Design and development guidelines for manufacturing at Volvo Cars

Standardising the manufacturing engineering process

MASTER OF SCIENCE THESIS IN THE MASTER DEGREE PROGRAMME, QUALITY AND OPERATIONS MANAGEMENT

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Division of Production Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Goteborg, Sweden, 2012

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Abstract

There are many aspects that need to be considered in production system development processes. Currently, there is no standardised and structured way of developing production systems at Manufacturing Engineering (ME), Volvo Car Corporation (VCC). In this master thesis, the framework Design Guidelines for Manufacturing (DGM) is presented with the aim to bring structure, standardise the work procedure and improve the quality of the development processes at ME. DGM is a wide framework of the aspects that need to be taken into consideration when designing a production system. The main task in this study is to design the guideline index that includes these aspects. The index is developed through information collected from interviews with experts at ME and through academic and VCC literature. Data collection runs simultaneously with the analysis of the data and the importance, correlations and influences of the aspects are constantly questioned. This leads to a finalised guideline index consisting of 23 aspects that are located in six different categories. The guideline index is compare to Volvo Cars Manufacturing (VCM) performance objectives in a workshop with experts at ME, to validate the chosen aspects and to align them with the strategy of VCC. This leads to the delivery of this master thesis, a wide framework of DGM consisting of the important categories and aspects that need to be considered in production system development. The aspects have to be further developed though, in order to work as a guidance tool in production development. Therefore, one of the aspects is further developed in order to create a demonstration aspect that can work as guide for further development of DGM.

Keywords:
Manufacturing, Production, Development, Aspect, Category, Process

Acknowledgment

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Lastly, a big thanks to those who have participated in the interviews and workshops during the research. Without you, we would not have been able to achieve the same level of outcome.

Regards,

Magnus & Henrik

Abbreviations

BoP	Bill of Process
CE	Concurrent Engineering
CNC	Computer Numerical Control
CSF	Critical Success Factors
DFMA	Design For Manufacturing and Assembly
DGM	Design Guidelines for Manufacturing
FMA	Failure Mode Avoidance
FMEA	Failure Mode Effect Analysis
GPDS	Global Product Development System
ME	Manufacturing Engineering
NPD	New Product Development
OEE	Overall Equipment Effectiveness
OWE	Overall Work Efficiency
PII	Product and Inspection Instruction
PoPS	Product and Process Sequence
QCDISMEL	VCM performance objectives
QFD	Quality Function Deployment
SP&C	Strategic Planning & Control
SVLs	Sheridan-Verplank Levels
TARR	Time Adjusted Rate of Return
VCC	Volvo Car Corporation
VCM	Volvo Cars Manufacturing
VCMS	Volvo Cars Manufacturing System

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1 Introduction

This study is carried out through the spring of 2012 at Volvo Cars, under the department of Strategic Planning and Control (SP&C) at Manufacturing Engineering (ME). The introduction aims to give the reader a clear understanding of the purpose of doing this thesis. The first part discusses the background as to why this research is relevant, followed by a description of the company in which the project is carried out. Further on, the purpose and goals are stated followed by problem description and the delimitations of the research.

1.1 Background

There is an increasing competitive situation in production industries today. According to Bellgran & Säfsten (2010), this motivates the need of understanding how to develop and establish operations into an effective production system. Managing and controlling existing production systems results in limited improvements, while the right thinking during the initial development phase of the production system can contribute to higher potential benefits.

After a number of studies carried out by Bellgran & Säfsten (2010) within Swedish manufacturing firms starting from 1990, the authors' shared unambiguous view is that manufacturing companies lack a structured and systematic way of developing production systems. Low priority under time pressure and the risk of jeopardizing the flexibility of a development plan are two common arguments against using a structured approach. However, Bellgran & Säfsten (2010) argues the opposite; that a structured way of working is what decreases the time spent on planning in an unstructured approach. Therefore one could argue that it would be helpful to use a structured approach in order to decrease wasted time when working under time pressure.

Beskow (2000) states that a structured way of working is a common element in companies' product development processes. Regarding the risk of losing flexibility, Bellgran & Säfsten (2010) makes comparisons with product development processes and points out several benefits with a structured approach. These are that the structured approach brings a holistic decision process where the logic of the decisions are clear and it is secured that important issues are handled. The authors also argue that the process is largely self-documenting and information is easy to access for newcomers.

The benefits of having a structure and standardised production development process insinuate the need to implement some sort of common approach in the company, with guidelines for instance. In product development this has already taken a start, with the implementation of design guidelines for specific sub-systems, such as fuel systems (Volvo Cars, 2012a).

1.2 Volvo Car Corporation

Volvo Car Corporation (VCC) is a global car manufacturer, founded year 1927 in Goteborg, with assembly plants in, for instance, Goteborg, Gent and Chongqing. VCC was owned by Volvo AB until 1999 when it was bought by Ford Motor Company and was under Ford's ownership until 2010 when Geely Holding Group acquired Volvo Cars. (Volvo Cars, 2012b)

1.2.1 Manufacturing Engineering

The department of Manufacturing Engineering at Volvo Cars is the link between product development and production, making sure that the journey from just an idea to the actual production runs as smoothly as possible. Product development and production both have different drivers and focus areas and it is in the interest of ME to make the best out of the situation, trying to fulfil the needs of both functions.

ME works with changes regarding both products and processes. Whenever a change is about to take place, ME starts with making a feasibility study to investigate if it is even possible from a manufacturing point of view. A system strategy is also created, before the project even starts. Then, in the start-up phase of the project, ME works parallel with product development by forming the manufacturing system. The development of the product and the manufacturing system are making mutual progress until the final stage is reached, when the project is ready for job one. This process can be improved by thoroughly investigate synergies in projects in order to communicate mutual guidelines for manufacturing design that will bring a shared vision within ME, a sort of framework of how the process can be done without forgetting an important aspect.

ME is a centralised function of Volvo Cars, located in Gothenburg. It highly affects other departments' work, which makes the effectiveness of the department important.

The vision of ME is to "define, prepare, launch and maintain waste free, defect free, highly efficient and flexible industrial systems and robust products".

1.3 Purpose & Goals

For the time being there is a lacking structure in the production development processes at ME. There is insufficient information regarding the topic in the academic literature. Therefore, the purpose of this master thesis is to propose a guided way of working with the development projects, which is both effective and secures the quality of the production development processes.

In order to fill this gap, the goal of this master thesis is to deliver a framework with guidelines to ensure the success of the development processes. The framework consists of a guideline index, i.e. a structured map of the important aspects that has to be considered during the projects. In this index, the aspects are ordered hierarchically and underneath each aspect there are several guidelines and considerations that have to be taken into account when developing production systems. Thus, the delivery of this thesis does not include all the important guidelines of how to develop production systems, since the focus is to deliver the structure of the guideline index. This study results in the following deliverables:

- *Important aspects:* The crucial aspects that need to be considered in a production development processes.
- *Structure of guideline index:* The structure of how the different aspects relate to each other in a hierarchical order.
- *Aspect descriptions:* Describing each aspect and its importance, complemented with guidelines explaining the issues that has to be considered.
- *Fields of expertise:* Mapping the departments of interest for further detailed description of the guidelines.
- *Exemplified aspect:* A more detailed description of an aspect that includes more concrete guidelines in order to exemplify how the guidelines can be further developed. The exemplified aspect is in this case *"material flow"*.
- *Implementation plan:* A suggestions for how the guidelines should be implemented.

Together, the deliverables results in the main delivery from this master thesis, the framework Design Guidelines for Manufacturing (DGM). This is a wide framework with a more detailed description of the aspect "material flow", which works as an example of how the aspects can be further developed.

1.4 Problem description

The focus of this study embrace the lack of structure and guidance concerning projects carried out at ME. To be able to solve the problem, the following research questions are investigated:

- What aspects need to be considered in order to prevent complications and secure the success when carrying out a production development project at ME?
- How should the aspects be categorised and what needs to be included in the aspects in order to ease the usage of the design guidelines?
- What factors affect the success of implementation of the guidelines delivered by this study?

1.5 Delimitation

The following delimitations are considered during the thesis work based on the stated objectives:

- This study mainly aims to give guidance applicable to Manufacturing Engineering department of Volvo Cars. No investigation regarding applicability on other functions, companies or industries is performed.
- This research should solve the problem on a high overview level and not a detailed requirement level. Only guidelines and considerations when designing and developing production systems are included whilst requirements are not.
- The different aspects and the content of these aspects will not be weighted and compared with each other in terms of importance. Hence, situations where aspects contradict will not be investigated in the research.
- This thesis does not involve the actual implementation of the guidelines. However, it does involve implementation suggestions as a result of the third research question.
- The resulting guideline index will not comprehend every guideline that has to be taken into consideration in production development. Future development of the guidelines has to be done by experts within the area. As earlier described, material flow is further developed, see appendix A.

1.6 Terminology

In order to facilitate the readers' ability to follow the reasoning throughout this research, this section aims to clearly state the different terminologies used in the work. The different terms and their hierarchical relations are illustrated in the picture below. The highest level of hierarchy that will be discussed is the term *"Design Guidelines for Manufacturing"*. This is the main deliverable towards Volvo Cars and the evolvement of this document is described throughout the report. DGM consists of a set of categories, which in turn consist of a set of aspects to consider when working within each category.

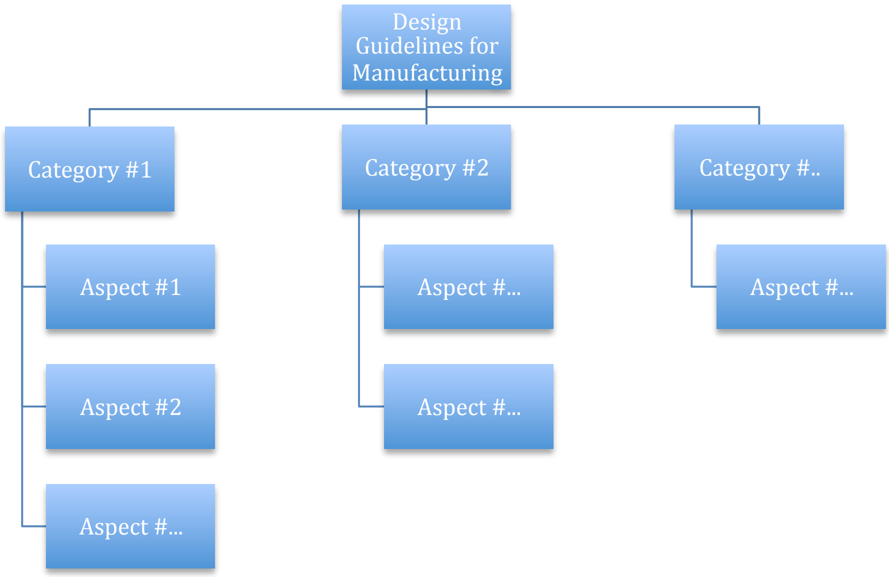

Figure 1 Illustrative description of the hierarchy.

Each aspect should then be filled with concrete guidelines for how to work. One example could for instance be that a category named *"Production system"* includes for instance the aspect of *"Level of automation"*. The aspect is structured around three parts; the first part is *what* and describes what the aspect is about, the second part is *why* and it describes why the aspect is important to consider, the final part *how* consists of the gathered guidelines. See section 5.6 for further clarification. As an example, the *How* part of the aspect *"Level of automation"* can for instance include guidelines such as:

- Consider implementing automated solutions in situations where man-hours are expensive.
- Consider implementing automated solutions when the work task environment can be hurtful for operators.

- Automated solutions should be supported by positive business cases before implementation.
- Automation might limit the process flexibility because of…

The level of detail in the guidelines differs depending on the detail level of the system on which they are applied. Some guidelines can be specific for design and development of a certain manufacturing system, whilst others can be very general. As mentioned in delimitation, this research aims towards a general view of manufacturing design and development. However, in order to give guidance for how the guidelines could be developed further, the aspect of *"Material flow"* is developed with more depth. Still, this is just a demonstration and the future of DGM is yet to be decided in the hands of Volvo Cars. See appendix A for the demonstration aspect.

2 The present state at VCM

This section describes the current state at Volvo Cars Manufacturing (VCM) with the purpose to give the reader a better understanding of what tools and work procedures that are used in todays work at VCM. Initially there is an introduction to the production system, followed by what tools and frameworks that are used in VCM and concluded with a description of the production design and development processes.

2.1 The production system

The general idea of a production system consists of having something produced. The input is the material, work and capital, which lead to the output, the product or service (Hågeryd et al., 2005).

This is also the case for the production at Volvo Cars, where the steel, rubber, fabrics, glass etc. are turned into finished cars as a factor of labour and invested capital. There are three main factories in the Torslanda plant in Sweden called A, B and C. A is the body factory, B is the paint factory and C is where the final assembly of the car takes place. Factories A and B has a high level of automation because there are unsafe and bad ergonomic situation for manual labour as well as high need for narrow tolerances. To support the production of cars in Torslanda there are several additional support factories, for instance the body components factories that are located in both Olofström and Göteborg, and the engine factory located in Skövde. An illustration of the Torslanda plant is shown in the figure below. (Volvo Cars, 2012b)

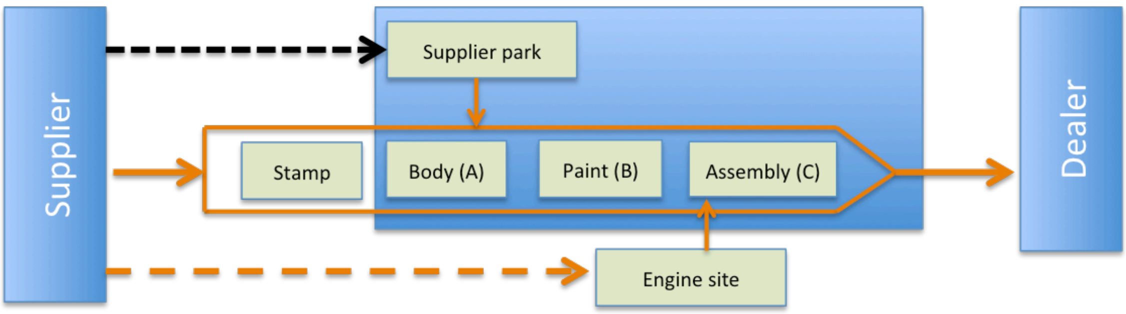

Figure 2 Illustration of the Torslanda production plant.

There are four main components that production systems consists of, namely product, machines & equipment, employees and facilities (Hågeryd et al., 2005).

The facilities are the factories earlier mentioned. The product is the outcome of VCC production system, which consists of the different variants of cars. The machines &

equipment are the invested capital in automated processes and the employees are the labour needed in order to produce the cars. Furthermore, it is important to note that additionally to the factories there are also many offices that contain elements of all these four components. (Volvo Cars, 2012b)

Line production is suited for a high volume with a small number of variants. This leads to the need of buffers in order to prevent stop in production as a result of:

- planned changes of tools
- tool adjustments and breakdowns
- defects in the products
- adjustments of the tolerances
- problems with the transportation of products.

A more flexible line allows a higher number of variants because the change-over between variants are easier. In order to lower the work in progress the production line can be combined with a customer order focus. (Hågeryd et al., 2005)

The production system at Volvo Cars is a flexible line production with customer pull focus. In order to decrease the production costs even more the production strives towards a just-in-time philosophy, which is a lean philosophy with the meaning to produce and deliver the right item in the right amount and in just the right time (Womack & Jones, 2008).

2.2 VCM tools and frameworks

In this section several of the tools and frameworks that are used in VCM is described.

2.2.1 Bill of Process

The Bill of Process (BoP) is a tool that is widely used at Volvo Cars. It describes the production processes and it is used both as a visual aid, since it illustrates the operation sequence at VCM, and as an aid to develop and refine the production system. The tool contains several different levels, where the description of the sequence gets more and more detailed with the increasing levels. Level 0 describes the operations on a plant level, including all the different factories of the plant illustrating the whole production journey from steel plates to a fully complete and drivable car. Level 1 describes all the processes of a certain factory, e.g. the Paint factory shown below. Level 2 describes the operations on a more stationary level and level 3 is the lowest described sequence based on measured values such as PII (product & inspection instruction), PoPS (product and process sequence), etc. (Volvo Cars, 2012c)

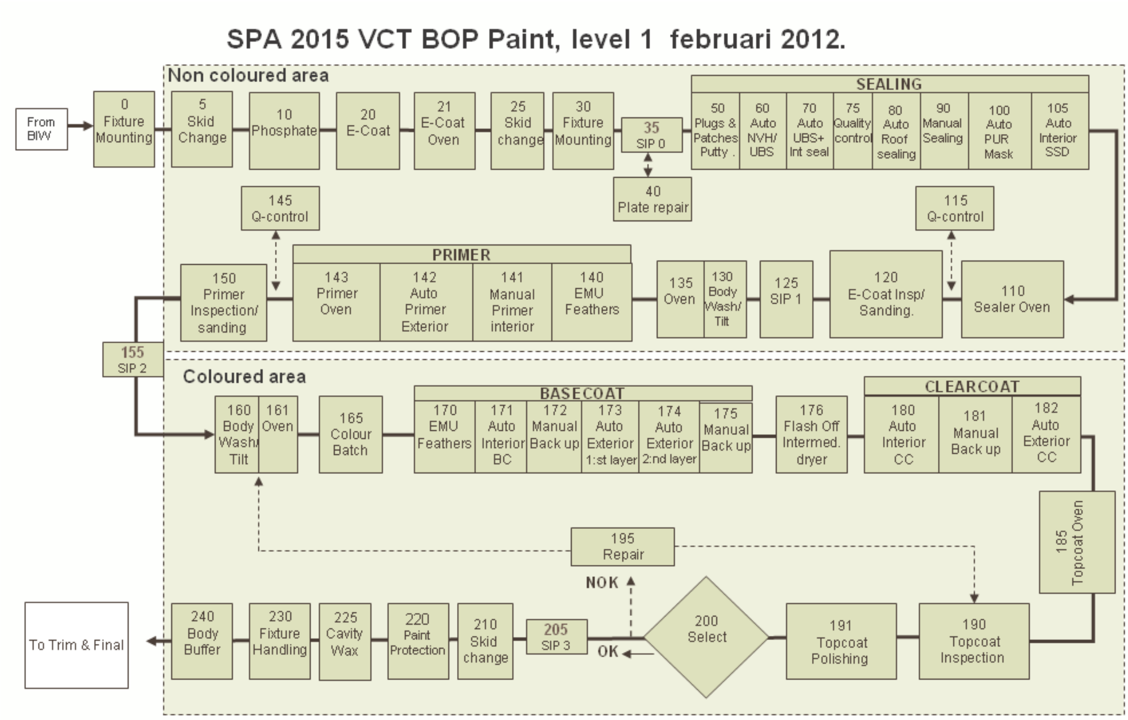

Figure 3 Illustrative example of Bill of process at Volvo Cars.

The BoP is a rather new tool at Volvo Cars and it is still under development. This means that it does not yet include every aspect of the production system, which is the goal of the tool. It is already enthusiastically used and the tool brings unity and clarity between the different functions and plants of VCC. (Volvo Cars, 2012c)

2.2.2 VCMS

Volvo Cars Manufacturing System (VCMS) is an adapted lean strategy that is used at Volvo Cars. Every employee at the company is familiar with the improvement initiative that VCMS stands for and the results of the introduction of the tool has led to many improvements in VCM. The system is similar to a lean temple including several important principles, adapted to the Volvo Cars language in order to be of the outmost effectiveness. (Volvo Cars, 2012d)

2.2.3 Performance objectives QCDISMEL

In order to know what to strive towards, VCM has performance objectives called QCDISMEL. They stand for quality, cost, delivery, improvement, safety, medarbetare (co-workers), environment and leadership. These objectives are continuously checked at departments meetings and with the help of scorecards at ME in order to keep the work focused on what is important. The objectives are widely used and acknowledged among Volvo Cars' employees. (Volvo Cars, 2012e)

2.2.4 Product development requirements

There are several requirements and pre-requisites derived from the production system. Many of these are directly affected by the characteristics of the product. Hence, there are a lot of product development requirements that has to be considered and followed by the product development department to make it possible to produce the product. Several of these requirements are coming from the department of ME and is constantly expressed and pronounced to the product developers. (Volvo Cars, 2012f)

2.3 Production design and development processes

As previously described, there are many functions of ME. In this master thesis the focus is on the projects that aims to design and develop production systems. For instance, these processes are:

- Small continuous improvements the production system in production – kaizen.
- Developing the existing production system.
- Designing new production systems when a new factory is designed or a new line has to be implemented.

Continuous improvement, kaizen, is mostly performed on the production floor by implementing smart solutions to the production flow. Future references of projects in this paper refer to these production development processes. Consequently, the main users from the deliverable of this research are those who work with these processes. Everyone that is involved in these types of projects would benefit from a more structured approach and the increased knowledge that can be obtained by using a standardised workflow.

2.3.1 The present ME process

When new cars and their productions system are to be developed today at VCC, the development process follows a certain path named Global Product Development System (GPDS). GPDS range from the project initiation all the way to start of production. This range requires a large amount of stage gates to secure that the development proceeds as planned. In order to explain the overview of the process from a manufacturing engineering point of view, one can divide it into three main parts:

- Manufacturing strategic planning and business compatibility.
- Virtual product and process compatibility.
- Physical product and process compatibility.

