative activities, of which all had depth in the reasoning of practical planning of approach, but which might appear superficial in the reported depth of analysis of their results, as the scope implied it was important for the research process to quickly progress forward.

The relating of the thesis' practical activities and the theory investigated in the literature review portion of the thesis, is more substantial regarding the research approach related theory in chapters 2.1 – 2.4. Due to the thesis ultimately focusing heavily on the initial phase of facilitating the start of the *Flow* EBMOM development project, instead of the detailed development and definition activities of its solutions as originally expected. The reviewed theory in chapters 2.5 – 2.7 could be only slightly related to at this stage of development, but it will stay in the contents of the thesis for basis of potential future applicability by the readers of this thesis regarding further development activities.

It is now clear in the eyes of the author, that a narrower initial definition of research questions and scope for this thesis would have likely benefitted its overall research outcomes depth and significance, on some more detailed area of interest. Also, the contribution of knowledge for the scientific knowledge base might be more valuable.

Regardless of the challenges, the author considers that the research approach was adequately planned, and an appropriate and effective use of research strategies and methods was achieved. Also, the scope of literature review sufficiently provides context of the used strategies and methods, but also connects the primary theoretical backgrounds to the thesis topic, and its considered research problem and -questions set for the thesis.

5.2 Significance and reliability of results

The practical results of this thesis can likely be considered valuable for Wärtsilä, as the thesis was able to start providing a practical solution to their defined research problem. This was achieved in the form of first facilitating the approach, and then the start of development for the preliminarily structured *Flow* EBMOM development project. Finally facilitating its initial machining model and simulation model development streams. Providing answers to the set research questions along the process.

The results of the thesis in the point-of-view of *Technical Action Research* study, and *Descriptive Case Study,* could be evaluated as highly valuable for the local practice of Wärtsilä Finland Oy, but likely minimal for the general academic knowledge base. However, generalizability of this thesis research approach might exist for other operating model development needs. Similar use of *research strategies*, -*methods*, and *creative techniques* could be implemented to solve similar research problems, where a vast number of stakeholders need to be consulted to facilitate development of a complex system. Problems where the facilitation of cooperative investigative development activities, outweigh the individual design inputs of the researcher, and where the leveraging of the relevant stakeholders' expertise and contributions is critical in producing solutions.

The data collected in this thesis and the subsequent results that were formed should be deemed reliable, since the use of established theory regarding group working methods was emphasized, and the information collected originated from internal expert stakeholders from the Wärtsilä organization. However, the practical implementation of the data collection phase could not collect inputs from all possible relevant stakeholders', and not all the possible point-of-views could be explored in consideration. The approach still likely produced at least a useful subset of results in relation to all of those that potentially could have been regarded.

The functionality of the *workshop findings* regarding identified development areas of interests, development objectives, and general issues to consider, was similar as described in the theory of Manufacturing System Design Framework by Vaughn et al. in chapter 2.5.1. Where inputs from various functions generate a set of requirements, considerations, and constraints for the design of manufacturing systems. The reliability of these gained results should be questioned though. Since the raw data of these findings were short notes quickly written down on sticky notes, they required extensive *Qualitative Data Analysis* to prepare, process, interpret, and transform into the presented mind map form. Mistakes could have been made, and the original meaning of the notes might have not been understood correctly, or it might have been lost in the transformative process.

In the initial form of the Work Breakdown Structure drafted by the author, its practical usefulness is limited, since the work could not yet be specified in high detail and according to the format recommended by established theory in chapter 2.4.3. The resulting WBS is therefore only a starting point from where it should be improved as the development project proceeds, to gain more value from it. The initial form of the Activity Network Diagram has the same limitations on usefulness as the WBS it was based on, but also the same potential for future value if elaborated on. The initial definition of the development process and its dependencies in the diagram, might be significantly different than the final true to-be carried out development process. It also lacks most of the descriptive project management related properties of an Activity Network Diagram that were defined in established theory in chapter 2.4.4. It also only considers the development project process in in the point-of-view of the machining model development stream.