The first part is about taking a strategic stand and plan for the future. This is for example where the Bill of Process tool comes in. It is a strategic matter to strive towards similarities in the operation sequences between different cars and factories. Another example is for instance to strive towards high compatibility between different interfaces early in projects, rather than putting all the focus on high completeness of the subsystem with low compatibility in-between. (Volvo Cars, 2012g)

The strategic part is followed by the part in which the products and processes are developed virtually with respect to specific requirements. When developed the compatibility is tested. This all takes place within the toolbox of software available at the company. This step ends up with an evaluation regarding how the concepts align with the goals. For instance, is it possible to produce this product (at desired level of quality) in the intended manufacturing facility? Is the solution within the limits of the allocated cost? Can we run this solution with the required line speed? (Volvo Cars, 2012g)

After the product and process have been developed virtually it is time to develop them and test their compatibility in physical reality. Following a so-called control plan does this step reliable and secures the quality. The control plan is a list of all the critical controls, inspections and tests, which needs to be verified when building the product and process. (Volvo Cars, 2012g)

2.3.2 Research gap

As earlier described, at present there is not a structured way of working with the production development processes at ME. By investigating the academic literature it is clear that information about adaptable guidelines in this case is absent. Certainly, there is information about what aspects that has to be considered from project initiation to production ramp-up. However, they are not nearly detailed or concrete enough to be implemented and used at VCC. The lack of academic literature suggests the need to investigate in more detail what aspects that have to be considered when developing production systems.

Today there are many tools and frameworks that cover several of the work processes at ME. However, they are not sufficient enough to guide and support the processes of designing and developing the production system. There are several requirements, strategies and tools such as BoP and VCMS. One of the mayor problems is that they are spread wide over the department of ME. This insinuates the need of a collective document that includes the information and expertise needed to not miss any important aspects when designing or developing the production system. It is important to note that the collected document is based on the present state of the VCC production system. This means that if the production system changes considerably, for instance if the production methods are vastly changed, the document might lose its validity. However, minor changes can be implemented into the document. This is further discussed in the discussion section 6.6.

3 Methodology

The methodology describes how the project research is performed. To start with, the research strategy and design is explained, including a section about the research execution. Then the methods used when collecting and analysing the data are described. Lastly, the methodology for controlling the quality of the research is discussed. The framework by Bryman & Bell (2011) is regularly used in the methodology to give structure and guidance throughout the research.

3.1 Research strategy and design

The research in this thesis is based on both a theoretical study and an empirical study. The theoretical study includes:

- Investigation of what tools and guidelines that are already in use at the ME department of VCC.
- Screening of external usage of design guidelines.
- Examination concerning production development processes.
- Research about production development phenomenon that is applicable on the situation at ME.

The empirical study consists of interactions with department heads and other employees of interest at ME.

An inductive research approach is used during this research since the theory is a result of the findings. The theory is in this case the guidelines that are formed by the findings from the study. As Bryman & Bell (2011) states, "with an inductive stance, theory is the outcome of research". In a deductive approach on the other hand, the authors explains that the theory and the creation of a hypothesis precedes the observation and findings. The hypothesis is translated into researchable entities and then tested. Because of these reasons, this approach is not applicable in this thesis.

The epistemology, the question of what is acceptable knowledge, is in this work based on an interpretivism view. By using phenomenology approach in the research, it is possible to interpret the actions of the employees and make sense of how they perceive the working processes at ME. The positivism standpoint would somewhat restrain the research, since a big part of this study is to examine the social scientific aspects when working on the development projects, which positivism does not approve as acceptable knowledge. It is important to take the social aspects into consideration in order to create useable guidelines. (Bryman & Bell, 2011)

Qualitative research strategy is the basis for this thesis. As stated by Bryman & Bell (2011), qualitative research "emphasizes words rather than quantification in the collection and analysis of data". Since the epistemology orientation in this paper is interpretivism, it is important to focus on the qualitative outcome of the research instead of quantitative factors that would be hard to assess (Bryman & Bell, 2011). Also, a qualitative research approach is more useful in the case considering that the empirical study consists of interactions with the employees at ME, meaning that the possibility to collect quantitative data is small. There is also no interest in using a lot of statistical tools, but rather to qualitatively analyse the gathered information from the interactions.

The research design used in this thesis is a case study design. As Stake (1995) mentions, a case study is performed when the case itself is of special interest and when the particularity and complexity of the case is the desired target. The comparative design or the cross-sectional design might have been good alternatives to the case study design in order to get good insight of the applicability of different guidelines in the production development process. However, the problem with the designs is that they both need more than one case to study. The accessibility to other companies' operations is only what can be found from an external point of view, and that is not nearly sufficient enough in order to adapt the designs. The comparative design would have been the better suited design of the two alternatives, because it would be possible to have the same research strategy approach as with case study design. Cross-functional design on the other hand uses a quantitative research strategy, which would change the research strategy considerably. (Bryman & Bell, 2011)

3.1.1 Research execution

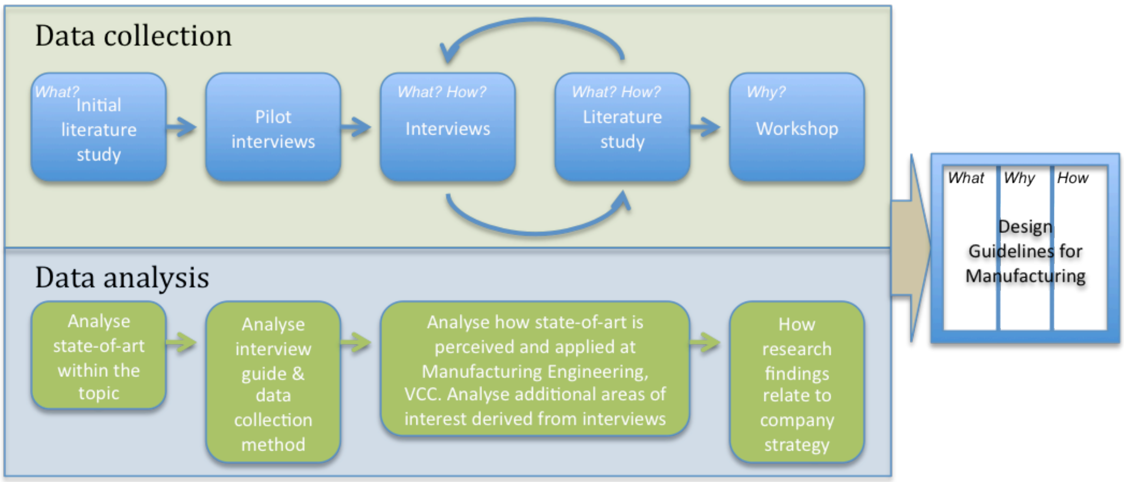

Figure 4 Research execution steps.

The research consists of five major parts in which data collection and data analysis are running in parallel. The investigation is performed in order to increase the understanding of *what* is important, *why* it is important and *how* it should be taken into consideration. The first part is an initial study of up-to-date academic literature. This initial study aims towards finding work that can facilitate and become valuable in the thesis, generally widen the knowledge base within the area and secure that no successful solution is already available. The findings from the first part are used as input into the second part, which regards pilot interviews. The aim with the pilot interviews is to investigate how well functioning the data collection method is, how clearly the participants perceive the purpose of the thesis and to what extent the participants' answers are answering the research questions. The third and fourth part is an iterative process of interviews and further literature studies needed to cover topics derived from the interviews. When it comes to analysing this part, it is about understanding how different aspects within the topic are perceived, classified and applied to Volvo Cars, in order to find synergies and develop a united bigger picture. When the bigger picture is clear, it is used as the input to the fourth part that is a workshop. The workshop is an approach of gathering data and in this case it aims towards investigating how the bigger picture, derived from interviews, align with and contributes to the performance objectives of Volvo Cars Manufacturing (VCM). The performance objectives are called QCDISMEL and stands for quality, cost, delivery, improvement, safety, medarbetare (co-workers), environment and leadership (Volvo Cars, 2012e). Finally, the data collection and analysis is concluded into the thesis delivery to VCC, i.e. the document of Design Guidelines for Manufacturing. These guidelines will not be fully finished however, since experts at Volvo Cars has to fill this document with information. Therefore a demonstration will be made of the aspect “material flow”, making it a bit more extensive than the others, in order to show how the guidelines can be developed in the future.

3.2 Data collection

According to Glass (1976), "primary analysis is the original analysis of data in a research study". It is based on the premise that the analysed data is not collected on a secondary level, which would be the case of secondary analysis. The purpose of secondary analysis is mostly to answer new questions with old data. In conclusion, the author suggests that extracting knowledge from accumulated studies is important since the wanted information often resides in an already existing and vast literature. (Glass, 1976)

On this note, the data collection in this research involves both primary and secondary data. The primary data collection mostly consists of interviews with persons of interest at ME. It is both persons who have a lot of expertise in different areas of the production development process as well as managers higher up in the hierarchy, who have a more overview understanding of the work process at the department. The interviews give a better understanding of what the design guidelines should include and it also leads to new Volvo Cars specific aspects. In addition to interviews to collect primary data, the study includes a workshop. The workshop is attended by personnel from ME that have a good understanding of the performance objectives at Volvo Cars Manufacturing (VCM) and also understands the purpose and importance of design guidelines. During the workshop, the produced guidelines are being compared to the VCM performance objectives in order to adapt the design guidelines with respect to the strategy of Volvo Cars.

The secondary data is collected in the theoretical study, described under research strategy and design. Investigation of the already existing tools at ME provides the research with an understanding of what tools the design guidelines should not be replacing as well as helpful information about the ME work processes that can be implemented in the design guidelines. The screening of external usage of design guidelines is an overview scanning of open material to see if there already is an existing and successful strategy that would make the creation of design guidelines at ME a whole lot easier. An examination concerning production development processes is performed in order to get a better understanding of production development. These theory studies are performed in the initial literature study. The final topic of the theoretical study, which is done in the literature study parallel to the interviews, is regarding other phenomena that are applicable on the situation at ME. This is done in order to investigate if there are other factors that have to be taken into consideration when creating the design guidelines. This data is collected both from internal literature at VCC and from external academic sources.

Structured interviews are a common approach when doing a quantitative research. When doing a qualitative research however, the interviews tend to be much less structured. According to Bryman & Bell (2011), that is merely one of many differences between interviews of a quantitative and a qualitative approach. For instance, the authors say that "in qualitative interviewing, there is much greater interest in the interviewee's point of view". Since the quantitative research is aiming for measurable and standardised data, the interviews are built in a structured way that leaves little or no room for deviation from the interview plan. The qualitative interviews on the other hand are far more flexible and deviation is even sometimes encouraged. Because this thesis is based on a qualitative research, the chosen interview approach is the semi-structured interview, with an interactive feature in order to get a good involvement of the interviewees. With this approach the interviewees are asked to place the different aspects under the categories they think they belong to. Both aspects and categories are developed in the initial literature study. An illustration of how the aspects are placed under different categories during the interviews is shown below.

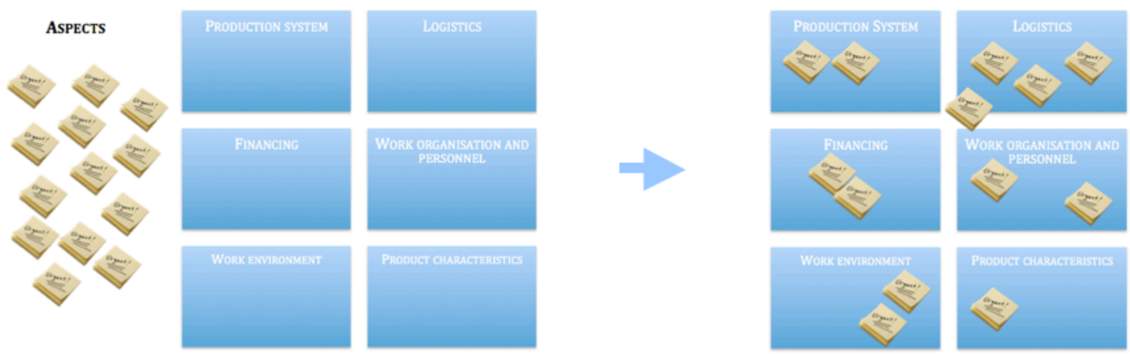

Figure 5 Interview procedure with participant placement of post-its.

While the interviewees are placing the aspects, a list of questions is covered with the use of an interview guide, see appendix B. This leads to a discussion about the aspects, opposite to if the interview would have been of a structured approach in which the interviewee has to answer much more narrow and direct. The answer in the chosen approach sometimes also leads to follow-up questions by the interviewer, leading to even more useful answers. In order to get the best result out of the interviews, an interview description is sent to all participants with a detailed explanation of the different parts of the interview as well as a description of the aspects and categories. The interview description can be seen in appendix C.

The risk with this approach lies within the amount of analysing that has to be done and the task to extract the useful information. There might also be a problem to keep the interviews somewhat on track. (Bryman & Bell, 2011)

Another possible approach when interviewing in a qualitative research is the unstructured interview. This approach does not consist of any actual guide and the topics that are covered are few. There could just be one question that the interviewer asks and the interviewee is then allowed to respond freely. This type of interview is similar to discussions and can be good to use when the root of a problem is hard to specify or the researcher does not exactly know what to look for. The unstructured approach needs a lot of analysing and it is even harder than with semi-structured interview to extract the useful information, which is why it is not applied in this study. (Bryman & Bell, 2011)

When creating the interview guide a couple of aspects have to be taken into consideration. For instance, the questions are formed in order to answer the research questions, leading questions are avoided, an order of the questions and topics are established and a standard form with questions about the name, age, gender, etc. is created. In order to ensure that the interview guide is valid and reasonable, three pilot interviews are held. The main benefit of these interviews is to ensure that the questions are easily understood and possibly to exclude questions from the interview guide or include new questions. (Bryman & Bell, 2011) In order to see the interview guide, see appendix B.

Once the pilot interviews are done and the interview layout is finalised, the interviews are held. There are 11 interviews, where the interviewees are experts from different departments of ME. During the interviews the layout is consistent and unmodified in order to have comparable result, free from any bias reasoning.

In this thesis there is a mixture of academic research, examination of already existing information and tools from VCC and also information input from the interviews. In order to create guidelines that fit the department of ME at VCC, these sources has to be integrated and formed, making the guidelines consist of elements from academic and Volvo Cars expertise, as well as integrating the VCC strategy so that the guidelines follow corporate strategy.

3.3 Data analysis

Altogether, there are four parts of analysing in this study, as illustrated in figure 4. The first part is the analysis of the initial literature study in order to secure that the topic is approached in a good manner. There is also an initial research of *what* the guidelines should consist of. Once the course of the research is set, the interview guide is developed and needs to be analysed in order to establish that the questions in the interview are answering the research questions. In a qualitative research, this part is especially important, since the quality of the outcome data is a highly affected by the quality of the input data. If the questions are wrong from the start, there is no way to accomplish a successful study. When the interview guide is finalised, the research enters the next stage, which is the iterative phase where interviews and literature study are performed and analysed. This analysing forms and develops the guidelines as a result of answering the research questions. When this step is done, the guideline index is fairly finished, meaning that the first two research questions are close to being answered and that the *what* and *how* of the guidelines are formulated. The last step concerns the workshop and the study of how the guidelines are aligned with the VCM strategy. It is important to work alongside the general strategy of the company to secure conformity of the departments and functions of Volvo Cars. The analysis of the workshop is the last piece of the puzzle to finalise the design guidelines for manufacturing by leading to the answering of *why* the guidelines are important for the production development process.

One could argue that analysing the data collected throughout this research is a complex process, especially since all the data is qualitative and as Bryman & Bell (2011) states, qualitative data bases has the tendency to grow big in rapid pace since it often consists of notes, interview transcripts and other types of documents. This motivates the importance of having a strategy for how to handle the analysis of data in an effective way. While quantitative analysis entails widely used and accepted techniques for analysing data, the authors argues that qualitative data analysis on the other hand, lack and might not even need a structured analytic procedure. Instead Bryman & Bell (2011) communicates the need of focusing on a broader perspective, a strategy.

3.3.1 Data analysis strategy

The purpose of the analysis strategy is to bring clarity to some major steps in the process of analysing the data. Unlike in quantitative analysis, where the analysis generally starts first when all the data is collected, the process in qualitative analysis implies that the data analysis takes place in parallel with gathering of the data and through that also influence the following data collection. (Bryman & Bell, 2011) This is an important aspect of the research. First of all because the literature study is one of the data resources used when constructing the interview guide, but also since the semi-structured interviews might bring unexplored important topics that could be interesting for the workshop or another further data collection method such as discussions. Two commonly used approaches for the strategy is *Analytical Induction* and *Grounded Theory.* The *Analytical Induction* is a process where the researcher investigates a phenomenon and tries to find a universal explanation. This search is carried out through a continuous collection of data until no further data, inconsistent with the potential explanation, can be found. At this point in the research, Bryman & Bell (2011) states that the hypothesis is confirmed. This strategy could probably be adapted to fit this study but there is no perfect match. First of all it lacks the focus on combining literature with practical knowledge in an iterative process of data collection. Second of all, this would waste the time of the interviewees since the hypothesis has to be reformulated every time a new aspect emerges.

Bryman & Bell (2011) states that Grounded Theory strives to develop new theory by analysing data and theory collected continuously throughout the research. The interaction and reflection between theory, data collection and analysis is constantly present and a central part of the strategy. This strategy was primarily developed in 1967 by two medical social researchers named Barney G. Glaser and Anselm L. Strauss. Further research performed within the area has led to two common perspectives and interpretations of the strategy, often referred to either "*a traditional Glaserian perspective" or "an evolved Straussian version of grounded theory."* The traditional Glaserian perspective is focusing on developing theory strictly from empirical data whilst the evolved Straussian version allows the inclusion of none-empirical data in the development of theory. (Birks & Mills, 2011)

The Straussian version fits this specific research rather well, for instance since it suggests a strong iterative process where the literature studies, primary data collection and analysis work in parallel. This means that the guidelines will embrace two points of view, both internal knowledge from VCC and external from literature, with the possibility to develop the guidelines continuously as soon as new knowledge is added. Therefore, some parts of this strategy are used when analysing the data in this research. However, because of the extensiveness of the theory it is not fully applicable. The following part of this section describes grounded theory as it appears in literature. For a description of how different parts of the Straussian version of grounded theory is adapted into this specific research, see section 3.3.2.

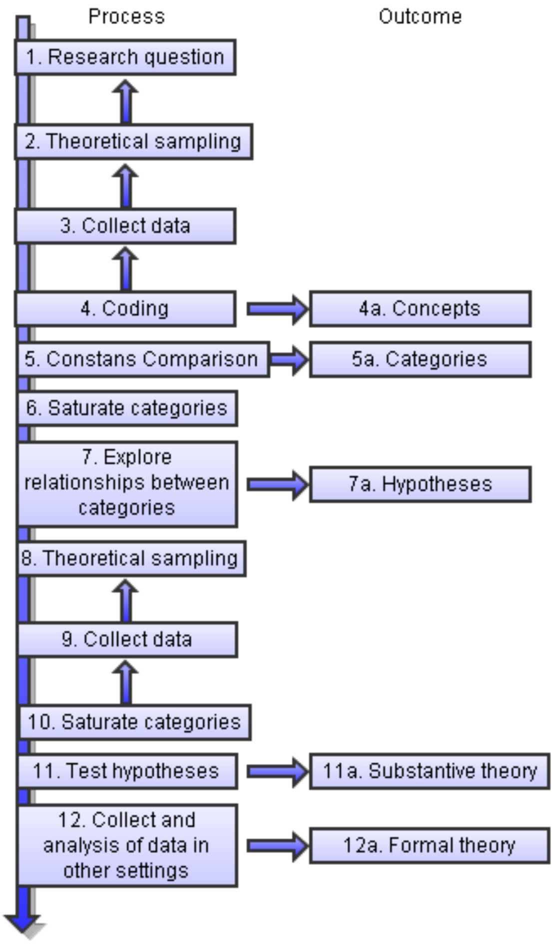

Figure 6 Grounded theory adapted from Bryman & Bell, 2011.

Figure 6 illustrates the work approach of the grounded theory. The first three steps in the strategy are mainly about formulating the research and collecting data. Still, since the data is qualitative, the researcher needs to analyse and evaluate the collected data continuously. In the fourth step the researcher starts coding the data, which is one of the most central parts in *Grounded Theory*. The data is broken down and gathered in different clusters that are then being further developed and given names. When all the clusters have names and include a set of data, they reach a new stage called concepts. Using coding, for example affinity diagram, is beneficial in this research since it supports the process of clustering the guidelines. In the grounded theory, there is a constant movement between the first four steps in order to develop the clusters as much as possible.

In step five and six the constant comparison is handled. This process aims to secure a correct link between data indicators and concepts. In this step the guidelines are compared to each other and the categorisation of the guidelines are correctly secured. In step seven the categories are being investigated in order to build hypotheses about potential relations between the different categories. This step contains an investigation of how the guidelines relate to each other, if they affect each other and to secure that no guidelines are communicating the exact same thing. The following steps of the process is once again to follow an iterative approach of gathering and analysing additional data needed in order to come up with a substantive theory, relating to the specific research at hand. The final step is about exploring the theory in different settings in order to investigate if it can be stated as a formal theory, not specifically related to the research area. Since this study has the delimitation of only focusing on the applicability at ME, the final step of the strategy is of no interest in this research.

3.3.2 Adapted analysis strategy

The adapted data analysis strategy is illustrated in the picture to the right. Similar to the grounded theory, it has the initial data screening step, consisting of formulating research question, theoretical sampling and collecting data. Next, the coding starts. In the coding there are mapping of the interviewees' placements of the aspects under the different categories, clustering of the interviewees' arguments and comparison of the arguments within the clusters. The coding and the data screening steps are continuously influencing each other with new information. The output of the coding is the aspects that are formed by the clusters. The aspects are continuously fed into the comparison step in which the aspects are compared and sorted into an index. Comparison consists of developing the aspects by comparing the information of the aspects with the audio recordings, as well as of constantly questioning and modifying

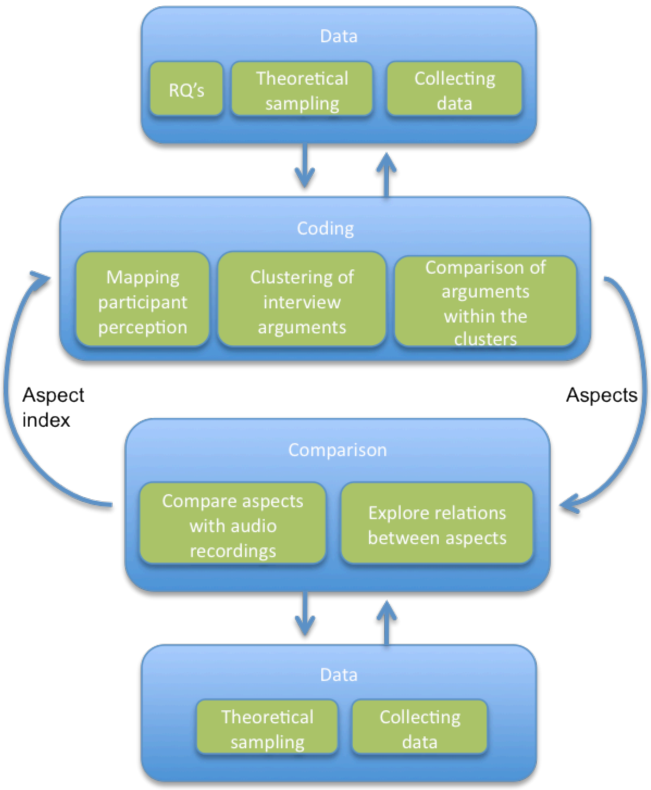

Figure 7 Adapted analysis strategy.

the relationship between the aspects. This leads to the outcome of the comparison, the aspect index. Coding and comparison are iterated like this, while it is also fed with new data, until the final aspect index is generated. The aspect index is completed when all relevant data from the research is represented in the index.

3.4 Research quality

In order to secure a high quality standard of the research, a set of evaluation criteria need to be discussed. Bryman & Bell (2011) states that the most common criteria are reliability, replication and validity.

Bryman & Bell (2011) say that the main focus of reliability is to discuss whether or not the measures and factors handled in the research are consequent in time. A simplified example explaining the criterion would be putting the same person on the same scale twice with only a short time interval in between. If the scale shows the same amount of kilos both times, one could say that kilos as measure has high reliability and vice versa. The reliability within this thesis appears in a slightly different way, since the data is qualitative. One can see two main risks towards the reliability in this case. The first one is the risk of interviewing only one person within a large working area. The thoughts expressed by this specific individual are not necessary consistent with the thoughts of his or her colleagues. This is known as a sample error. In order to avoid this, interviews are spread out among colleagues with similar work responsibilities in order to get more than one perspective. The other risk is the risk of persons changing their mind during the time of the study, meaning that a person would give different answers to the same question during the study. In order to prevent this from happening, the interview questions should be clear to reduce the risk of misinterpretations.

Bryman & Bell (2011) states that replication of research is generally quite rare in business research. The value of the replication lays within the possibility for other researchers to perform the study again in order to confirm or question the result. The authors also say that in order to reach a high level of a replication, the researchers must explain all the different steps in detail. Since this thesis is out of a qualitative nature where data continuously needs to be interpreted, it is hard to keep detailed notes of all the steps and reasoning throughout the study. It is in the interest of the researchers to strive towards as high level of replicability as possible. Therefore, important discussions and decisions are documented in a journal. Another important aspect of the replication of this study is the availability of collected data. Since the interviews are performed with employees of VCC, a replication would need to have access to the same people. This could be a problem for example if the interviewed persons retire, leaves the company or if the researcher lacks access to VCC.

According to Bryman & Bell (2011) the validity is often the most important aspect when evaluating a research. The aspect concerns the "integrity of the conclusions" from a research. The authors describe validity in two separate parts, internal and external. The internal validity discuss how well aligned the developed theory is with the performed observations. When it comes to this specific study, a lot of the researchers' time is spent on site in order to thoroughly understand the observed situation and through that secure the alignment. A second approach to secure the alignment is to develop theory out of combined data from different data resources, including internal reasoning captured at interviews and workshops at VCC. The external validity regards how the research findings can be generalised into other settings. As mentioned in the delimitations section, this study mainly aims to develop a theory applicable at ME. However, this does not necessarily mean that the developed theory is limited to ME and VCC. One could suspect that the guidelines can be applicable at companies with similar strategy in a similar market.

4 Theoretical framework

The theoretical framework strives to investigate up to date reasoning and approaches within the topic of Design Guidelines for Manufacturing, both internally at VCC and externally in the academic world. The investigation is performed in order to gather information about the topic. To get a deep understanding of the subject, both overview perspective frameworks and more detailed topics are investigated.

4.1 A structured way of working

Bellgran & Säfsten (2010) presents their framework for supporting a generalised approach during the production system development processes that is called "A structured Way of Working". The approach is built on a time line perspective, from the very beginning of a project to production start-up, with five main phases during the development process.

4.1.1 Management and Control

The initial phase of the framework handles the preparations and foundation of the project. This includes both establishing documents, which can be used for investment request, and developing a project plan. The project plan should discuss estimated project time, people involved in project management, outlines for requirement specifications etc.

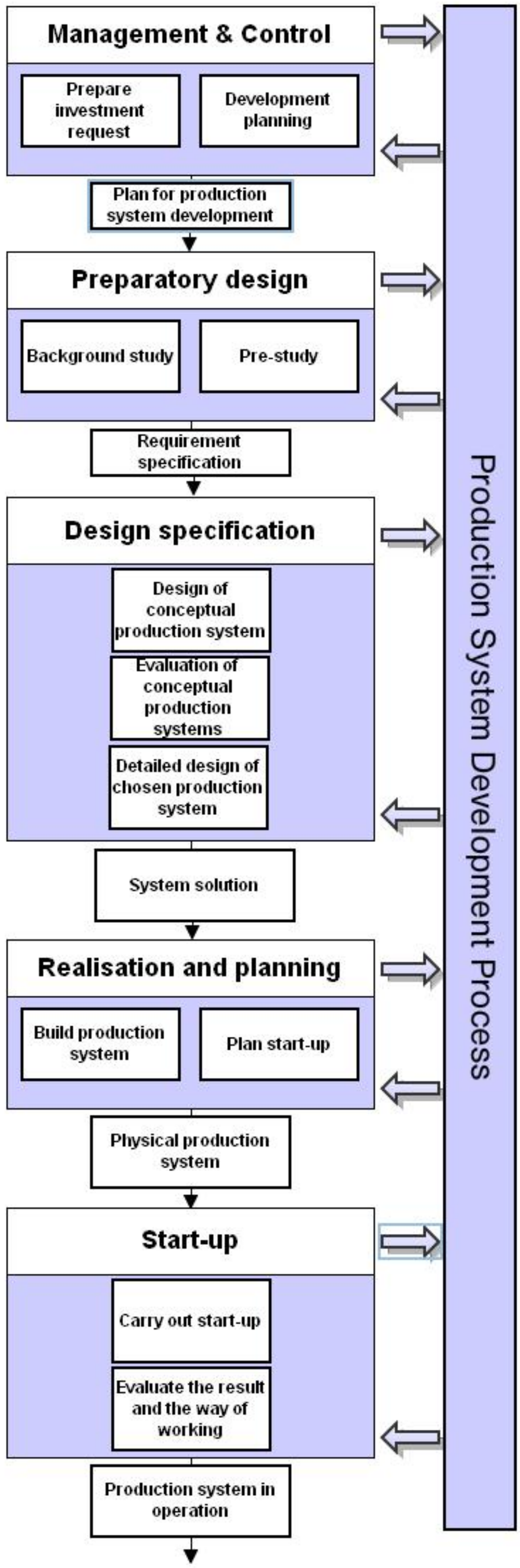

Figure 8 A structured way of working, adapted from Bellgran & Säfsten, 2010.

4.1.2 Preparatory design

The second phase of the framework is about investigating the state of art. This includes performing a background study that will contain an analysis of product and existing production system, benchmarking etc. The information found in this step can be transferred and used as requirements for the production system. The other half of the preparatory design step is called pre-study. The pre-study aims to analyse the market development, market potential and applying the company strategy and objectives at a managerial level.

4.1.3 Design specification

The third phase is design specification, where the framework of the production system should be developed in detail. The phase starts with the process of designing several potential production systems which will include information about machines, equipment, automation level, work environment etc. When several possible solutions are available the screening process starts. After choosing a specific method for how, and according to what, the concepts should be evaluated, the process of screening the concepts begins in order to find the best solution possible. When only the best solution according to the evaluation criteria is left, the framework continues with designing the production system in detail (e.g. work location and work tasks).

4.1.4 Realisation and planning

The purpose of the realisation phase is to take the detailed design from the minds of the developers and build this system in real life. This means for example to take make or buy decisions regarding the equipment must be discussed and once the equipment is available it has to be installed and verified. When the system is built it is time to start planning for the start-up. This means appointing responsible people, plan for training of the staff and develop a start-up strategy.

4.1.5 Start-up

When the start-up phase is reached in the framework one can really start to see the final result of the development process. The production system is supposed to work according to the start-up plan performed in the previous phase. When start-up has been carried out it is time to evaluate both the production system and the development process. The result of the evaluation should then be delivered to the process owner.

4.1.6 System Aspects

The framework described above shows a structured approach from an overview perspective, regarding what steps to go through during a development process. In addition to this Bellgran & Säfsten (2010) adds a more hands-on checklist of the aspects to take into consideration during the development process. Some interesting aspects mentioned in this checklist are for example modularisation, operation sequences, tolerances etc. For the whole checklist, see Appendix D.

4.2 Operation Strategy Matrix

Research performed by Skinner (1969 cited in Säfsten & Winroth, 2002) states that manufacturing departments generally have a hard time reaching their proper level of status within companies. Even though many companies spends up to 70% of total investment capital on tasks related to manufacturing, the department still suffers from the underlying thought of them only being the executors of what other decides. Finding effective solutions regarding how to allocate the given resources, in the striving towards competitive advantage, can be called manufacturing strategy.

According to Säfsten & Winroth (2002) the production system of a company should reflect the internal manufacturing strategy. The company view on competitive aspects must therefore be well connected with a clear link in the production system. In order to secure the alignment between the strategy and the system, and through that improve the competitive situation of the company, different tools can be used.

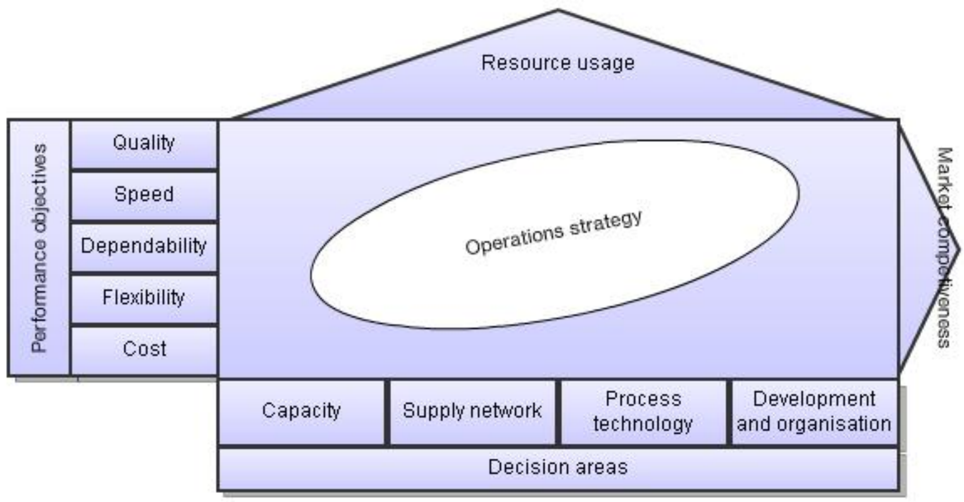

Figure 9 Operation strategy matrix, adapted from Slack & Lewis, 2008.

Slack & Lewis (2008) presents the Operation Strategy Matrix as one approach to tackle this situation. The matrix is mainly built out of an intersection of two perspectives; the market requirements and the operation resources. In this framework, a strategy that aims to bring a competitive advantage on the market should be developed through the five performance objectives: quality, speed, dependability, flexibility and cost. These performance objectives are the foundation for how a company differentiates and competes on the market. The other part of the matrix focuses on the decision areas: capacity, supply network, process technology and development and organisation. These variables embrace the resource usage part of the matrix.

Slack & Lewis (2008) states the importance of investigating how the different factors influences each other in the intersections. This means that when using the matrix in order to develop or investigate the alignment between performance objectives and decision areas, one should for example be able to tell exactly how the process technology will influence each and every performance objective. One can expect that not all intersections will be as critical as others during the process since this depends a lot on the nature of the operations and focus of the company.

4.3 Concurrent engineering

In the beginning of the 1990s, it was clear that time to market was an important competitive leverage regarding product and process development. Wheelwright & Clark (1992) describe the increasing competitiveness by three critical forces; intense international competition, fragmented and demanding markets and diverse and rapidly changing technologies. Further on, they describe speed as one of the competitive imperatives for development of new products and processes. A main reason for the importance of a fast development process is the decreasing life cycles of the products, which originated in the increasing competitive responsiveness to the customers' needs. A shorter time to market for the development projects will therefore lead to a competitive advantage. (Wheelwright & Clark, 1992)

According to Swink et al. (1996), many companies adapt to the higher demands on the new product development (NPD) process by adopting concurrent engineering (CE). Yassine & Braha (2003) states that the main principle of the CE philosophy is to integrate downstream concerns into the upstream phases of the development process. This cross-functional integration is further described by Wheelwright & Clark (1992), who focuses on the pattern of communication between the upstream and the downstream group. The authors described it with the four dimensions of richness, frequency, direction and timing, which determine the quality and effectiveness of the communication. The authors also states that the most communicative mode, *integrating problem solving*, includes rich communication with a high frequency, that goes in both directions with an early start of communication between the upstream and downstream group. Lack in communication can lead to that problems occur later than necessary, which in turn leads to increased costs since the adjustment to handle to problem gets more and more expensive over time. (Alfredson & Söderberg, 2010)

A definition of CE can be found by McGrath (1992), who says that "concurrent engineering means developing the product and all its associated processes, that is, manufacturing, service and distribution, at the same time". Sage & Rouse (2009) presents a more modern definition by saying that there are two ways to define CE. Firstly, it can be defined as "the practice of considering the entire functionality of the product, as well as its assembly and manufacture, in an integrated design process". This definition is according to the authors the original vision for CE initiatives. However, later on, this perspective was widened and led to the inclusion of the entire life cycle leading to the second definition, which reads; "the practice of considering the entire product life cycle, from design to disposal, in an integrated design process". Even though the CE concept includes and considers the whole life cycle when developing a product, by using tools such as design for manufacturing and assembly (DFMA) and quality function deployment (QFD), the authors states that "the need to integrate experts from all functions in the product development process remains at the heart of CE". (Sage & Rouse, 2009)

The wide definition of CE that includes the entire life cycle is commonly found. As noted by Xu et al. (2007), all the factors involved in the life cycle has to be taken into consideration in the CE process in order to fully accomplish a successful development process. Although this is a good goal to strive towards when designing new products, the implementation of the sometimes distant and abstract life cycle factors are hard to accomplish. As Gehin et al. (2008) states, it is necessary to find the key success factors for a given business model and try to implement them into the early phase of the development process. Further described by the authors, designers will need tools that can be integrated into their daily work, which enables them to evaluate environmental impact of the product and its components and indicates the prospective potential for reuse, recycling and remanufacturing.

Also Xu et al. (2007) concludes that concurrent product development processes need effective support systems to be able to evaluate the design comprehensively. In the article it is described how the information in the early designing process can be fuzzy and it can lead to problems in the future development process. As Xu et al. states, "if the previous decision is incorrect, the following design stages will be affected significantly".

4.4 16 losses

Total Productive Maintenance (TPM) is a managerial initiative that has reached a broad acceptance in industry. The initiative brings several benefits and could lead to large cost savings for a company mainly by focusing on avoiding and reducing disturbances of a production system. (Gosavi, 2006) These disturbances leads to various sorts of losses and research performed by Ahuja & Khamba (2008) describe the sixteen major losses within TPM. The authors cluster these sixteen losses into four different categories handling different types of losses. The first category describes losses that can be linked to *equipment efficiency*; the second category describes losses regarding *machine-loading time*; the third category describes losses regarding *human performance*; the fourth category describes losses regarding use of *production resources*. The following list shows the authors view on the different losses:

1. *Breakdown/failure loss*: Losses due to functional failure in the system that leads to a lower utilization of the capacity than normal.
2. *Set-up and adjustment loss*: Losses due to the down-time needed when changing the conditions of a system (e.g. for changing tools for different variants.)
3. *Reduced speed loss*: Losses occurring when the system in practice operates below the speed it was designed for.
4. *Idling and minor stoppage loss*: Losses related to when the system idles or temporarily stops due to problems in sensor activation, jamming of the work, etc. The system could work normally again after removal of jammed pieces or a system reset.
5. *Defect and rework loss*: Decreasing volume capacity due to rework, financial losses due to downgrading, and time loss due to the time spent on repair the product.

6. *Start-up loss*: Losses related to the start-up time of the production, until the production-processing conditions stabilize.
7. *Tool changeover loss*: Stoppage time loss from when worn-out tools must be replaced. (e.g. changing the cutting blades due to breakage)

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8. *Planned shutdown loss*: Planned downtime of equipment in order to perform inspection.

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9. *Distribution/logistic loss*: Losses from failing to automate logistics as loading/unloading, leading to no manpower reduction.
10. *Line organization loss*: Waiting time losses for operators and line-balance losses in conveyor work.
11. *Measurement and adjustment loss*: Losses from measuring and adjusting the quality to prevent outflow of products exceeding the tolerances.
12. *Management loss*: Losses due to managerial waiting time (e.g. waiting for material, waiting for instructions, etc.).
13. *Motion-related loss*: Losses due to inefficiency in motion patterns (e.g. walking patterns as a result of an ineffective layout).

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14. *Yield loss*: Material losses in terms of differences in input material and output material with the value added effect of the system.
15. *Consumables (jig, tool, die,) loss*: Financial losses related to cost of repairing and changing broken tools and other consumables of the equipment.
16. *Energy loss*: Loss due to ineffective use of input energy of the system (electricity, gas, fuel oil, etc.)

Volvo Cars (2012) presents an adapted and more hands-on approach of working with the 16 losses. This approach divides the losses into the three main clusters of *equipment efficiency*, *human performance* and *production resources*. The losses should be used as a measurement of effectiveness within the production system by calculating the Overall Equipment Effectiveness (OEE) and Overall Work Efficiency (OWE). The input numbers of the losses should be measured and reported from the running production system. (Volvo Cars, 2012h)

4.5 Lean layout

According to Womack & Jones (2008), lean is the most powerful tool available in order to create value and eliminating waste. The seven wastes presented by the theory are transportation, inventory, motion, waiting, over-processing, over-production and defects. There are five lean principles, which are described below.

- *Specify value:* The value intended is the ultimate value for the customer.
- *Identify the value stream:* The value stream includes all the actions needed to get the product the customer.
- *Flow:* Includes the processes of the value-creating actions.
- *Pull:* Use a pull mindset instead of push.
- *Pursue perfection:* There are always room for improvement.

With these principles the process can be perfected and the wastes can be reduced. (Womack & Jones, 2008)

A good way to start to incorporate the lean thinking is by identifying the value added flow of the production system and to calculate the value added percentage. This helps to identify and remove wastes in order to continuously improve the production system. The layout of the production system should also be product focused and not process focused, which can help reduce the material handling, improve visual control and communication, simplifies product flow and emphasizes customer focus. An increased visual control is another big part of the lean production philosophy that is embraced by the concept “andon”, clear signals for notifying about quality or process problems. (Volvo Cars, 2012i)

A traditional way of production has been the batch-and-queue system, where large lots are made and then sent to wait in queue for the next operation. Womack & Jones (2008) explains that converting a batch-and-queue system to a continuous flow with pull instead of push, will double labour productivity, reduce the throughput time and inventory by 90 %, lead to half the errors and cut injuries. The authors further discusses how to successfully achieve a continuously flow by focusing on the product, remove boundaries of jobs and departments and to rethink the process in order to eliminate backflow, scrap and stoppages. (Womack & Jones, 2008)

Just-in-time is an important tool in order to achieve a lean production system. Womack & Jones (2008) describes it as "producing and delivering just the right item at the right time in the right amount". To achieve this concept at a low cost, a U-shaped production layout with multi-function workers can be used. Ohno & Nakade (1996) present a study where they show the benefits of a U-shaped production layout. The research shows how workers with multiple functions decrease the overall cycle time and how the U-shaped production layout is superior to a linear production layout for lines with one or two workers. (Ohno & Nakade, 1996)

According to Miltenburg (2001), the U-shaped production line can effectively be implemented when there are many to several products, with a low to high volume. In other words it can be widely implemented in order to be an effective option in production systems.