The significance of the definition of the new 1st scenario machining model for the *Flow* EBMOM, and the updating of the simulation model to match the model and the MTAC Large CM system, is also questionable. The results are useful for aligning the three elements as a starting point and enabling the use of the simulation model for more accurate potential analysis purposes. However, plans for the machining model or the Large CM system might drastically change, and the simulation model might require several more updates to keep it valid. Also, accurate base data for manufacturing operation process times were not available at the time of the thesis, so collecting or estimating those would still require further investigative work also.

The outlined approach and reasoning for arranging a *Value Stream Mapping workshop* was described only on a high-level, so it will not provide the full solution for any case. However, the plan was drafted according to generally deemed good practices found in various literature while researching *Lean*, so at least it might provide useful basis and should not be disregarded. This *Value Stream Mapping workshop* plan along with the literature review theory of *Workflow Modelling* in chapter 2.4.2, and *Continuous Improvement* in chapter 2.7 could be used in the future to gain better descriptions or understanding of the *Flow* EBMOM's at that time state, and to seek opportunities for development after its ramp-up.

The writing of this written thesis was eventually finalized over 2 years after the ending of the practical activities of the thesis, due to external factors causing long timeframes where the author was unable to write it. Even though the overall thesis process was challenging, the thesis in general can be considered a success in the point of view of the author. The practical development process activities were regardless carried out in the originally planned timeframe of 6 months from the start of the thesis, and the practical results of the thesis process were provided to Wärtsilä's during that time.

The effects of the aspect of *Flow* vision manufacturing strategy on the way of operating with the EBMOM in the future, could not yet be defined to any detailed extent of solutions due to the early stage of development during this thesis. However, the need to consider it was made prevalent in all discussions, planned approaches, and executions of development activities during this thesis. In further detailed development activities after the thesis scope the considerations of the implications of the Flow manufacturing strategy will be increasingly more important.

6. CONCLUSIONS

The defined research problem as written in the simplified form of: “The need to develop the *Flow* Engine Block Manufacturing Operating Model (EBMOM), according to the *Flow* manufacturing strategy vision, while pursuing overall business goals of improved lead time, total cost, and throughput”, and the preliminary set research milestones of: “Creating a mapping of the current-state operating model.”, and “Creating an outline of the concept operation model.” could not be fully satisfied in this thesis. This was due to the ultimately realized vastness and complexity of development work, and the relatively long timeframe of the process needed to define and develop the engine block manufacturing operating model, in comparison to the thesis practical process timeframe. However, through the defining of several intermediary research questions, and attempts to answer them through the practical process of this thesis, this research resulted in:

1. Documenting the initial questions, considerations, and opinions raised regarding the approach to development of the *Flow* EBMOM, as identified important by the operating model key stakeholders in initial introductory development meetings.
2. Carrying out literature review in the areas of the theoretical research approach, but also the conceptual theory of: Design of manufacturing systems, pursued manufacturing process performance characteristics, relationships of process laws and factors, and the alternative approaches to continuous process improvement in the point-of-views of Lean and the Theory of Constraints.
3. Planning of the appropriate research approach, to introduce and commit stakeholders to the development project starting point. Also, to facilitate collecting of needed development base information inputs from stakeholders, and processing the resulting findings into a useful format: As the development Work Breakdown Structure, and as the development process Activity Network Diagram, together defining the needed development project structure and its considerations.
4. Facilitating in cooperation with stakeholder experts, a limited scope of the defined development project in the form of the: *Flow* EBMOM machining model development stream, and the MTAC Large CM simulation model development stream.
5. Producing together as a result, the preliminary design of the new *Flow* EBMOM machining model, the accordingly defined Large CM process sequence, and the matching updated structure and functionality of the existing Visual Components and Excel based simulation model.

While the thesis, was not able to analyse the workings of the starting point current-state EBMOM, or define the needed changes to operations according to the new future-state *Flow* EBMOM in a deep detailed level of investigation. The thesis however, was able to investigate on a vast but high-level scope the approach preferred and prioritized by stakeholders, and subsequently define and put into motion the necessary deemed structured plan for the initial starting phase of the *Flow* EBMOM development project process.

The key takeaways identified during this thesis process are:

- The development of the engine block manufacturing operating model, and other similar systems, is a topic of vast conceptual framework with complex interdependencies. It inherently requires the knowledge, skills, and experience of a collective organisation, to cover the consideration and conclusions regarding the definition of all the system's aspects of operation.
- The critical need is to tap into and bridge, the information silos belonging to different stakeholders of departments, functions and experts in an organization and its environment. In order to gain a holistic understanding regarding the inputs for development of these kinds of vast systems of manufacturing or operating models. Finally gaining synergy, vision, and clear objectives for the executed process.
- The usage of a defined development framework is key, to efficiently enforce structured and logical progress and firm grip, for effective development, already from its earliest stages. In order to avoid conflicting activities or disregard due to ambiguity among the elements of a development project. Instead gaining commitment, momentum, and overall intended results in the end.

As discussed in the thesis, further development would more effectively continue, produce intended results, which could be further improved, by referring to the practises, relationships, and structuring suggested by the literature review chapters regarding: "*Manufacturing system design"* (2.5), "*Manufacturing process performance characterization" (2.6)*, and "*Continuous process improvement towards the perfect state*" (2.7) according to the methods of *Lean (2.7.1)* and *Theory of Constraints (2.7.2)*, along with a structured *Project Management (3.3.3)* approach, leveraging the support of important deemed project management items and matters listed by the author, but not defined in this thesis scope.

In the point-of-view of the Design Science Research Process, the thesis regards the development of the engine block manufacturing operating model with the focus in the steps of *problem explication*, *requirement definition*, and partial *artefact design and development*. After the thesis, the research process should continue further in other research and development activities lead by internal Wärtsilä processes, with the focus now on extensive *artefact design and development*, *artefact demonstration*, and *artefact evaluation*, regarding the developed *Flow* Engine Block Manufacturing Operating Model.

REFERENCES

1. Wärtsilä. 2022. About Wärtsilä | Learn more about the company. Web page. Cited 10.7.2022. https://www.wartsila.com/about

2. Wärtsilä - Sustainable Technology Hub. 2018. Wärtsilä makes significant investment in Finland – the Smart Technology Hub, next-generation innovation and production centre, will be built in Vaasa. Web page. Cited 16.10.2022. https://www.sustainabletechnologyhub.com/wartsila-makes-significant-investment-in-finland-the-smart-technology-hub-next-generation-innovation-and-production-centre-will-be-built-in-vaasa/

3. Johannesson, P. & Perjons, E. 2014. An Introduction to Design Science. eBook. Switzerland: Springer International Publishing. Requires access. http://link.springer.com/10.1007/978-3-319-10632-8

4. Järvinen, P. On Research Methods. 2018.

5. Tiainen, T., Aittoniemi, J., Haukijärvi, I. & Yli-Karhu, T. 2015. Toimintatutkimus tietojenkäsittelytieteen tutkimuksessa. Tampere: Tampereen yliopisto, Informaatiotieteiden yksikkö. Informaatiotieteiden yksikön raportteja, 38/2015.

6. Geng, H. 2016. Manufacturing Engineering Handbook. 2nd edition. eBook. New York: McGraw-Hill Education. Requires access. https://www.accessengineeringlibrary.com/content/book/9780071839778/chapter/chapter12

7. Ovaska, S., Aula, A. & Majaranta, P. 2005. Käytettävyystutkimuksen menetelmät. Tampere: Tampereen yliopisto, Tietojenkäsittelytieteiden laitos. (Julkaisusarja B), Report No.: B-2005-1.