4.6 Level of automation

The first type of automation appeared in the beginning of the 20th century, particularly in the Ford Motor Company. In their production they implemented what is called fixed automation, which is a group of technologies with the purpose of performing simple tasks many times. As the manufacturing evolution continued, the need for more flexible solutions appeared, leading to the flexible automation. This type of automation contains blocks of Computer Numerical Control (CNC) machines, which has a computer dedicated to that single machine tool, making it easy to programme the actions directly into the computer with a low downtime. Consequently the flexibility increased. However, if the volume is the only objective, fixed automation is more effective. (Stecke & Parker, 1997)

Parasumaran et al. (2000) defines automation as “a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator”, which is a definition that has been refined from the earlier works by Parasumaran & Riley (1997). This definition focuses on the relationship between the human and the machine and it implies that the automation does not have to be all or none of the operations, but can be of many levels. (Parasumaran et al., 2000)

In the 20th century there has been an increasing trend toward automation. The belief has been that implementing automated systems will decrease the dependence of manual labour and errors, as well as improve performance, decrease the costs and provide higher reliability. The operator's role has therefore changed dramatically from performing the task to supervising the task, looking for failures in the system. However, with the increasing complexity of the systems, an increasing trend of large failures has occurred. An error in the controlling function of the automated system can lead to a failure since the complexity of the system is too vast for the operator to fully understand. (Endsley, 1996)

Parasuraman & Riley (1997) states that initially the primary criteria for using automation were technological feasibility and cost. Furthermore, the general perception has been to implement automation whenever higher efficiency, increased reliability or better accuracy could be achieved, or even if the implementation would lead to a lower cost by replacing the operator. The primary reason that this perception has not lead to systems fully performed by automated processes, is that humans are better to respond to changes or unforeseen conditions since they are more flexible, adaptable and creative. (Parasuraman & Riley, 1997)

Adler (1988) identifies three types of automated processes as design automation, manufacturing automation and administrative automation. He describes the most appealing aspect of the automation to be the divergence to what is called Computer Integrated Manufacturing (CIM), which comes from the possibility to link the different automation types. The obtained values of the automated technologies are further described as cost, quality and time. (Adler, 1988)

Moray et al. (2000) discusses the level of automation that is appropriate for a station and how it can be decided. The level of automation is described as to what level the human-machine interaction is performed. In order to describe the different levels, the authors use the Sheridan-Verplank levels (SVLs), which were published by Sheridan & Verplank (1978). In this system level 1 describes a manually controlled process and level 10 is fully automated. The list is briefly explained below.

1. Manual control, the human does all the planning, selecting, preparing and monitoring, up to the point of when the machine carries out the action.
2. The human asks the computer for suggestions and then selects an option from the given suggestions.
3. The computer spontaneously suggests options for the operator.

4. The computer both suggest options and proposes one for the operator.
5. The computer selects action and implements it if the human approves.
6. The computer selects an action and performs it, but gives the operator plenty of time to stop it.
7. The computer does the entire task and informs the human of what it did.
8. The computer does the entire task and informs the human if the human explicitly asks.
9. The computer does the entire task and decides if the human should be informed.
10. The computer does the entire task autonomously.

Moray et al. (2000) concluded that there is no simple answer to the question of what automation level is the best. Firstly, it depends “on the complexity, difficulty, and dynamics of the incidents that have to be managed”. It also depends on the goal of the automation. (Moray et al., 2000; Sheridan & Verplank, 1978)

4.7 Manufacturing flexibility

There is a consensus about increased competition on the market going further into the 21st century. D'Souza & Williams (2000) describes the major manufacturing competitive areas as cost, quality and responsiveness. The responsiveness depends a lot on the manufacturing flexibility of the company and when studying the definitions given by the literature, they converge towards being the capability to react to changes in the company's environment. It also includes the time to make those changes, the costs of the changes and the efforts needed to do them. (D'Souza & Williams, 2000)

Most of the available theory implies that there is a trade-off between flexibility and efficiency in production because it is believed that efficiency requires bureaucracy, which inhibits flexibility. However, according to Adler et al. (1999), a lot of companies are trying to improve simultaneously on both flexibility and efficiency as a result of the growing competition. The authors look into NUMMI, a join venture between Toyota and GM, and conclude that there are four mechanisms that make it possible for NUMMI to stay both flexible and efficient.

- Better structure of routines with the help of meta-routines
- Job enrichment
- Switching roles between improvement and production tasks
- Partitioning the structure into a changeover team and an operation core

The first of these mechanisms primarily increases the efficiency but it also creates opportunities to increase the flexibility. The following three increases the capacity for flexibility of the organisation. (Adler et al., 1999)

Vokurka & O'Leary-Kelly (2000) presents a list of 15 different dimensions of manufacturing flexibility that they have adapted from previous frameworks and complemented with own review. The list is found below with a description of the different flexibility dimensions.

- *Machine:* The different operation types a machine can perform.
- *Material handling:* The ability to move different parts within a manufacturing facility.
- *Operations:* Number of ways a product can be produced.
- *Automation:* The extent to which the manufacturing technology is housed in the automation.
- *Labour:* The range of tasks an operator can perform.
- *Process:* The set of products the system can produce.
- *Routing:* Number of routes a product can take through the production system to be completed.
- *Product:* The ability to add new products or parts into the system.
- *New design:* How fast the products can be designed and introduced into the system.
- *Delivery:* The ability to respond to changed delivery requests.
- *Volume:* How the production system respond to increases or decreases of output.
- *Expansion:* The ability to expand the capacity of the system.
- *Program:* The length of time that the system can run unattended.
- *Production:* The range of products a system currently can produce.
- *Market:* The adaptability of the system to changes in market demands.

The authors mentions that many studies have suggested a hierarchical order of these dimensions but that there are no study that thoroughly investigates the interrelationship between the dimension, which is probably a consequence of the complexity of the variables involved. (Vokurka & O'Leary-Kelly, 2000)

4.8 Modularisation

The fundamental ideas behind modularity are not particularly new. Fixon (2006) found in his literature research arguments from Swan (1914) that can be looked at as the early movements of modularity. Swan identifies an engineer who strives towards having subassemblies of product parts in order to make it easier to customise the products and reduce costs. Today's situation is slightly different and more complex mainly due to the highly developed production technologies. This leads to higher customer expectations regarding product customisation and characteristics which forces companies to learn how to mass-produce customised products in effective ways.

Sanchez & Mahoney (2005) describes modularity by using two different terms; loosely coupled vs. tightly coupled. The terms describe to what degree different components in a product influence other components. In other words, how much a change of design in a specific part of the product will require compensating design changes in another part of the product. The author argues that modularity is a situation where the parts are 'loosely coupled' by using standardized component interface specification. Traditionally companies have had the tendency to develop products with constrained optimization meaning that a product are developed to reach the highest level of performance within a certain cost constrain, or developed with the lowest cost needed to reach the lowest acceptable performance. This type of product development method leads to highly integrated products that are 'tightly coupled'. Situations like this require an intensive managerial coordination since a minor change in one component could cause the need of complimentary changes in another. In other words, if you have 'tightly coupled' products you also need to have a 'tightly coupled' organisation managed by an authority hierarchy.

Another approach to the development method which will shape 'loosely coupled' components is to start with designing standardized component interfaces based on the function the component fulfils. Changes can be made within the interface boundary while cross-boundary changes only can be implemented when a higher-level decision is made to change the product architecture. In a situation like this the organisation should strive towards having a strong information structure which will work as the glue combining the different interfaces together. Sanchez & Mahoney (2005) argues that the concept of modularity should not be limited to increase the flexibility only at a product development level. Instead it should be spread and applied widely within the organisation to increase the flexibility in departments as for example marketing, distribution, etc.

Salvador et al. (2002) states that today's production firms face a trade-off between product variation and operational performance. They also states that both theory and practice shows that modularity is an effective approach to reach high product variation with as low operational losses as possible. Loosely coupled modular systems, leads to the possibility of building different parts of a product at different locations and then put these parts together effectively in a main assembly line. Besides facilitating for production effectiveness and product mix, this could also ease decision making in the process of vertical integration since different products and functions are distinctively separated. (Ernst & Kamrad, 2000; Novak & Eppinger, 2001; Sanvador et al, 2002)

4.9 Commonality

In today's manufacturing climate mass customisation is a term that has become more and more popular to focus on. As described by Jiao & Tseng (1999), the paradigm is the result of an increased product variety as a consequence of higher customer needs and the importance to deliver the products at a low cost in order to be competitive on the market. In order to meet this contradiction, the industry has to "perceive and capture latent market niches and subsequently to develop technical capabilities to meet the diverse needs of the target customers". One of the technique challenges to achieve this balance is to increase the repetition and reusability in mass production, which is enabled by increased commonality in the design of the product. With increased commonality, the opportunity to reuse tools, equipment and expertise also increases. Increased commonality can be achieved by implementing product family architecture (PFA), which is a way of clustering the product variants into groups in order to find similarities between the products. This will make the production costs decrease with increased repetition and reusability as well as rationalise product development for mass customisation. (Jiao & Tseng, 1999)

Nagarur & Azeem (1999) presents a study about how communality in the component leads to a more effective manufacturing system and how it is explained as a big factor towards achieving a higher product variety whilst keeping high productivity in the production system. The study shows how introduction of communality to the production system can decrease the makespan and increase the machine utilisation and factor productivity. It also shows that an introduction of increased flexibility also contributes to a more productive manufacturing system. (Nagarur & Azeem, 1999)

In a study by Heese & Swaminathan (2006) it is pointed out that commonality as a cost reduction tool might lead to unwanted consequences. The authors discuss how segmentation and cannibalisation are two reasons why a manufacturing system might not want to use the same components for different products and how they have to be taken into consideration when implementing commonality in the production system. If two car models from different quality classes are produced by similar components, the customers might ask themselves why they should pay extra for the more luxurious car, when the cheaper car consists of the same quality components and vice versa. (Heese & Swaminathan, 2006)

4.10 Material flow

In today's market, lean thinking and agile manufacturing are important success factors. The need to adapt to changes and the ability to keep the production costs low are both of high importance to stay competitive. Naylor et al. (1999) states that these factors highly depend on the efficiency and effectiveness of the whole supply chain strategy. (Naylor et al., 1999)

The importance of integration of logistics in early phases is also supported by Sage & Rouse (2009) who states that involving experts from each function is the main purpose of concurrent engineering. Concurrent engineering is according to Wheelwright & Clark (1992) an important tool to stay competitive on the market.

Three mayor concepts within logistics concerning the production system at VCC are replenishment, material façade and re-packaging. Replenishment involves the issue of bringing the material from the storage or unloading area to the point-of-use with the purpose to implement the most cost efficient fork-lift-free replenishment method available. Material façade regards the interface between material handling and the operator with the vision to decrease the none value-added work performed by the operators and to obtain a maximum of 80 % filling degree in the material façade in order to always have some extra room when implementing new variants. Re-packaging concerns the method and size in which the parts are brought to the material façade from the unloading area or storage area. The vision is to keep it cost efficient, have low administration work, locate the re-packaging at an optimal place and to optimise the space utilisation. (Volvo Cars, 2012j)

There are several logistic costs that should be considered with regards to the production system. Perego (2011) presents a list with the different costs that are associated with logistics:

- Inventory control
- Transportation
- Picking and handling
- Storage
- Set-up in the production lines
- Packaging
- Lost sales because of stock out
- Information systems
- Obsolete material and products

Perego (2011) further discusses that the sources of value within logistics is reducing the logistic costs and to contribute to increase the revenues, for instance by improving the customer service.

4.11 Robust design methodology

Research has shown that the way organisations choose to develop their products and processes are becoming a more and more important success factor. Robust Design Methodology (RDM) is a methodology that strives towards supporting the development of products and processes so that they are less sensitive to variations. This insensitivity is especially useful in situations where natural variations, so called noise factors, are present. These noise factors could for instance be variations derived from the environmental conditions in which the product or process are operating. Hence, this type of variation can be hard, very extensive or even impossible to control. Therefore, it is effective to design the product or process so that it can operate as usual even when variations are present. (Hasenkamp et al., 2008) When it comes to the influence robustness have on products, one can argue that the geometrical variation of a product is highly dependent on how sensitive it is towards variations. In other words, one can use robustness to decrease geometrical variations in products. (Soderberg, 2012)

4.12 Implementation

This section aims to describe critical success factors (CSF) to consider when facing an implementation step of a tool, method, framework, etc. The goal is to use this information in the development of DGM in order to facilitate a successful implementation and usage of the framework.

CSF can be described as factors that are vital for the success of an organisation. Hence, failing to take these factors into consideration or adapt to them can lead to negative impact for the business. Coronado & Antony (2002) performed a research aiming towards finding CSF for the implementation of the six-sigma projects in organisations. The authors find a set of different CSF, for instance:

- *Management involvement and commitment*: The management should be involved in the methodology initiative at the company by supporting and participating in related activities.
- *Cultural change*: Be aware of the changes in organisation structure due to the implementation. When changes occur, people tend to be afraid of the unknown since they do not understand the need for change. One way to tackle this situation is to increase and sustain communication, motivation and education regarding the change.
- *Communication*: It is important to communicate a lot of practical feedback linked to the implementation. How the new methodology works, how it relates to the workers jobs and what are the benefits of using it.
- *Organisation infrastructure*: Some organizational culture characteristics that should be present to facilitate the implementation are for instance an established nature of communication, long-term focus and teamwork. Furthermore, the organisation needs the have funding enough to carry out the implementation.
- *Training*: Training of the intended users is key in implementation. The user should understand why and how definitions as early as possible. There should be training opportunities for the one who wants it; this will increase the comfort level of using the methodology.

5 Iterative generation of the guideline index

In this chapter, the results and analysis is described. Since the data collection and analysis of the data is overlapping each other throughout the study, it is clearer to present the results and analysis of the iterations that this research has included, rather than to divide them into two different chapters. The purpose is to make it easier to understand the reasoning behind the results.

The Design Guidelines for Manufacturing are generated continuously through an iterative approach of collecting and analysing data. The following chapter describes how the guidelines evolve through these different iterations. The first iteration consists of the initial study of academic literature and how it is applied to the case study with the support of internal experts at VCC. The second iteration describes how the guidelines change when applying the guidelines from the first iteration to pilot interviews. The third iteration explains how reasoning at the interview rounds forms the guidelines. The fourth iteration regards how investigation of additional aspects from documents at VCC and academic literature affect the guidelines. The final iteration describes how reasoning from the workshop shapes the guidelines. The end of this chapter describes the completion of the guidelines with revision and judgements, and also how the document should be implemented to be successful.

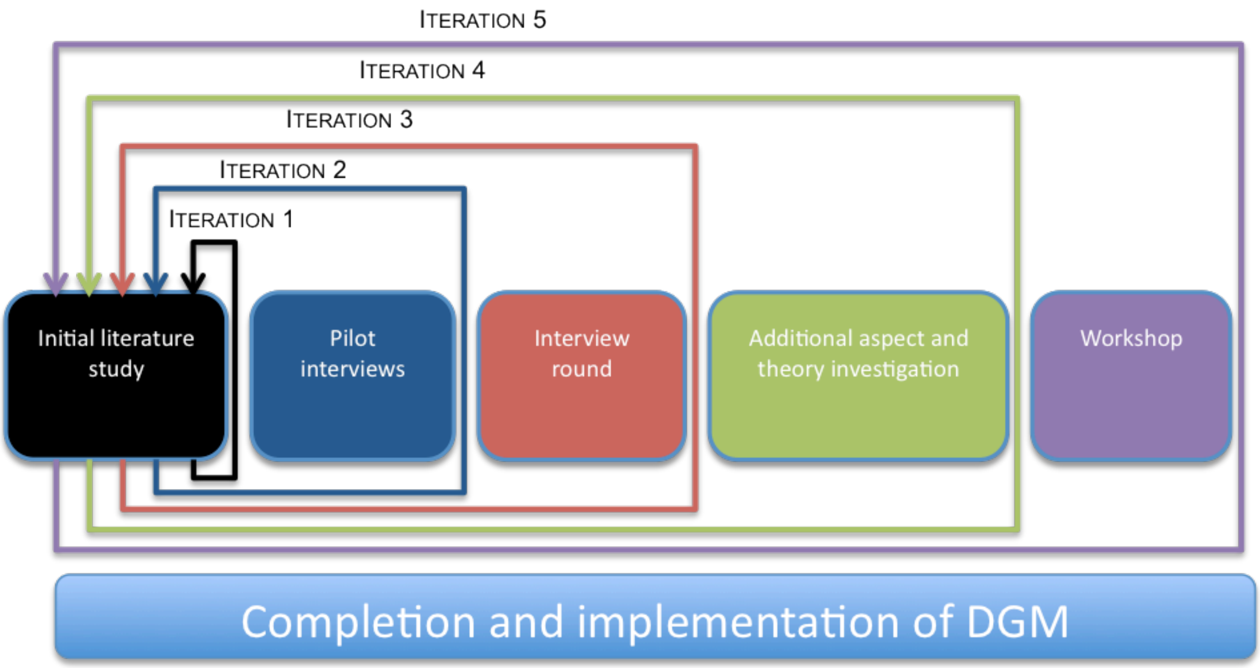

Figure 10 Illustrative pictures of analysis iterations.

The process of describing how the guidelines are developed requires a distinct differentiation between hierarchical levels of detail, in which each guideline belong.

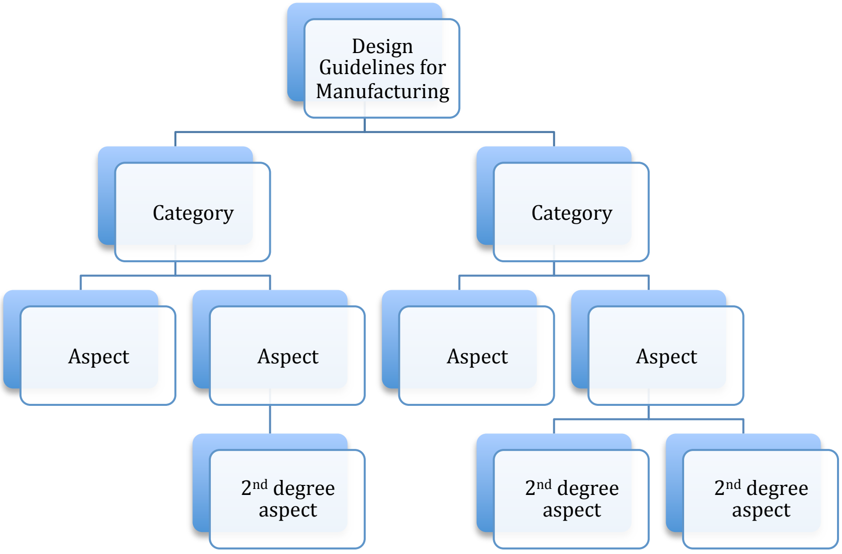

Figure 11 Illustration of the hierarchical levels of DGM.

The highest level in the hierarchy is Design Guidelines for Manufacturing, which is the name and the entire framework. The framework consists of a number of categories that is the level that can be found beneath DGM. Beneath the categories there are aspects, which, in turn, consist of 2nd degree aspects and so on. This is how DGM is built up and a large part of the analysis is concerning what the different levels include and how they can be related to the different hierarchical levels.

5.1 Iteration 1 – Literature checklist and basic concepts

The first iteration in the process of generating the guidelines is about adapting the findings from the initial literature study into the situation at VCC. The checklist of important aspects to consider during production development, described by Bellgran & Säfsten (2010) and seen in appendix D, is the starting point of this process. The checklist consists of nine categories, each of which embraces several different important aspects within the area. As stated in *"3.1 A structured way of working"* from which the checklist originates, the checklist grasps a very wide spectrum of aspects. This leads to that there are aspects that are hard, or in some cases not even possible to apply to the case study at VCC. Therefore, this checklist is adapted to fit this study through discussion meetings with experts at ME. Aspects that for some reason do not affect or cannot be related to the work of production development are left out for now in the investigation. Of course, a continuously revision of the initial checklist is performed throughout the data collection process, in order to secure that all applicable aspects are handled.

The high-level categories only undergo slight changes in this early process, mainly since the focus is to screen and adapt the meaning of the underlying aspects. Although, the first change in the process is that the category *"Market – Strategic level"* is considered to be something that is out of the hands of production development and therefore deleted. The reasoning behind this is that aspects such as new market opportunities, market demands, competitors and product price level could not be controlled in production development. Neither is the daily production development activities directly affected by these aspects. Also, the category of *"Product Concept"* including aspects such as product price, product mix, design, customer adaption, delivery time and product complexity, is considered to be managed too far away from the production system and is therefore eliminated. Eliminating these two categories and its content of aspects is favourable in terms of adapting the literature to the production development situation, but it still to some extent leaves holes in terms of valuable knowledge. To ensure that this type of information will be considered, a new category named *"Other"* is created with the purpose of handling aspects that not primarily can be affected by the user of DGM but still is important to understand.

Further discussion with experts regarding the adaption of categories and aspects leads to a developed version, which could be viewed as an early version of the design guideline index. This version is used as an input in the pilot interviews in order to see how the guideline index, generated from literature and subjective thoughts of experts, is perceived during pilot interviews with other employees at ME. The index is presented below:

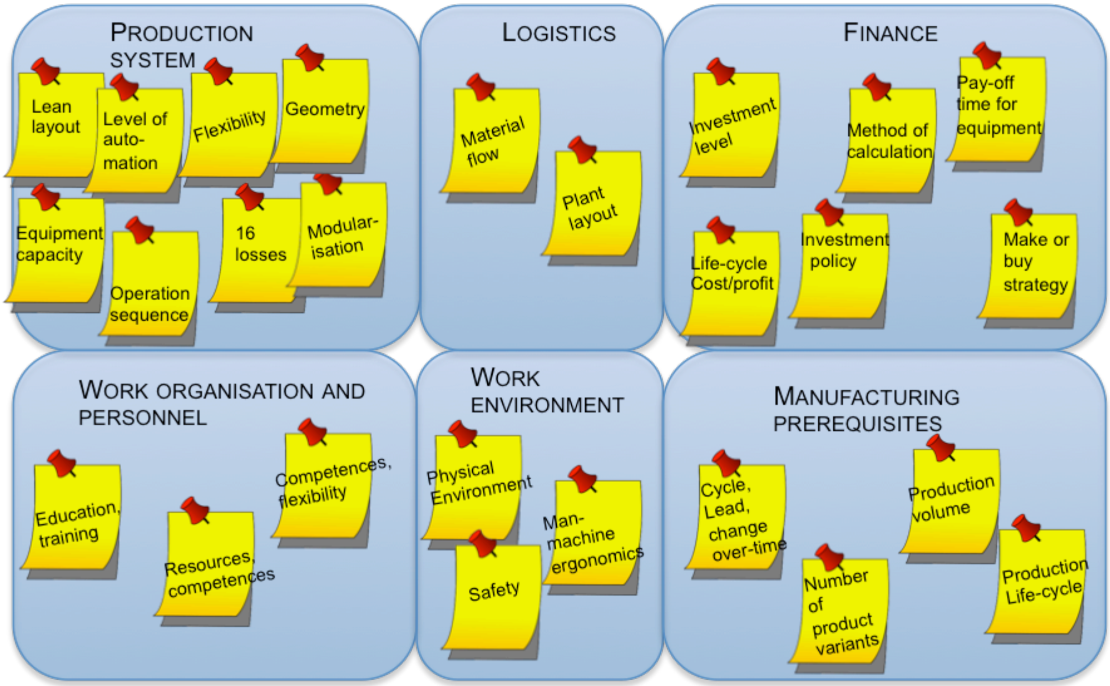

Figure 12 Index of DGM used as input to pilot interviews.

In comparison with the changes mentioned above, one can see that the category have changed a bit. *"Other"* has turned in to something called "*Manufacturing prerequisites"*. The thinking behind the category is still the same as explained before, but discussions have shown that a prerequisite is a generally accepted term within the company for describing this type of knowledge. The category of *"Company – strategic level"* has been eliminated since its important aspects, when applied to production development at VCC, seems to have a fit under other categories. The aspect of investment policy is moved to *"Finance"* since it in this stage seems to regard financial strategies for how investments should be handled. Resources and competences is an aspect which fits perfect under the category of "Work organisation & Personnel" since it is a question of availability of needed competences. One could of course argue that this aspect is a financial issue in terms of man-hours, but on the other hand the cost is driven by a lack of competence within the organisation. The aspect regarding make or buy strategy is placed under finance because it on a high level has a large impact on costs.

In addition to the screening and adapting of the literature findings, this first iteration also allows for the experts to add aspects to the index they feel that the literature left out. Typical aspects deriving from this process is "*16 Losses"* and "*Bill of process"*. These aspects are added to the index since they are routed and generally accepted within the company.

5.2 Iteration 2 - Pilot interviews

After the initial literature study, the pilot interview checklist consists of 26 aspects, sorted under six different categories. During the three pilot interviews the guideline index changes considerably, leading to a guideline index that is used in the actual interviews. This index is presented in the picture below.

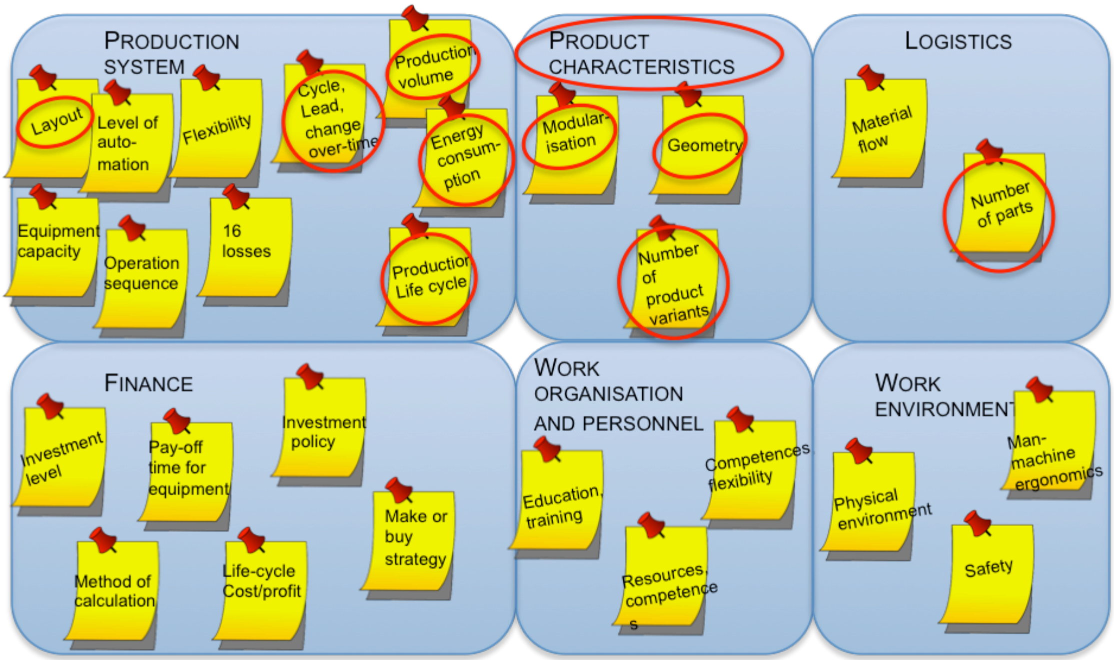

Figure 13 Index of DGM used as input to interviews.

The biggest change from the pilot interviews is the changed number of categories. After the first pilot interview, it became obvious that one of the categories cannot be *"manufacturing prerequisites"*. The interviewee pointed out that roughly all of the aspects can be looked at as a prerequisite, requirements given from another department. Most of the aspects were placed under the *"manufacturing prerequisites"*, making it overrepresented. This was not the initial thought with the category, but rather that some aspects are out of the production developers control. After further discussions the conclusion was that the category should be removed, because the aspects are still important to take into consideration when developing a production system, even if it is inhibited by requirements. The prerequisites of the different aspects has to be mentioned in the guidelines, giving the developer a good understanding of what is out of its hands and what he or she can have more influence over in production development.

Secondly, the category *"product characteristics"* has appeared in the index. There was comments from the interviewees that the lack of a product associated category might lead to an insufficient guideline index, both because the product should be in focus when developing production systems and because the communication between product and production development is very important in order to deliver a successful system. As mentioned earlier, concurrent engineering is an effective tool to use in order to respond to higher demands on the new product development process (Swink et al., 1996) and the main principle is to integrate downstream concerns into the upstream phases of development processes (Yassine & Braha, 2003). By implementing a category affected by the product development department, the needs of production can be more easily communicated and implemented into the product from the start. By looking at the initial checklist by Bellgrand & Säfsten (2010) that can be viewed in appendix D, there are a category called *"product concept"* that was removed in the early process because the aspects under the category was not considered of high importance in the production development process. After looking further into the chosen aspects however, it was discovered that several of them would fit well under a product-oriented category. This led to the creation of the new category and the affected aspects were moved. As can be seen in the picture above, these are *"modularisation"*, *"geometry"* and *"number of product variants"*.

"Modularisation" and *"geometry"* were both moved from *"production system"*. The aspects both affect the production system a lot, but rather in a secondary manner. They are shaped by the design of the product and dependent on how the product is developed. As Sanchez & Mahoney (2005) describes, it is the correlation between the product components, described in terms of loosely couple or tightly couple, dependent on how much the part influences each other. This later on decides how the production system has to be adapted to be able to produce the product. This said, it is important to note that production gives prerequisites to product developers, in order for the product developers not to design something that later cannot be produce. This emphasises the importance of a good communication between the two departments. Moreover, the concept of modularisation should not be limited to increase the flexibility at a product development level, but spread within the organisation to increase flexibility in many departments (Sanchez & Mahoney, 2005). Also the impact from *"number of product variants"* on the production system is important to communicate with the product developers. A

"product characteristics" category can hopefully be used to improve this communication.

There were three aspects moved from the former category *"manufacturing prerequisites"* to the category *"production system"*, namely *"cycle time, lead time, change-over time"*, *"production volume"* and *"production life-cycle"*. They have all an evident impact on the production system and were originally placed under *"Production engineering"* by Bellgran & Säfsten (2010) in their checklist that can be viewed in appendix D. That the aspects belong to the category *"production system"* was also confirmed in the pilot interviews, since all of the interviewees placed the aspects under this category.

The aspect *"layout"* has been put together from the both aspects *"lean layout"* and *"plant layout"*, which existed in the pilot interview index. During the interviews it was hard for the interviewees to separate the two types of layout. The purpose was initially to emphasise the importance of logistics when it comes to layout by having a separate aspect of layout under *"logistics"*, which would include the layout of the whole plant. However, it was decided to include both *"lean layout"* and *"plant layout"* under one common aspect and to emphasise the importance of logistics considerations throughout the entire aspect. The importance of including logistics concerns within the *"layout"* aspect was later confirmed in the interviews, which can be illustrated by interviewees' placements graph below.

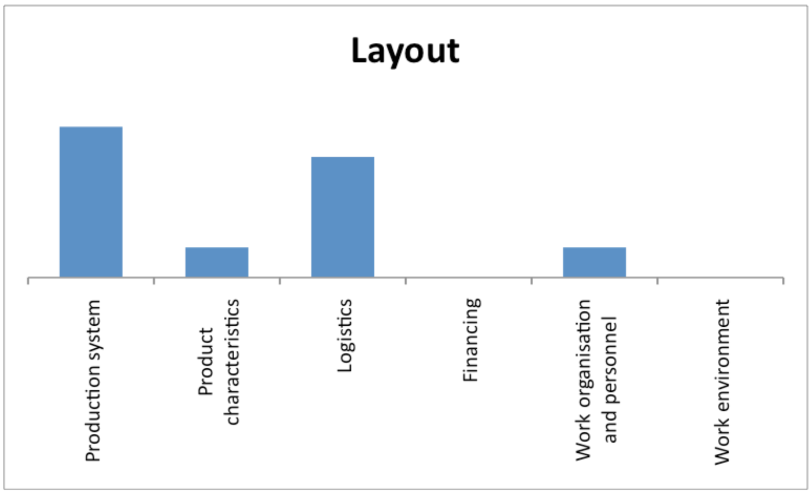

Figure 14 Statistical illustration of the interview participants' post-its placement regarding the aspect of layout. The height of the bar represents the number interviews in which the aspect was put under the category.

However, the importance and concern of lean layout is not minimised by taking it down to a second-degree aspect. Lean is an important tool in order to create value and eliminate wastes and it can partly be achieved by implementing a lean layout in the form of a U-shaped production line (Womack & Jones, 2008).

"Energy consumption" is a new aspect under *"production system"*. It was pointed out by an interviewee that the aspect is significant in today's culture, where environmental considerations are becoming more and more important, which was later confirmed by other interviewees who thought that the aspect was one of today's more important issues. The aspect was put under *"production system"* because it is mainly there that the consideration for reduced energy consumption should be implemented in order for the best effect to be achieved.

Lastly, *"number of parts"* under *"logistics"* was added. It was discussed during the interviews how much *"number of product variants"* affects logistics by the increased need for space a higher set of variants leads to. However, the *"number of product variants"* is affected by the *"product characteristics"* just as much. The solution was to implement a new aspect that affects the *"logistics"* and not the *"product characteristic"*, but at the same time is a result of the problem that arises with an increased spread of product variants.

5.3 Iteration 3 – Interviews

The guideline index used in the interviews consists of 27 aspects sorted under six categories. After interviewing 11 persons on several different positions at manufacturing engineering and with different expertise areas, the index was transformed into an almost finished index. Different factors that lead to changes in the guideline index are:

- The outcome of the interviewees' placements of the aspects under the different categories.
- Arguments of the existing aspects that changes the content of the guidelines.
- Arguments regarding the correlation of the different aspects.
- New aspects suggested by the interviewees.

See section 3.2 for further information about the data collection process. To view all the graphs of the interviewees' placements, see appendix E.

The index output from the interviews consists of 23 aspects, still underneath six categories, and can be viewed in the figure 15 below.

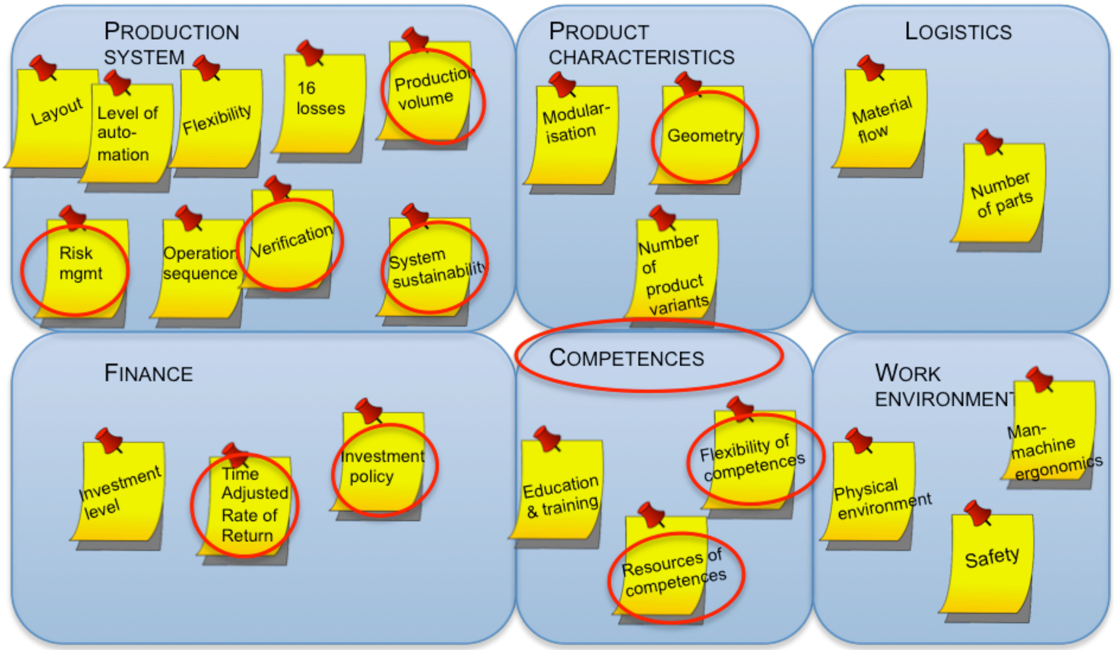

Figure 15 Index of DGM, output from interviews

The changes resulting from the interviews are extensive and they are therefore described one category at a time.

5.3.1 Production system

Starting with *"production system"*, there are several changes. First of all, both *"cycle time, lead time, change-over time"* and *"equipment capacity"* has changed from being first-degree aspects and can now be found under *"production volume"* as a second-degree aspect. Under the interviews there were a lot of connections between the three aspects, pointing towards that they have a correlation. Examining it even further led to the conclusion that most of the interviewees thought that production volume leads to the decision of how well the operations in the production system have to perform. One interviewee especially pointed out that production volume is a prerequisite from higher instances that is decided based on forecasts of the customer demand. The interviewee continued by saying that the performance capacity is then directly dependent of the capacity of the single station, which can be dimensioned by the *"cycle time, lead time, change-over time"* and *"equipment capacity"*. Hence, the two aspects were put under *"production volume"*.

There are two new aspects under *"production system"* as a result of suggestions from the interviewees. Several persons thought that *"verification"* was missing from the aspects. Both verification in the form of production development verification, which consists of tools such as pilot plant and digital plant, and running production verification, which aims to increase quality safe methods in the production as well as including signals and signs in the production flow to easily detect errors and production defaults. Verification in running production is also a big part of lean production, which with the help of signals for notifying about quality or process problems, *"andon"*, can increase the output quality of the production system (Volvo Cars, 2012i). Furthermore, *"risk management"* appears in the index as a result of suggestions from the interviewees, since they thought that there should be a standardised way of working with a safer and better delivery. There were a lot of references to the usage of tools such as Failure Mode Avoidance (FMA) and Failure Mode Effect Analysis (FMEA). Both these aspects are significant to take into consideration since they both emphasises the importance of doing the right things in the right way. The costs to adjust errors and mistakes increases with time and there is a lot of money to be saved by implementing standardised work routines that can prevent errors in later stages (Alfredson & Söderberg, 2010).

Two more aspects in *"production system"* has been somewhat changed from the interviews. Firstly, *"production life-cycle"* often confused the interviewees, who wondered if it was not in fact a typo and was meant to be product life-cycle. However, the purpose of the aspect was to take the sustainability of the production system into consideration when developing the system, because it is important to create the system with the right sustainable requirements. This led to reflections about the aspect and resulted in the aspect *"system sustainability"*, with the arguments that it better describes the purpose of the aspect. Furthermore, it is important to consider the sustainability of the production system with an economical, ecological and social consideration, which will be reflected upon by the implementation of this aspect. Secondly, it was for a moment decided that *"16 losses"* should be placed as a section under every aspect. There are losses in every aspect that can be minimised, which can be derived from the list presented by Ahuja & Khamba (2008) that describes the sixteen major losses within TPM. However, when discussing the subject further with the department at Volvo Cars, it was decided that *"16 losses"* should be its own aspect after all in order to emphasise the need of the aspect by bringing it higher up in the guideline index.

The last change in the *"production system"* category is that *"energy consumption"* has been moved. The aspect can no longer be found as a first level aspect but was placed under *"physical environment"* in the category *"work environment"*. There was a consensus between the interviewees that the aspect was important to take into consideration, but perhaps rather as a factor in the external environment that is found under *"physical environment"*. Below is a graph illustrating the outcome of the interviewees' placements of the aspect *"energy consumption"*.

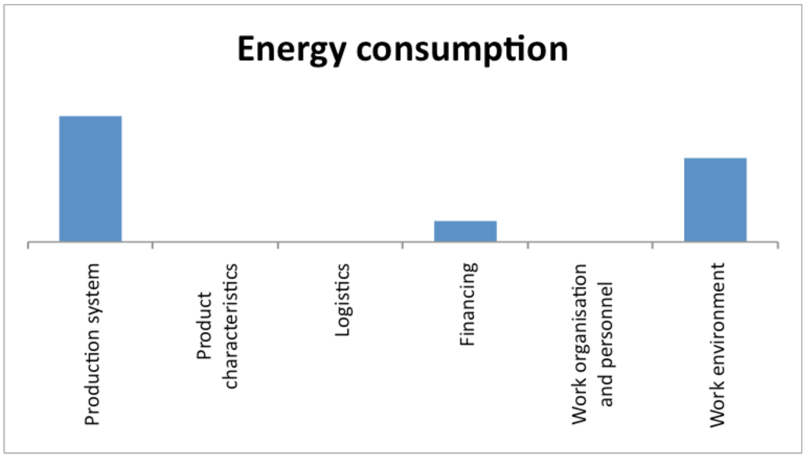

Figure 16 Statistical illustration of the interview participants' post-its placement regarding the aspect of energy consumption. The height of the bar represents the number interviews in which the aspect was put under the category.

The aspect was put under *"production system"* in the majority of the cases. This probably is an effect of where the interviewees see the potential of improvements in reducing the energy consumption, rather than what area the improvements will affect. The second view is probably the opinion of those who put it under *"work environment"*. All the aspects regard the production system in one way or another, since the design guidelines concerns production system development. In this case it seems more important to consider what area an improvement of the aspect will affect, leading to the placement of *"energy consumption"* under *"work environment"*. In order to support this placement one can think of a situation where a decrease of energy consumption within the production system also will decrease the negative environmental impact on the factory surroundings.

5.3.2 Product characteristics

In *"product characteristics"* there was not a lot of changes from the interviews. The first-degree aspects were the same both before and after the interviews. The content of *"geometry"* was changed a bit though. A lot of interviewees mentioned robustness as an aspect to consider in the production development. Since robustness could be thought of as a way to affect geometry variation of the product (Söderberg, 2012), it was suitable to put it as a second-degree aspect under *"geometry"* together with *"variation"*. Also, the content of *"modularisation"* was discussed a bit. The outcome of the placements is shown below.

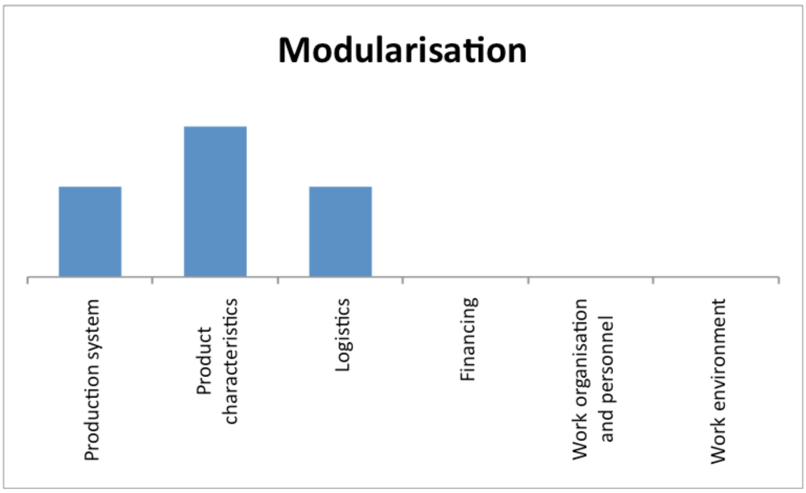

Figure 17 Statistical illustration of the interview participants' post-its placement regarding the aspect of modularisation. The height of the bar represents the number interviews in which the aspect was put under the category.