8. Tiainen, T. 2014. Haastattelu tietojenkäsittelytieteen tutkimuksessa. Tampere: Tampereen yliopisto, Informaatio-tieteiden yksikkö. (Informaatiotieteiden yksikön raportteja), Report No.: 25/2014.

9. Innokylä. n.d. Kumuloituva ryhmä. Web page. Cited 9.8.2022. https://innokyla.fi/fi/tyokalut/kumuloituva-ryhma

10. Sirola-Korhonen, K. 2022. Osallistavat menetelmät – vinkkejä ja virikkeitä kouluttajalle. KSL Opintokeskus. Web page. Cited 9.8.2022. https://www.ksl.fi/julkaisut/osallistavat-menetelmat/

11. Wikipedia. n.d. Tuplatiimi. Web page. Cited 9.8.2022. https://fi.wikipedia.org/w/index.php?title=Tuplatiimi&oldid=20625334

12. Oulun ammattikorkeakoulu. n.d. Yhteistoiminnallinen oppiminen: Lumipallo. Web page. Cited 9.8.2022. http://www.oamk.fi/amok/oppimat/LO/Opetusmenetelmat06a/html/yhteistoim_.html

13. Sharp, A. & McDermott, P. 2009. Workflow Modeling : Tools for Process Improvement and Applications Development. 2nd edition. eBook. Boston: Artech House, Inc. Requires access.

http://libproxy.tuni.fi/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=cookie,ip,uid&db=e000xww&AN=284232&site=ehost-live&scope=site

14. Campbell, M. Project Management. 2014. 6th edition. eBook. New York: Alpha, Penguin Group (USA). Requires access. https://learning.oreilly.com/library/view/project-management-sixth/9781615644421/

15. Hopp, W. & Spearman, M. 2011. Factory physics. 3rd edition. eBook. Long Grove, Illinois: Waveland Press, Inc. Requires access. https://www.amazon.com/Factory-Physics-Wallace-J-Hopp-ebook/dp/B00H85T466/

16. Vaughn, A., Fernandes, P. & Shields, J. 2002. Manufacturing System Design Framework Manual. Massachusetts Institute of Technology Lean Aerospace Initiative. Available from. https://dspace.mit.edu/handle/1721.1/81902

17. Bellgran, M. & Säfsten, K. 2010. Production Development: Design and Operation of Production Systems. 1st edition. eBook. London: Springer London. Requires access. http://link.springer.com/10.1007/978-1-84882-495-9

18. Modig, N. & Åhlström, P. 2021. This is Lean: Resolving the Efficiency Paradox. 1st edition. eBook. Stockholm: Rheologica Publishing. Requires access. https://www.amazon.com/This-Lean-Resolving-Efficiency-Paradox-ebook/dp/B00JZZS7Q0

19. Cox, J. & Schleier, J. 2010. Theory of Constraints Handbook. 1st edition. eBook. New York: McGraw-Hill. Requires access. https://www-accessengineeringlibrary-com.libproxy.tuni.fi/content/book/9780071665544