The placements under *"product characteristics"* are in majority, but there are also connections to the *"production system"* and *"logistics"*. Hence, it was decided to discuss these aspects as well in the guidelines, in order to cover the affected areas.

5.3.3 Logistics

"Logistics" was not changed that much from the interviews, but filled with a lot of information regarding the guidelines. *"Material flow"* was placed under *"logistics"* by all the interview participants and there was a consensus that the aspect is of great importance when developing production systems. One of the interviewees, that works with logistics, say that the traditional way of working was that the production developers designs the production system and when they are finished it is up to the logistics department to implement the best possible material flow solution. He says that if there would be more integration in early phases there would be a lot of money to save. This also corresponds with the mentioned theory by Wheelwright & Clark (1992) that the cost of errors and mistakes increase with time. Moreover, there is a clear connection to the importance of implementing concurrent engineering, by involving different departments early in the decision-making processes (McGrath, 1992; Sage & Rouse, 2009). Lean thinking in the production system layout is an important tool in order to achieve optimised material flow, by implementing continuous material flow with a pull approach (Womack & Jones, 2008). This emphasises the importance of cross-functional integration between the departments in the upstream and downstream functions

(Wheelwright & Clark, 1992) and an optimised material flow can also lead to minimising loss number nine of sixteen losses, which refers to the logistic and distribution solutions of the production system (Ahuja & Khamba, 2008). These and many more, are reasons for why *"material flow"* is so important to focus on when developing production systems.

"Number of parts" had some interesting inputs during the interviews. The graph showing the interviewees' placements of the aspect is presented below.

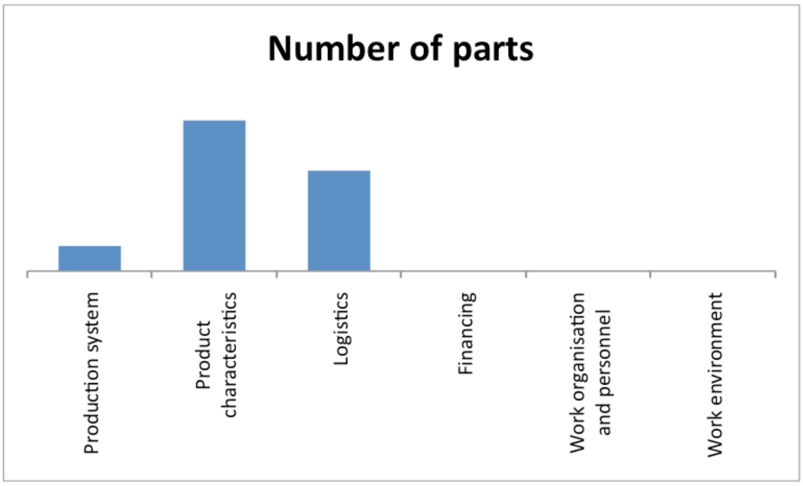

Figure 18 Statistical illustration of the interview participants' post-its placement regarding the aspect of number of parts. The height of the bar represents the number interviews in which the aspect was put under the category.

Most of the participants placed it under *"product characteristics"*. However, most of the times this happened it was when the participant had not seen the *"number of product variants"* aspect yet. Some of the times the interviewee even thought of changing *"number of parts"* to *"logistics"* when they did see the aspect about the variants, but decided that it could just as well remain at the *"product characteristics"*. The purpose of the aspect was to take the concerns that the increased set of product variants brings to logistics into consideration, which was somewhat confirmed by the reasoning of the interviewees. One interviewee says that some variants are only made about once a year, which means that the parts has to be in store for that specific variant, even though it does not bring enough revenue to uphold the storage costs.

5.3.4 Finance

The appearance of the category *"finance"* has changed considerably. Of the six initial aspects, only three remain. Firstly, *"make or buy strategy"* has been changed from being a first-degree aspect to a second-degree aspect underneath *"investment policy"*. During the interviews there were a lot of connections between the two of them. Many of the interviewees mention how make or buy is a question that is handled under *"investment policy"* and how it comes from what the current strategy within the company is when it comes to outsourcing. After talking to an expert at ME that works with the financing a lot, it was agreed upon that *"make or buy strategy"* fits under *"investment policy"*, since it is a part of the company's strategy, but that the policy contains more strategy related issues than what the company should outsource or not.

"Investment level" remains as it was and works like a complement to the *"investment policy"*. The policy regards the strategies of the company when it comes to financing, whilst the level tends to the issues of the actual budget. Most of the interviewees say that the *"investment level"* is about coping with the budget that has been decided for the project by higher instances. They state that the Industrial Business Office (IBO) is the department that decides the budget based on a build-up calculation made in the early phases of the project. Even though this calculation is based on very uncertain estimations, the budget has to be followed with only a small margin of error.

Lastly, the *"method of calculation*" has been changed to *"Time Adjusted Rate of Return"* (TARR), because when the interviewees speculated about the aspect, they instantly went to the TARR-calculations as the only method they used. When talking further with the expert at ME that handles a lot of financing issues, he states that the only financing tool that is used in the production development projects is the TARR-calculations. He continues by explaining that it is an easy tool that can compare the profitability of different cases, including calculations about pay-off time for equipment and a machines life-cycle cost. This led to the change to put *"pay-off time for equipment"* and *"life-cycle cost"* under the TARR aspect, making them second-degree aspects. This leads to a more structured and logical index, where *"finance"* consists of the three aspects concerning investment strategies, actual usage of the budget and how to financially compare different cases of profitability.

5.3.5 Competences

First of all, the category has changed name from *"work organisation and personnel"* to *"competences"*. The reason for the change was that as it turns out, all of the aspects in the category concern the personnel and not so much the organisation, making *"competences"* a more suitable category name for the underlying aspects. Overall, there are not so much changes in the category other than name changes. The aspects concerns the same issues but was changed to better describe the content of the aspects. The interviewees' placements of the aspects were also confirming that the aspects are under the right category. Shown below are the placements of *"education & training"*.

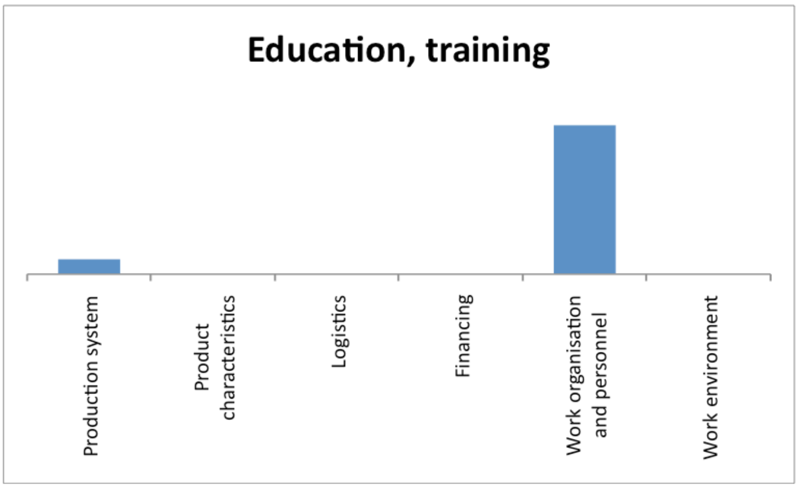

Figure 19 Statistical illustration of the interview participants' post-its placement regarding the aspect of education and training. The height of the bar represents the number interviews in which the aspect was put under the category.

There are a considerable majority of the placements on *"work organisation and personnel"*. The other aspects have similar graphs of the interviewees' placements.

There is one second-degree aspect that was communicated by the interviewees, which is *"man hours"* under *"recourses of competences"*. There were several comments about the need to calculate the man-hours and to include the thinking of total cost calculations into the balancing of resources. The optimisation of the man-hours can be achieved by implementing a U-shaped production layout with multi-functional workers, which decreases the overall cycle time (Ohno & Nakade, 1996). The aspect also affects sixteen losses, since loss number twelve are referring to management losses, which involves the balancing of man-hours (Ahuja & Khamba, 2008).

5.3.6 Work environment

The aspects of *"work environment"* were not changed during the interviews. There was an overall concurrence of the interviewees' placements and opinions of the aspects, saying that the aspects are important to take into consideration and that they belong to the category *"work environment"*. *"Safety"* did diverge a bit in the placements, though, which can be seen below.

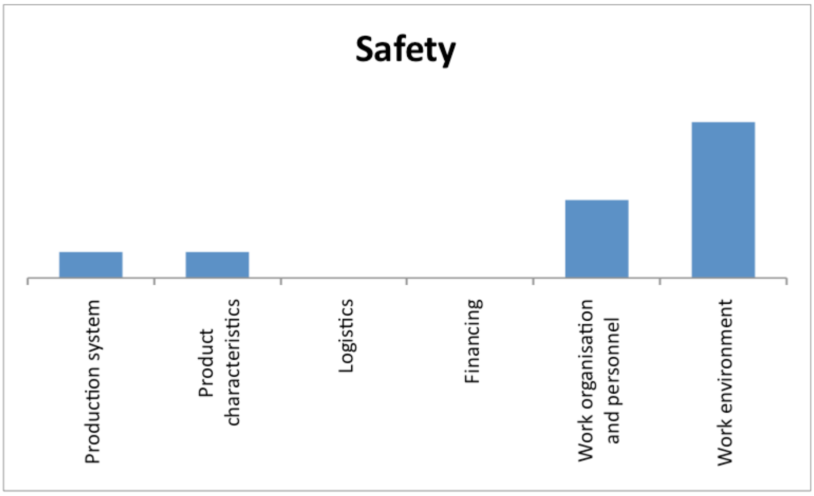

Figure 20 Statistical illustration of the interview participants' post-its placement regarding the aspect of safety. The height of the bar represents the number interviews in which the aspect was put under the category.

This can be explained by the reasoning of the interviewees that did not put it under *"work environment"*. The participants that put it under *"product characteristics"* mentioned that the safety is always about the safety for the customer, which makes it a product aspect. The purpose of the design guidelines however, is that they should be used when developing production systems, which means that this reasoning concerns a whole other aspect. The persons who put it under *"work organisation and personnel"* discussed that the safety should refer to the safety of the personnel, making it an organisational issue. This is not at all far from the purpose of the aspect, but there is still more important to take it into consideration when it comes to consider the work environment, because it is in this area the safety has to be secured.

5.4 Iteration 4 – Additional concepts and theory

The output from the interviews is an almost finished structure of the guideline index. Additional research within the literature from the academic world and from the documents at Volvo Cars, results in a valid guideline index with both academic and organisational support. First of all, the aspect order was investigated and reworked, making the guidelines easier to grasp. These decisions were made with the help of an internal discussion within the department, founded in the prioritising of the aspects. Moreover, several aspects were investigated, with a focus on those that had been mentioned a lot during the interviews.

An investigation was made on the aspect *"operation sequence"*. Beneath the aspect, Bill of Process could be found as a second-degree aspect, which is a sequencing tool used at Volvo Cars. However, from the interviews it became clear that for most of the employees the BoP was equal to the operation sequence. A study was made of the topic showing that the tool is under progress, with the purpose of consisting of a full description of the operation sequence at VCC by showing the sequences on several different levels (Strategic Planning & Control, 2012). Since the DGM is implemented with the purpose to follow the VCC strategy and the development of the company, the aspect was renamed to *"Bill of Process – the operation sequence"*.

One other change in the guideline index was under the category *"product characteristics"*, where *"modularisation"* has gone from a first-degree to a second-degree aspect underneath the new aspect *"product flexibility"*. This was developed after investigating modularisation in the academic literature. It turns out that mass customisation, the paradigm to lower the production costs whilst increasing the product variety as a result of meeting the customer needs, can be achieved by increasing the product flexibility with tools such as modularisation and commonality (Jiao & Tseng, 1999). Hence, the aspect was renamed *"product flexibility"* and consisted of the two second-degree aspects *"modularisation"* and *"commonality"*. Using modularity in the products is an approach to reach higher product variety with a low trade-off towards operational costs (Salvador et al., 2002) and the mentality of modularisation should be spread throughout the company, since there is not only product development that can benefit from the increased flexibility modularity brings (Sanchez & Mahoney, 2005). Increased commonality in the product leads to a more effective manufacturing system (Nagarur & Azeem, 1999), because it increases the repetition and reusability in production, which enables the opportunity to reuse tools, equipment and expertise (Jiao & Tseng, 1999).

During the interviews there were several remarks about how important it is to have a good system for lessons learned in the company. None of the interviewees had any concrete suggestion on how this should be done however, which held the aspect out of the guideline index. When asked about if they new anything about design guidelines, many of them mentioned the design guidelines document that exists in product development. By investigating one of these design guidelines documents, it was clear that the guidelines were much more narrow and specific than the intended guidelines resulting from this thesis (Volvo Cars, 2012a). However, it did have a comment about how the document should be developed with lessons learned. This led to further discussions about the subject involving an expertise at ME who works a lot towards product development, leading to the implementation of the aspect *"lessons learned"* under the category *"competences"*.

"16 losses" is an aspect that is important to communicate throughout the company, according to the employees at ME. After finalising the interviews, a research was made on the subject both internally and externally. There is much information on the subject in the academic world. One of them is presented by Ahuja & Khamba (2008), who describes the sixteen major losses within TPM. There was also an adapted version of the sixteen losses at Volvo Cars (2012). This framework was better suited for the company and also easier to understand with a VCC mind-set, which led to the conclusion that there should be more focus on the Volvo Cars adapted version of sixteen losses in the design guidelines, because it is easier to understand for the intended user.

Another hot topic during the interviews was *"lean layout"*. This was for the time being a second-degree aspect, but it turns out that the thinking within Volvo Cars about layout leant more and more towards a lean mind-set. The information on the topic in the academic literature is vast and also internally there is a lot of information to be found. The benefits from lean layout is stated by Womack & Jones (2008) to be increased labour productivity, reduced throughput time and inventory, lead to decreased errors and cut injuries. Lean layout also enables continuous improvement of the production system by easier identifying and removing wastes and having a better customer focus by using a continuous flow with customer pull approach (Volvo Cars, 2012i). Because of the direction in which VCC is going concerning lean layout, and also because of the stated advantages of the philosophy's implementation in the layout, *"lean layout"* was promoted to a first-degree aspect, replacing the previous *"layout"*.

As a result of the interviewees' placements of the aspect *"level of automation"*, there was no doubt that the aspect belonged to *"production system"*, as seen in the graph below.

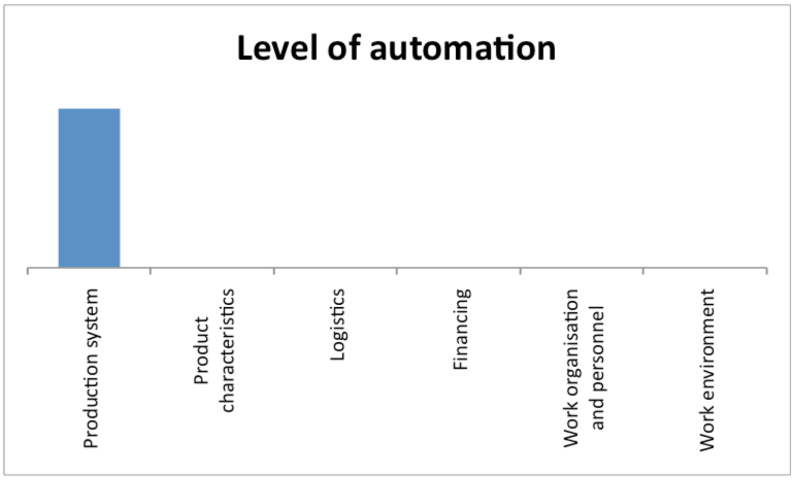

Figure 21 Statistical illustration of the interview participants' post-its placement regarding the aspect of level of automation. The height of the bar represents the number interviews in which the aspect was put under the category.

However, the speculations of the interview participants included several of the other categories, such as *"financing"*, *"product characteristics"* and *"work environment"*. For instance, it was said that the question about automation was highly affected by the investment level of the project, that automation could be a necessity because of narrow geometrical requirements and that automation sometimes has to replace manual work labour because of bad working conditions. The speculations about the topic led to an investigation, where an immense amount of academic literature sources were found. The importance of the aspect was validated because of the many issues that the aspect regards. According to Endsley (1996), the increased complexity of the systems as a result of increased automation has led to a growing trend of large failures in the systems, since the complexity of the systems gets too vast for the operator to understand. There is also a large focus in the literature on the norm of using a high level of automation. Initially, the norm was that automation was implemented whenever it was feasible and the costs could be reduced as a result, but that the reason this perception has not led to fully automated systems is that humans better respond to changes since they are more flexible (Parasuraman & Riley, 1997).

"Flexibility" was another topic that was discussed a lot during the interviews. One interviewee stated that there are three main types of flexibility, namely volume flexibility, model flexibility and flexibility of change. After researching the topic, a list with 15 different dimensions of manufacturing flexibility presented by Vokurka & O'Leary-Kelly (2000) was found. The dimensions can in turn be divided into larger clusters, for instance volume flexibility, model flexibility and flexibility of change.

Therefore, these three types of flexibility was placed as second-degree aspects under flexibility in order to involve the important parts of flexibility in the guidelines.

5.5 Iteration 5 – Workshop: What? Why? How?

When the guideline index enters this phase, it consists of a finished structure as well as important guidelines and considerations that the aspects include. However, it is not decided in what shape and form the guidelines tool should be presented in order to most effectively be understood and implemented in the organisation. Under the implementation section of the interviews, there were several remarks about how important it is that the purpose of implementing a new way of working is communicated to the employees in order for them to adapt to the change. Furthermore, it was discussed how important it is that the tool is understood, which leads to the need of a standardised delivery of the guidelines that is easy to grasp. As a result of these comments and further reasoning, each aspect was decided to consist of three parts, *what*, *why* and *how*. *What,* describes the content of the aspect and the different second-degree aspects it includes. In *why*, it is explained why the aspect is important to consider when developing production systems. *How,* consists of the guidelines and considerations that the aspect regards.

A workshop was used in order to motivate the importance of the aspects. The workshop involved the department of SP&C with the objective to compare the aspects with the performance objectives at VCM. This motivates the importance of the aspects as well as it aligns the aspects with the strategy of the company. The idea of the comparison derives from the operation strategy matrix presented by Slack & Lewis (2008). The matrix consists of an intersection between the market requirements and the operation resources. Adapted to this research, the intersection instead consists of the aspects in DGM and the performance objectives of Volvo Cars Manufacturing, the QCDISMEL. During the workshop the different aspects were compared to the performance objectives in order to find connections. As Slack & Lewis (2008) states, it is important to focus on the critical intersection and to specify these in order to get a good understanding of the influence they have on each other. After completion of the workshop, the results were used in the *why* section of all the aspects. Since the QCDISMEL is widely used and acknowledged among Volvo Cars' employees, the guidelines are now motivated with the performance objectives that they work with every day. This hopefully simplifies the implementation of the guidelines as well as gives the users a good understanding of why it is important to regard the aspects in DGM.

5.6 Final version

The design guideline index has been finalised and the aspects are motivated with alignment to the VCC strategy. The final guideline index is shown in figure 25 at the end of this section. It consists of six categories and 24 aspects. The structure is finished and the information about the guidelines that has been researched is formed under each aspect. However, as earlier mentioned this is not comprehensive enough to include all the important guidelines within each aspect. In order to exemplify how the potential future document of DGM can look like, a demonstration version of *"material flow"* is made. This means that the aspect regarding the material flow is more extensive than the others aspects and can be used as a reference in future development of DGM. A discussion with an expert in logistics at Volvo Cars was held, leading to rather extensive information regarding production development guidelines within *"material flow"*. This said, the guidelines regarding material flow should as well be developed in order to include all important guidelines. In order to view the "material flow" from the finalised version of DGM, see appendix A.

5.6.1 Aspect example – Verification

This section illustrates the aspect of *"verification"* included in DGM. As mentioned earlier, the aspect is structured into *what*, *why*, and *how* in order to use a more user-friendly layout. This example aims to bring a better understanding to the reader regarding to what extent and detail the different aspects are developed.

What?

Verification is about gathering evidence to support that the product and production meets the initial set of requirements and specifications. The topic is handled with two different perspectives:

- System development verification - to find the best solution and prepare for changes.
- Running production verification - to hinder quality issues in running production.

Why?

This aspect is relevant and important to take into consideration since it relates to and affects the VCM performance objectives as follows:

- *Quality*: The quality of products and processes can be increased through verification since the aspect facilitates the finding and choosing of the best available solution early.
- *Cost*: The aspect can cut down on costs by identifying potential problems and improvement potentials in early phases.

How?

System development verification

The most important guideline regarding verification is to only implement reliable and thoroughly tested products, processes, systems and routines. When the verification level is high, the implementation will most certainly be successful.

Virtual verification

Use computer simulation tools for evaluating and comparing alternative design solutions in a digital plant. Strive towards choosing the solution that best meets the customers' needs. Do not stop simulating just because the design is implemented, study new simulations continuously in order to test and improve the system design. All simulations should be based on estimated numbers, e.g. cycle times, repair time, machine downtime, reject rates, etc.

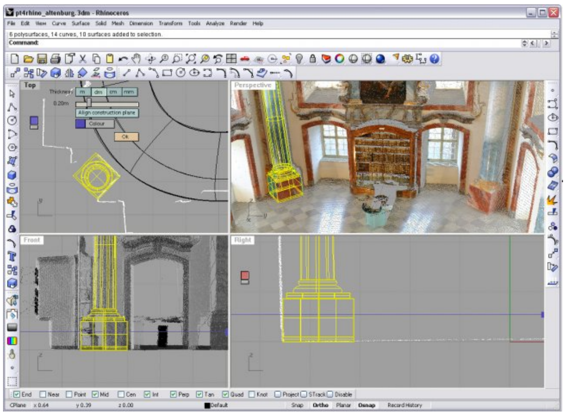

Figure 22 Example of virtual verification software

Physical verification

When a concept has been verified through simulations, its validity should be further tested in the pilot plant. The testing in a physical environment should involve persons from commodity departments as well as production operators.

Running production verification

Design equipment and supporting processes to continuously prevent and detect quality issues.

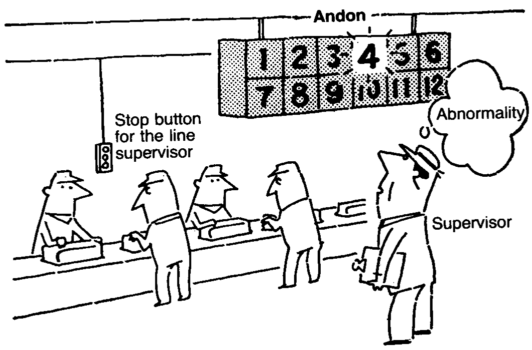

Figure 23 Andon illustration.

Provide the production system with real-time visual management (lights, screens, signals, etc.) in order for the operator to get a good overview of the system and to detect abnormal conditions.

Strive towards implementing fail-safe sub-systems in the production, in order to secure that defects are never passed on e.g. force gauge, light sensors, etc.

Figure 24 Illustration example of a fail-safe system

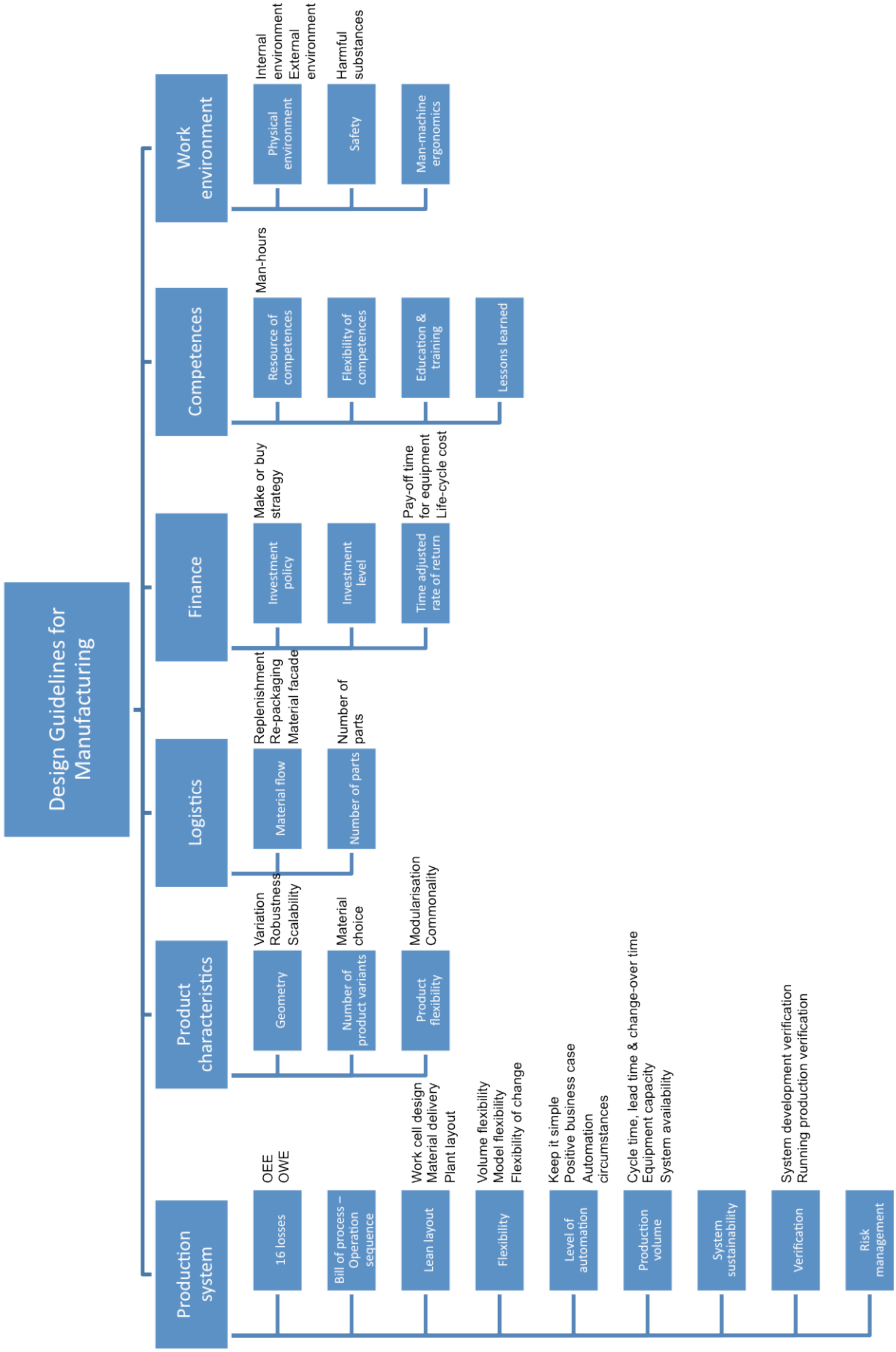

Figure 25 Final layout of DGM index

5.7 Implementation

Since this thesis aims towards creating the framework of DGM and investigating success factors of implementation, rather than actually carry through the implementation, this part of the thesis is divided into two sections. The first part grasps the findings regarding how the DGM should be designed and developed in order to reach success, whilst the second part consists of findings regarding in what way the framework should be implemented.

5.7.1 Further development of DGM

The data collected during this thesis points towards a common set of prerequisites for a successful future development of the framework. First of all, the developer has to have a clear understanding of to whom the guidelines are developed. Without understanding the customer and his or her needs, there is a risk that the message will be unclear and misinterpreted along the way. Linked to this, one of the interviewees in this research stated that the level of complexity is also important to take into consideration. The opinion of the interviewee is that if the complexity of the guidelines is either too low, meaning that no new information is brought to the table, or too high, meaning that the information is too complex for the user to understand, there is a risk that the guidelines will not be used at all. Another common argument mentioned by the participants during the interviews is the importance of having the intended users involved in the development of the framework to as high extent as possible. The argument is based on the belief that this will reduce resistance of change and actually support the process of adapting the guidelines into standard routines.

The guidelines should be updated by lessons learned. This was described during the interviews to be a problem at VCC, since there is a lack of common document in which the lessons can be saved. By updating DGM with lessons learned, it would enable continuous improvement of the production development processes and help the employees to standardise the lessons learned procedure.

Finally, the most common remark of the interviewees regarding the implementation is the importance of clearly stating the aim of the framework and the benefits of using it. This argument is aligned with what Coronado & Antony (2002) states as important for implementation in their mapping of CSF. Their research presents clear communication of aims and benefit to the users as one of the CSF of implementation. This is one of the reasons why all the guidelines should be presented in terms of *what* should be handled, *why* it is important and *how* it should be treated. It is crucial that the further development of the guidelines will follow this design in order to maintain a standardised structured overview of the document.

5.7.2 Future implementation of DGM

Interviews have shown that there are several important things to take into consideration in order to facilitate a successful implementation of DGM. One important issue is regarding the fact that the implementation will involve first-time-users, which was stated by some of the interviewees meant that there is a need of developing a training package. Firstly, the training should consist of a brief presentation regarding the aim and purpose of the framework. Secondly, a hands-on case should be performed where the education participants get to practice the usage of the framework. Lastly, the participants should be assigned a framework sponsor for future support when using DGM in practice.

The interviewees also pointed out a number of important things to consider in order to keep DGM frequently used and valid after the implementation. The interviewees especially pointed out the importance of getting the management committed to the framework. Meaning that managers at a higher hierarchy level should allocate time for the user to work with DGM, and frequently ask for the results of the usage. Several interviewees also stated that some sort of summative checklist could facilitate and make this communicating process more standardised and effective. Furthermore, the interviewees said that it is crucial to decide who is responsible for developing the framework. One of the interview participant explicitly said, "shared responsibility is no one's responsibility". Therefore one can argue that it is vital that the further development always should be connected to for instance a manager or a department, which clearly have the responsibility for this specific development. Since the framework evolve several fields of knowledge and departments it is also important to have a good communication channel regarding how DGM is used in various ways. The *"material flow"* aspect can be used as a demonstration for how the other aspects and guidelines can be further developed into a more detailed level.

The interviews also derived interesting information regarding the layout of DGM. The participants stated the importance of having an actual document to screen, rather than a slide presentation. This would form a more professional expression and open up for further developments within the standardised framework. In order to avoid the risk of having the document perceived as too heavy and complex, the interviewees suggested to use simple and illustrative pictures connected to each aspect.

6 Discussion

In this chapter, there is a discussion of the findings that includes; the comparison between the final guideline index and the origin of the research, some of the problems that have occurred, the validity of the results and how they are aligned with the strategy of the company, alternative research direction and potential future opportunities, the importance of the guidelines from a sustainability perspective.

6.1 Initial research considerations

In the beginning of this research, there was just a faint idea of what the design guidelines might be. The product development department have over the past years worked on design guidelines for developing products, which are specific for the different sub-systems that occur in the automotive industry (Volvo Cars, 2012a). But how can this kind of guidelines be applied to the production development processes? Is there a way and form in which the guidelines can be presented and used when it comes to developing production systems?

These were the initial questions in this study. There are a lot of different tools, documents, guidelines, policies, strategies and plans when it comes to developing production systems at VCC. However, the problem is that the company needs a collected framework that can support the decisions during the production development projects at ME, which is supported by the reasoning of Bellgran & Säfsten (2010) who states that a structured approach brings a more holistic and logical decision process. Most of the employees working with these projects have done so for a long time and they do their jobs on routine rather than with the help of a standardised way of working. This might lead to a divergence of the production system output, since there might be a lot of different opinions of how the production system should be designed. And what happens when there are new production developers that do not know what to do? Who do they seek for consultation if the more experiences developers are not available?

When starting to scan the academic literature for help within the process of working with production systems in a structured and standardised way, the framework presented by Bellgran & Säfsten (2010) was found. The authors presents *"a structured way of working"* including the important steps to consider during the production system development process, from project initiation to running production. This is a guide for what to include throughout the whole project, which makes it a good start for this study but far from a solution to the lack of guidelines at ME. The primary reason for this is that the framework describes the steps in the form of a timeline when working on the production system development process. The idea with this study is to deliver guidance that is not dependent of in which phase the project is, but rather regarding different production system aspects. Moreover, the framework also includes unwanted elements such as preparing the investment request, development planning, production system in operation, etc. The projects for which these guidelines are intended for, ranges from project start to production first job, which excludes several of the steps that are presented in the *"a structured way of working"*.

In addition to *"a structured way of working"*, Bellgran & Säfsten (2010) presents a checklist of important aspects that the process includes. This checklist is the start of what later on becomes the finished Design Guidelines for Manufacturing. As with the timeline process framework, the checklist includes several aspects that are not applicable in DGM. However, it is a wide framework that works as a good foundation. It is better if the foundation is too wide than too narrow, since a wide aspect range can be tested against Volvo Cars Manufacturing and narrowed down to a more specific and VCC applicable framework. With a narrow starting point, the risk of missing some important aspects is much higher. This said, the checklist presented by Bellgran & Säfsten (2010) does not include all the aspects that are included in DGM. There are several other aspects that have been highlighted during the study and included into the guideline index.

6.2 Comparison between starting point and end results

When looking at the differences between the starting point, which is the checklist, and the resulting document DGM, there are some notable changes that have been made. Instead of nine categories there are six, and almost every category has been renamed. A probable reason is that the checklist covers a wider process range than DGM. The changes in category names are a result of making the guidelines more adaptable to the VCM language and to better fit the aspects that are the outcome of this research. In addition to the fact that the checklist is founded in a wider process range than DGM, the structure of the categories in DGM is connected to different departments in another way than the checklist. For instance, the category *"Company – Strategic level"* of the checklist contains aspects that is divided between several of the categories in DGM, because the company strategy should be established within all the operations of the company. In other words, the company strategy should be embedded in all the categories. The categories in DGM are also more specifically connected to the different departments. *"Production system"* is connected to ME, *"product characteristics"* is connected to product development, *"logistics"* is connected to the logistics department, and so on.

Similar to the categories, the aspects have been strongly reduced from the checklist presented by Bellgran & Säfsten (2010) to DGM. This is probably also a consequence of the fact that the checklist covers a wider process than DGM. It is also a result of the reason that a lot of the aspects have been sorted under other aspects. For instance, *"cycle time, lead time, change-over time"*, *"availability"* and *"equipment capacity"* are all included as second-degree aspects under *"production volume"* and *"control principle: push/pull"* and *"work in progress, buffers"* are included in the aspect *"material flow"*. These regroupings are an outcome of the interviews and the discussions that have followed. If a strong connection between the aspects was discussed, it sometimes led to a change where first-degree aspects became a second-degree aspect and vice versa.

In many cases, an aspect could be located in many different places of the guideline index. Often it was a question of how to approach the aspect. For instance, *"energy consumption"* was previously in the category *"production system"* but was moved to *"work environment"*. It has a clear connection to *"production system"* since it is there that the changes and implementations regarding the aspect can be done in order to affect the energy consumed. On the other hand, the outcome of the aspect is a question of influencing the external environment, which can be found as a second-degree aspect in *"work environment"*. In other words, the aspect can be placed on both locations. Since it seemed more important to take the aspect into consideration as a factor of the external environment, it was placed under *"work environment"*. Another example of a problem that could arise is the aspect *"number of product variants"*. The aspect affects the logistics, because the number of parts that has to be taken care of is directly correlated to the number of product variants, which lead to the introduction of the new aspect *"number of parts"*. In this way the aspect is treated in both categories. It is important to note that decisions like this might include some subjectivity, but that the aim has been to remain as logical and objective as possible throughout the research.

Similar to this reasoning about how aspects can be perceived and interpreted, the aspects and guidelines can also be perceived differently from person to person in accordance to importance. This can mean that persons working with the guidelines rank the importance of the guidelines differently and ignore one guideline in favour for another one. Even if the aspects are perceived in the same way, situations can occur where guidelines are contradicting each other and therefore force some sort of ranking in-between the guidelines. A situation like this could be when the design of a manufacturing process concerns several aspects for instance costs, operator ergonomics and product quality. Guidelines related to these types of aspects runs a high risk of being contradictive and can therefore lead to trade-off decisions. As mentioned in delimitations (section 1.5), the ranking and contradictions in-between the aspect is outside the scope of this research, yet it is an interesting topic that deserves some attention and discussion. The reasons why this topic is not included in this research are many, apart from that the scope already is large within the time frame; the part was mainly left out since it was considered that involving this topic would bring too much complexity to DGM. The vision is that DGM will be a document that, when contradictions occurs, will raise the question rather than calculating the exact answer. It is the researchers' unambiguous opinion that this step would require a more case specific adapted version of DGM.

6.3 Workshop reflections

The workshop was held in the end of the research in order to validate the guideline index and the aspects' alignment with the performance objectives at VCM, the QCDISMEL. This enriches the aspects with the purpose of why to include them in the production development process. By comparing the aspects with the performance objectives at VCM, it motivates the use of the guidelines in a way that appeals to the employees. Since they are already working to implement production systems that enhance these objectives, the implementation of DGM is simplified. This is why one of the most important properties of this research is to implement a solution that consists of several dimensions. If the resulting guidelines would consist of only theory, the employees would have a hard time to apply it to their situation at VCM. In the opposite way, if the information in the guidelines only consisted of the opinions of the employees, the production development process be worse than the competitors since there might be new effective work processes available that the employees does not know of. By uniting the information from both external and internal sources and then align them with the strategy of manufacturing, the user can see the purpose of using the guidelines from all the angels.

The result from the workshop resulted in the *why* descriptions under the aspects in DGM. The figure below illustrates how often each VCM objective was linked to the aspects in DGM, as a proportion of the total number of connections.

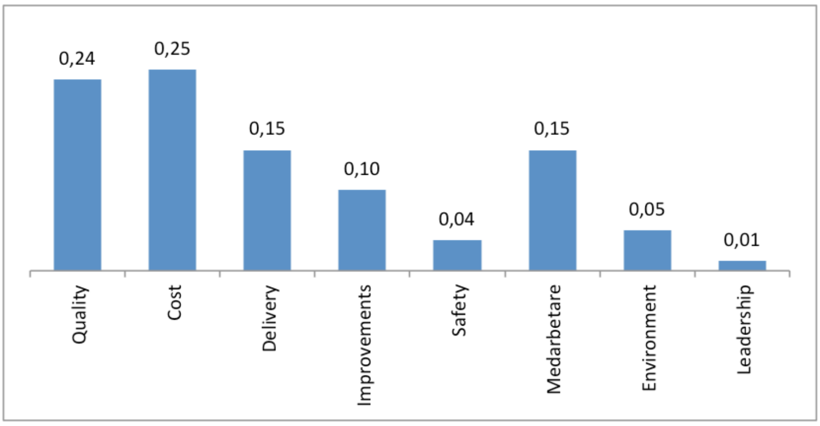

Figure 26 Statistical illustration regarding the link between DGM aspects and QCDISMEL

"Quality" and *"cost"* together fill 49 % of the connections between the performance objectives and the aspects. This is probably a consequence of the fact that DGM is a document that concerns the development of production systems, and that quality and cost are two main competitive areas in manufacturing (D'Souza & Williams, 2000). As illustrated in the graph above, *"leadership"*, *"safety"* and *"environment"* are connected to few of the aspects in DGM. In the performance objectives at VCM, *"leadership"* does actually have brackets around it, indicating that it is not as highly involved in the actual manufacturing performance as the rest of the objectives. However, it is still an important objective to consider from a company perspective. For one, management involvement and commitment is a critical success factor in order to implement changes in a company (Coronado & Antony, 2002). *"Safety"* and *"environment"* are two objectives that are both important, but have dedicated aspects in DGM, leading to the outcome that they are not connected to the other aspects as much. Both of the objectives are handled under the category *"work environment"*.

6.4 Thoughts on further development

During this research the focus has been to develop a guideline index that can work as a framework for the whole production development. This means that the guidelines within each aspect is not fully developed and only consists of the guidelines that were collected whilst forming the guideline index. However, one aspect was developed a little bit further, namely *"material flow"*. The aspect was discussed with an expert within logistics at ME, leading to several concrete guidelines. This is meant to work as a demonstration guideline for future development of DGM. It gives an idea of how the rest of the aspects can be filled with information and how DGM can look if it continues to be developed. A demonstration aspect might help with the implementation of DGM, since it clarifies the meaning of the tool. Moreover, since the guideline index was formed so that each category is connected to a certain department in the company, it eases the possibility to continuously improve DGM. Each aspect can be delegated to experts within the aspect area, which enables that the aspects are filled with valid information about important guidelines and considerations in production development. Furthermore, it can work as a source where lessons learned are saved in order to continuously improve the development process. For instance, a meeting can be held each year where the past years lessons are discussed and implemented into DGM. Other than improving DGM, it would also enable the possibility to save the lessons learned in a document, which have been understood to be a current issue at VCC.

6.5 Alternative research directions

As earlier mentioned, the focus of the research has been the guideline index framework. One alternative focus with the research could have been to focus on several of the important aspects and develop them into containing concrete and graspable design guidelines. Instead of interviewing a broad spectre of expertise within ME, experts within the areas of the aspects could be interviewed, in the same manner as the demonstration aspect was developed, but with further depth. This would give ME some instant guidelines and considerations within a few selected aspects of additional importance. However, the aspects would still have to be chosen somehow, which insinuates the need of starting the alternative research in a similar manner as the research in this thesis. By stopping to investigate the correlations and influence between the aspects and the importance they have in production development processes, this could lead to the conclusion that an aspect with low importance could have been developed whilst an aspect of more importance is not. Furthermore, it would be much harder to continue the development of DGM. There would sooner or later be needs of a research of an optimal guideline index in order to know what aspects to continue developing. This supports the course of this research. The foundation of DGM is now set as a result of the guideline index and future development of DGM would consist of filling the document with concrete guidelines. The index could also be used on sub-systems in the production system in order to acquire even more concrete guidelines. This would increase the similarities with design guidelines at product development, which have guidelines for specific sub-systems of the product (Volvo Cars, 2012a).

There were many decisions in the beginning of the study concerning the methodology. With different choices in the early phases, the outcome of the research would change considerably. One of the discussed alternative study approaches was to do a comparative design rather than a case study design. This implies the need of another case to study in order to compare the different cases. This could lead to a better result since the two cases might have different speciality areas. However, it is hard to get the hold of another case to study. Nonetheless, if the possibility would arise, a further research is suggested in order to improve the results. A second methodology decision concerned the interview structure. The chosen structure was semi-structured interviews, but the structured interviews were also discussed. With structured interviews the outcome would be more based on quantitative results, similar to the interviewee's placements of the aspects during the interviews, seen in appendix E. In order for this to be possible, the interview guide would have to be more direct and easier to summarise. The problem with the results would have been that the analysis of DGM index would be different, since a lot of the changes in the index were a result of the arguments of the interviewees. The aspects in DGM would be more similar to the initial checklist by Bellgran & Säfsten (2010), seen in appendix D. This means that the aspects would be less adapted to the processes at VCC, which can be seen as a decreased quality of the index. Because the outcome of the study is believed to be improved with semi-structured interviews, the confidence about the chosen approach is still high. Lastly, the data analysis strategy was discussed in the beginning of the research. An adapted version of *Grounded theory* was used instead of using an *Analytical induction* approach. With the use of the later, each interview would have been unique, since the hypotheses would change after each interview. The end results could possibly have been similar to the results in this thesis, but the workload would have been much higher. The interviews would not have been comparable either, since the hypothesis would change between the interviews. Hence, to choose an adapted version of *Grounded theory* is still believed to be the best choice when analysing the data in this research.