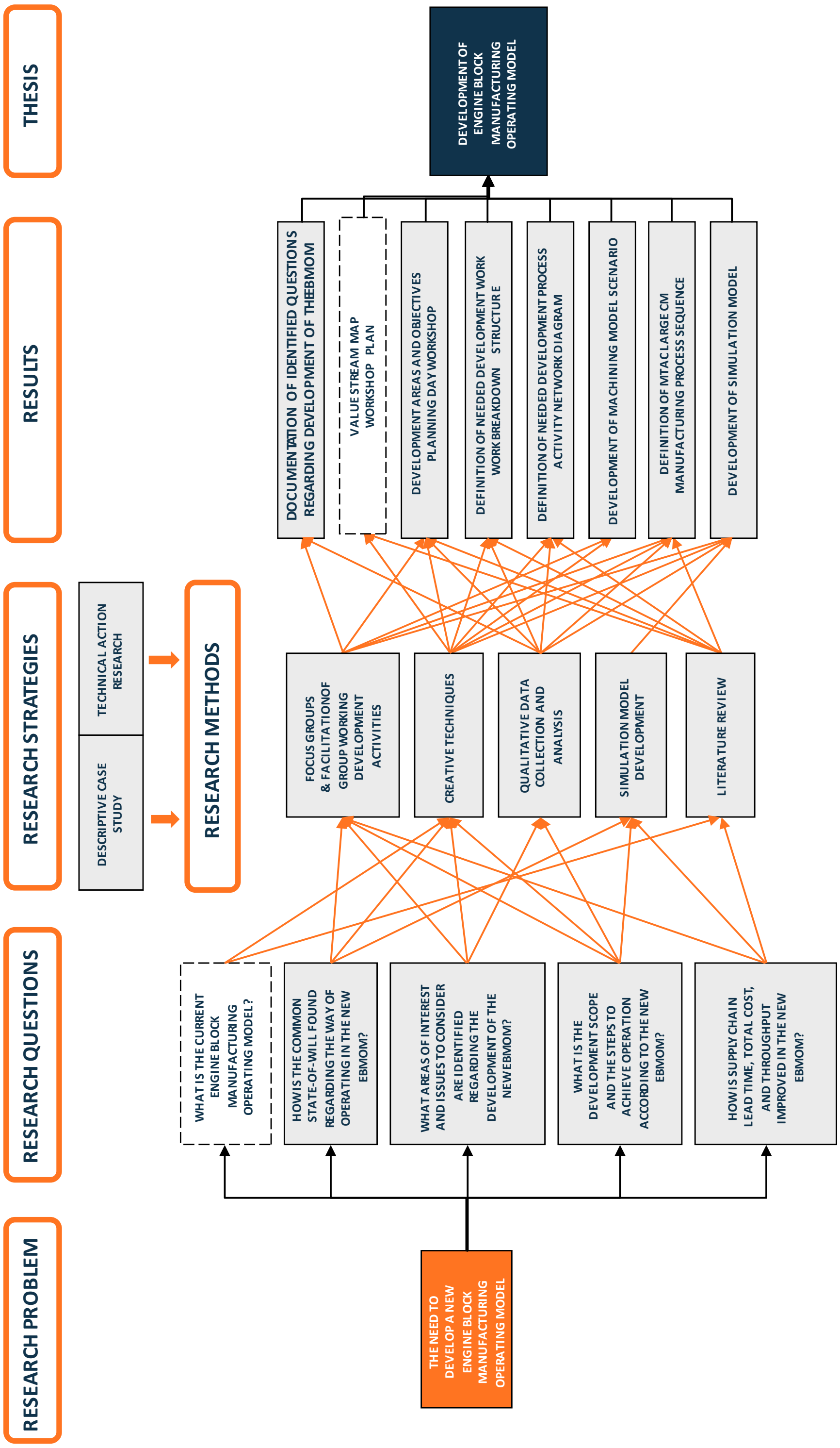
20. Goldratt, E. 1990. What is this thing called theory of constraints and how should it be implemented?. 1st edition. Great Barrington Massachusetts: North River Press.

21. Theory of Constraints Institute. n.d. Five Focusing Steps, a Process of On-Going Improvement. Web page. Cited 23.7.2022. https://www.tocinstitute.org/five-focusing-steps.html

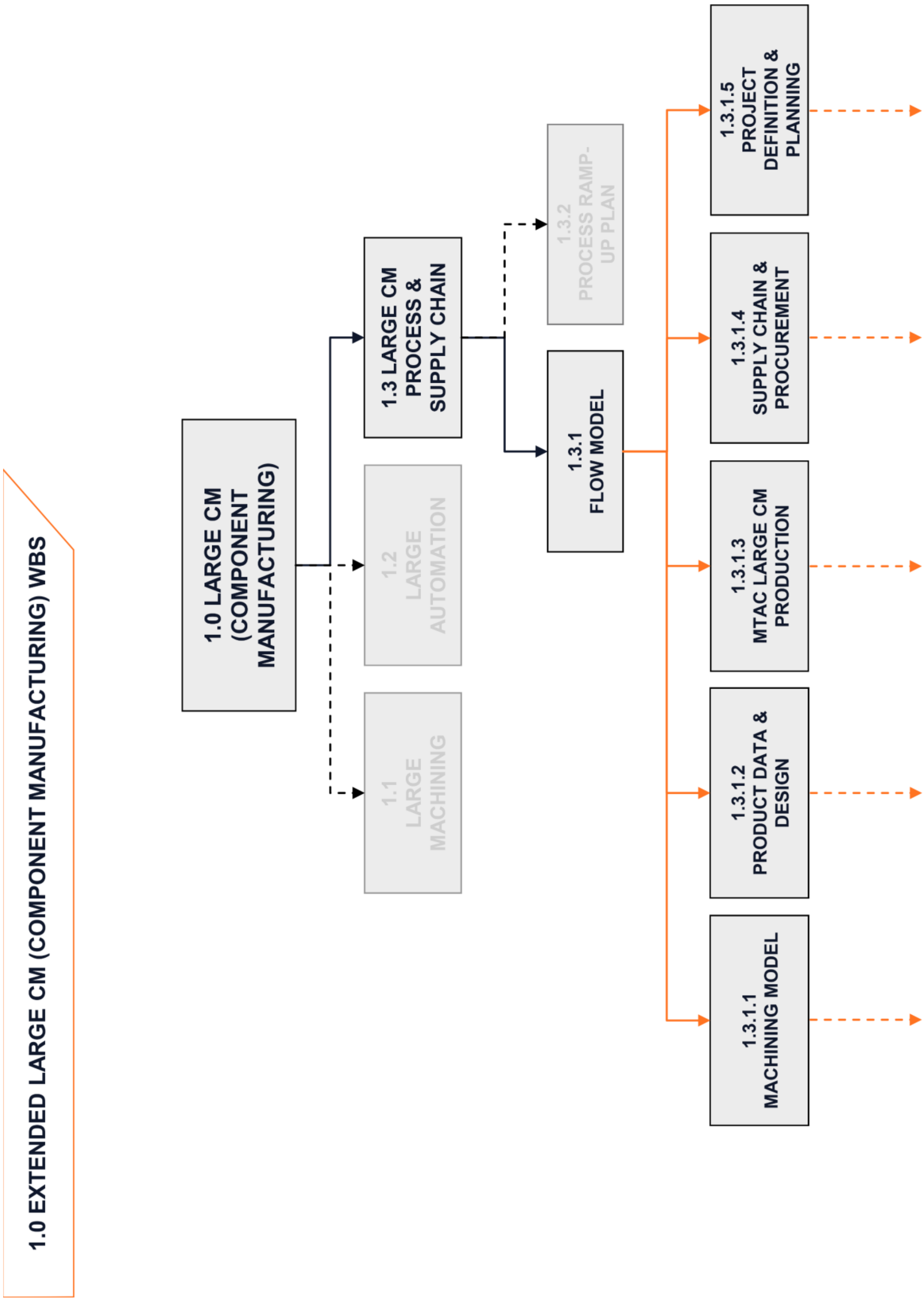
22. Wärtsilä internal document. 2016.

23. Wärtsilä internal document. 2019.

APPENDIX A: THE STRUCTURE OF THE THESIS



APPENDIX C: WORK BREAKDOWN STRUCTURE OVERVIEW



APPENDIX E: ACTIVITY NETWORK DIAGRAM