6.6 Impacts of DGM implementation

When looking at the present state at VCM, the implementation of DGM can increase the stability at ME, since the information sources is gathered in one master document. Though, not all documents are suited to be included in DGM. The product development requirements are not meant to be included since it explains too detailed information. However, it has been hinted by some interviewees that the implementation of DGM may decrease some of the requirements since it sometimes includes content that would better fit in the form of a guideline. With the lack of a guideline document it does instead end up among the requirements, which can be bad for several reasons. For one, the product developers might think that the requirements are not always accurate and necessary to apply. It also increases the number of requirements, which according to several interviewees are considered to be too vast. Another problem with the present lack of standardised processes is the amount of different strategies that exists. Many are contradicting and a strategy is usually pretty vague and lacks concrete information of how to act in certain situations. It is also interesting to reflect upon how DGM will change if the production system changes. If that there is a big change in the production system the whole sequence of the production flow will change making the BoP a lot different. However, unless the thought of how the production system should look like changes, DGM stays pretty much the same as it did before since it does not contain the actual tool of BoP, but rather a suggestion that the tool should be used. This makes the document more flexible to change than the actual tools. Though, it is important to keep the document updated because the perception of the perfect production system will change over time. These changes together with lessons learned should be implemented into DGM to keep the document valid and up to date.

The main question is to what purpose the design guidelines should be used at ME. If DGM is developed into general guidelines, the opportunity to reflect over the different issues and difficulties when designing an optimised production system is acquired. If the guidelines are even further developed and applied on sub-systems as earlier described, there might be even more concrete guidelines as a result. The problematic aspect with the latter is that this leads to several documents, which might lead to confusion of ownership and increase the management needed in order to develop the guidelines continuously. With one master document, the process of lessons learned and development of the guidelines are simplified. Even if one or the other direction is taken, DGM is now built on a valid foundation that has been confirmed in both the academic literature as well as within VCC. There are many opportunities to develop DGM and this study has enabled that.

6.7 Expected effects on sustainability

A further development of the design guidelines is also encouraged from a sustainability point of view. VCC can gain from the implementation of the guidelines on an economical level by standardising the work procedures, easier being able to spread information within the company and by having an easier way to make use of lessons learned. This can ensure that the projects are performed right the first time, which leads to saved money because problems are handled earlier in the process (Alfredson & Söderberg, 2010), and continuously improving the process with the help of lessons learned enables the possible to only make mistakes once. The guideline index also covers environmental issues, for instance under the aspect *"external environment"*. By further development of the aspect, the ecological sustainability is improved. Lastly, one of the main uses of DGM is to increase the communication within VCC. To be able to spread the objectives of ME with other departments and to take other departments concerns into consideration when making decisions at ME. This enables an increased social sustainability by encouraging the need for concurrent engineering to integrate the upstream and downstream groups of the company (Wheelwright & Clark, 1992).

7 Conclusion

In this chapter, the research questions are answered, followed by a suggestion of future research within the area.

The purpose of this master thesis is to improve the structure and standardisation of production development projects at ME. This is done by the creation of Design Guidelines for Manufacturing, a framework that aims to give guidance throughout the production development processes.

What aspects need to be considered in order to prevent complications and secure the success when carrying out a production development project at ME?

The approach in this thesis is to create an index with aspects that includes guidelines to consider when developing production systems. The index is developed through information collected from interviews with experts at ME and from literature, both internal and external. Lastly, the aspects are compared to the performance objectives at VCM in order to validate the aspects and to align them with the strategy of VCC. The result is DGM that consists of 23 guideline aspects within which guidelines and considerations about production system development exist. DGM is currently an unfinished framework that consists of the structure but lack the depth needed to give good guidance in production development. The aspect *"material flow"* works as a demonstration aspect, which means that the aspect is further developed in order to suggest future development of DGM.

How should the aspects be categorised and what needs to be included in the description of the aspects in order to ease the usage of the design guidelines?

The structure of DGM, seen in figure 25, is the result of a thorough investigation based on analysis of the data collected in this research. There are six categories, all which connect to departments of expertise within the category area. This eases the possibility for further development of DGM as well as the usage of the guidelines by clarifying the guideline index. Each aspect location under the categories is an outcome based on analysis of the importance, correlation and influence of the aspect. The aspects are presented with the three sections *what*, *why* and *how*, so that the user can easier understand and grasp the aspects. *What* contains a description of the aspect, which increases the users understanding of the aspect and thus eases the usage of DGM. *Why* is a motivation of the importance of the aspects, founded in the performance objectives at VCM. *How* consists of the guidelines and considerations that each aspect contains.

What factors affect the success of implementation of the guidelines delivered by this study?

After researching factors for successful implementation, both by gathered information from the interviews as well as information from academic literature, it can be concluded that there are several important key factors. First of all there are some important organisational issues that have to be considered. Since DGM is a new tool, there should be a presentation that explains the purpose and benefits of the tool for the first time users, followed by training that shows how it is used. *Why* in each aspect is a good starting point to present the importance of the tool, since it relates to the performance objectives at VCM. Also, it is important to allocate the responsible of the tool since "shared responsibility is no one's responsibility". Furthermore, the tool should be standardised into the work process in some way. If it is encouraged to use a tool but there is no requirement to do so, the tool will be left unused more often than not. Frequent usage should also be encouraged by managerial commitment. In addition to the organisational aspects regarding implementation, the layout of the tool is also important. The tool has to be simple to understand and to use. A document is a good format for an informational tool. The document should be simple and illustrative with a clear and standardised layout.

7.1 Future research

There are two parts of the future research of DGM. One of them is the research within each of the aspects that can be used for further development of DGM at VCC. This development can be done by assigning the aspects to the departments of expertise and let them fill the document with valid information, or by interviewing persons of interest that has good expertise in the area of the aspect. In both cases, the demonstration aspect *"material flow"* can be used in order to get a consistent appearance and content of the document. The depth of the aspects can also be narrower by applying DGM to sub-systems. This will lead to the divergence of DGM, creating several documents that all consist of guidelines for their specific sub-system. This would increase the similarity to the design guidelines used at product development, but it will also be harder to manage because the ownership of the documents will be spread between several departments.

The other part of future research that can be derived from this thesis is to investigate the applicability of DGM on other functions, companies or industries. This thesis has the delimitation not to investigate the applicability on other cases than on ME at VCC, but this does not mean that it is not possible to apply the guideline index on other functions, companies or industries. The guideline index is derived from a checklist by Bellgran & Säfsten (2010) and adapted to the situation at VCM. The possibility that DGM can be used and adapted on other cases is fully possible.

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Appendix A – Design Guidelines for Manufacturing, Material Flow

3.1 Material flow

What?

Material flow concerns the material handling activities in the production system. It is important to embed the material flow into the production system in an effective way. There are three second-degree aspects discussed under this topic, namely replenishment, re-packaging and material façade. These are more thoroughly described below.

- **Replenishment**: It involves the operations of bringing the material from the storage or unloading area to the point-of-use and returning empty packaging. The purpose is to design and implement the most cost efficient fork-lift-free replenishment method.
- **Re-packaging**: It regards deciding the most efficient re-packing method for one or a selection of parts. It can be achieved by transferring parts from the original packaging to a more appropriate size or type of packaging, using downsizing, kitting or sequencing. There are internal re-packing, which is done by internal personnel, and external re-packing, which is done by a logistic provider or by the supplier.
- **Material façade**: It is concerning the interface between material handling and the operator, e.g. in final assembly, the area between a production line and the aisle. The purpose is to decide and implement the most cost efficient material façade layout that has a maximum 80% filling degree.

Strive towards involving logistic engineers in early phases of production development. This will ensure that the design is smart in terms of material delivery interfaces.

Why?

This aspect is relevant and important to take into consideration since it relates to and affects the VCM performance objectives as follows:

- Cost: Material flow is affected by cost in several different ways, for instance, higher work in progress increases the cost, transportation costs of the material, man-hours can be decreased with a better material flow design, packaging can be optimised regarding the cost, the space needed for storage can be decreased, etc.
- Delivery: With a more effective material flow, the production can be secured by ensuring that the material needed in production is always available.
- Medarbetare: The interaction between workers and material flow is a safety issue, for instance, the material flow routes should not intersect with the walking routes of the employees to avoid safety issues.

How?

3.1.1 Replenishment

Vision

- Minimise handling and administration work.
- Deliver the right material and amount on the right place, on the right time with right quality.
- Fork-lift free line feeding.

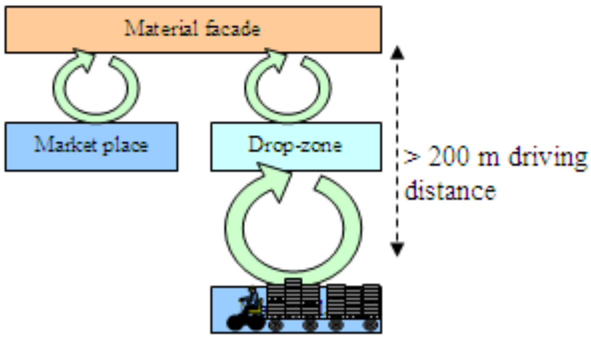
Strategy

- Assure efficient replenishment by using flexible routes, group balancing and route planning.
- Automated line feeding for modules with: low unit load, high frequency of transport and long distance & voluminous packaging.
- Fool proof system for sequential rack supply.
- Access to all points of use.
- Fork-lift safe/free line feeding, start with solutions for standard packaging and small sequential racks (<450 kg) in highly populated areas and after that continue with other areas.

Execution

Fork-lift-free replenishment
Replenishment could generally be done with or without forklift. The aim is to have all material replenished Fork-lift-free (FLF). Therefore, the production system should be developed to support FLF delivery of the material. This leads to several benefits such as improved safety and efficiency, reduced amount of transports, cheaper replenishment equipment, less maintenance cost of packaging, etc. All packaging (pallets and racks) should be put on wheels (FLF). If manual handling is needed to put the packaging on line, the max weight is limited to 450 kg due to ergonomics.

Distance from market place
Plan the production system so that the distance between market place and the point-of-use. If the distance is too large (>200 meters) a drop zone might be considered, which has to be considered in the designing face of the production development process.



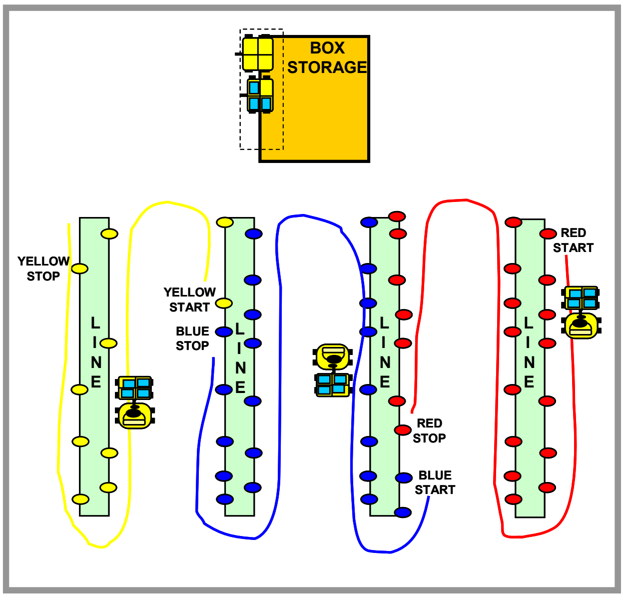
Accessibility
Always strive towards placing the delivery in rear end of the machines, out of the way of the operators. This leads to no production stop while stocking the material. Plan the layout so all delivery points are accessible. There should be no dead-end aisles and the aisle design should allow 180° turns between two aisles. The truck roads needs to be planned in such a way that the drivers easily can deliver material and then continue driving

Automated replenishment
If cost efficient, automate the replenishment but be aware of the flexibility. Automated line feeding should only be used for modules with: low unit load, high frequency of internal transport, long internal distance and voluminous packaging.

Route planning, group balancing and flexible routes
Three enablers to create an efficient replenishment set-up:

- Route planning: Define a total workload considering the delivery addresses and the time parts are needed at line side. The aim is to decrease the total travel time and to define the most optimal delivery route for the total workload.
- Group balancing: A group of operators have a common responsibility to perform replenishment tasks within a predefined area or flows. The aim is to reduce balancing losses (waiting time).
- Flexible routes: In flexible routes the number of deliveries is normally the same but the starts and ends are varying every replenishment cycle. All routes usually start at the same predefined time (e.g. every 60 minutes). The last route is the only route that has a varying working load. The aim is to sum up all balancing losses in the last route and use this time for value adding activities. All other routes are fully balanced.

An illustration of a set-up with route planning, group balancing and flexible routes are shown below.



The routing example shows how the blue and red route works 100%, but that the yellow route delivers the remaining orders and can be used for other value adding activities.

Replenishment efficiency

To reach an efficient replenishment process the non-value added work must be kept to a minimum. Examples of non-value added work are driving, reading information, handling, waiting time, etc. Design factors to get lean are; short driving distance, minimal handling, no waiting time, several orders are grouped together in one route. In the picture below, examples of efficient replenishment time in different flows are presented. The data comes from solutions at Ford, Mazda and VCC.

Replenishment method	Minutes/unit
1. Pallets	4,0
2. Seq. Racks	2,0-4,0
3. Small boxes	1,0
4. Int. transports	2,0-4,5

3.1.2 Re-packaging

Vision

- To have the same packaging from supplier to material façade, unless it is cost efficient to re-pack.
- Minimal handling and administration work.
- Locate the re-packaging at an optimal place.
- Optimal space utilisation.

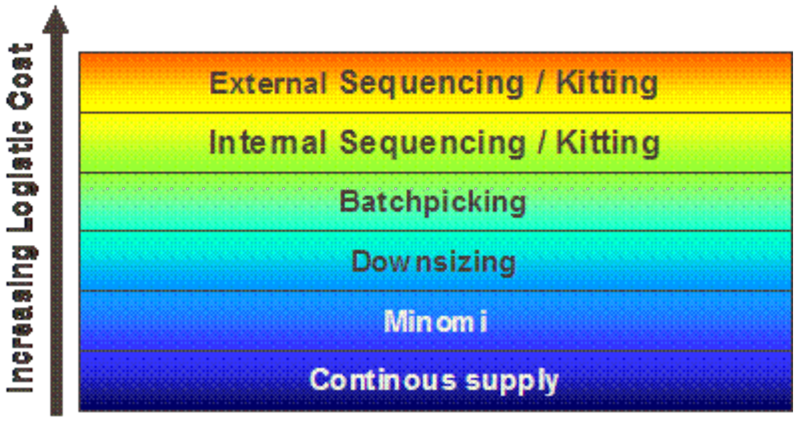
Strategy

- Choose the most cost efficient re-packing method (downsizing, kitting, internal sequencing, external sequencing).
- Place the kitting and internal sequencing area as close as possible to the point of use.
- Centralise the re-packing areas and/or organisation (or increase work content for operators if not line balanced).

Execution

Re-packaging methods

Different re-packing method could be used. The cost matrix for different packaging and supplying methods, seen below, indicates the methods that normally should be chosen concerning logistic cost, but of course the total cost must be considered.



For further description of the re-packaging methods, see logistics documented descriptions at BMS.

Re-packing locations

Kitting and sequencing areas should be located as close to the point of use as possibly. The reason is that the efficiency increases concerning:

- Inventory reduction
- Lead-time reduction for replenishment (order-to-delivery)
- Manpower needed for replenishment
- Number of special types of packaging needed in flows.

The first choice should always be to locate as close to production as possible.

1. In material façade to utilise free space and opportunity to cut balancing losses for operators and/or decrease workload for operators.
2. If not possible directly in material façade, look for free areas nearby.
3. Install specific kitting areas or outsource this operation. The decision must be based upon a business case.

However, always consider local conditions and requirements, such as fork-lift-free replenishment.

Centralise the re-packing areas and/or organisation (or increase work content for operators if not line balanced) to gain efficiency. The reason is that the efficiency increases concerning:

- operator balance
- needed equipment
- replenishment
- production operator ergonomics
- increasing work content for production operator .

Re-packing efficiency
To reach an efficient re-packing process the non-value added work to perform the picking must be kept to a minimum. Examples of non-value added work are reading picking information, walking time, handling of packaging, etc. In the picture below, efficient re-packing times with different re-packing methods are presented. The data comes from solutions at Ford, Mazda and VCC. To reduce the time needed to transfer picking information a pick-to-light system is preferable.

Re-packing method	Seconds/part
1. Downsizing	0,2 - 0,5
2. Batch Picking	2 - 5
3. Kitting	5 - 10
4. Sequencing	10 - 20

3.1.3 Material façade

Vision

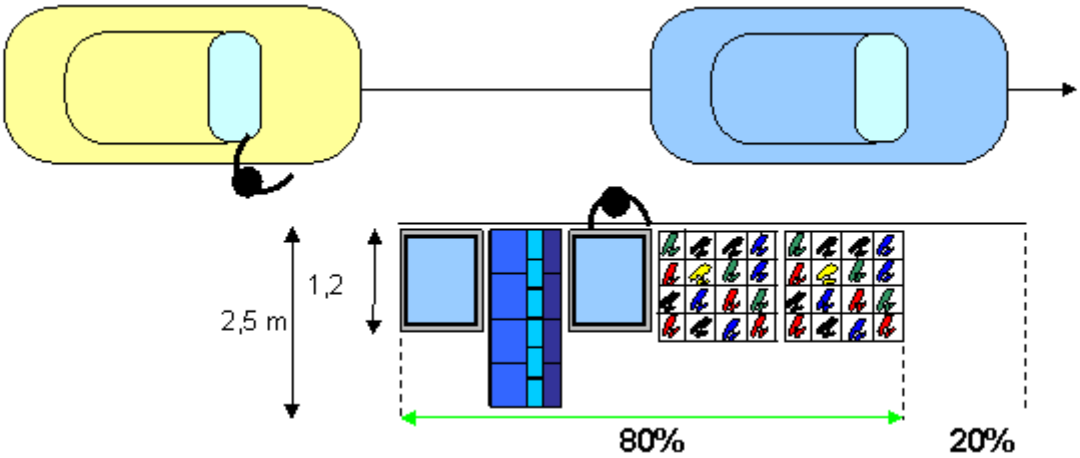
Strive towards decreasing none value-added work performed by the operators and obtain a maximum 80% filled material façade.

- Maximum 80% filling degree in the material façade.
- One pick place and no handling of packaging by the operator.
- Line side is only utilised for materials and equipment needed for production.

Strategy

- MP&L together with ME & production will choose the most cost efficient packaging method to support the maximum 80% filling degree.
- Decrease non-value added work performed by the line operator with the packaging and group parts to create one picking places.
- Standardised height of the assembly lines.
- All points should be accessible for material handling with equipment needed for replenishment.
- Line equipment shall easily be movable.
- Materials and equipment needed for direct production have priority 1 in the material façade.
- Initially aim to utilise smallest boxes that holds 2 hours of production, which in practice could be decreased depending on logistic and material façade set-up.

Execution



Filling degree of material façade
The total goal for the material facade set-up is an 80% filling degree. This is just a mind-set and for specific workstations it could vary from 0 to 100% due to production set-up and cost aspects. The general aims are to:

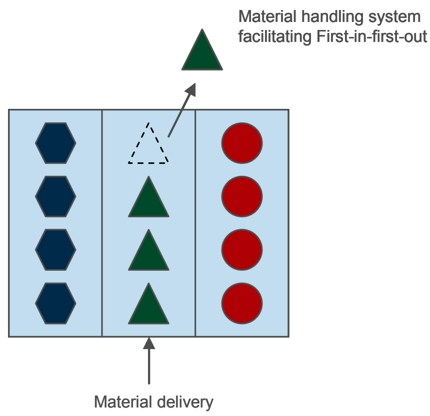
- Facilitate a flexible set-up for quick changes of materials between stations.
- Be able to bring in new projects/products and meanwhile increase the filling degree above 80% but aiming to continuously work to go below 80% again.

Accessibility of material
It is also important to design the material façade with one pick place. This means that parts are grouped in the material façade to decrease walking and picking time. Parts could be grouped by variant or in another efficient way. The aim is to decrease the non-value added work done by the production operator.

- The operator has to easily be able to choose and pick the right parts.
- The information given to the operator should be done in a way so that picking errors are avoided.
- The operator should easily reach the parts (short distance).
- The material facade should support minimal walking distance for the operator.
- Decrease the non-value added work by the operator.

Control principle
The material flow of the company should be customer order driven to as high extent as possible. This means that production should start when a customer has placed an order and no products should be produced for storage. Focus on total efficiency and make only what is demanded from the next operation.

One way to reach and support this control principle is to design material handling equipment in smart ways. The picture to the right shows a material handling design that clearly shows when a part has been removed and indicates the delivery need of a new part. If all the parts had been randomly mixed in the box, it would be much harder to keep track on the delivery need. This design also supports the first-in-first-out approach, which is favourable since it ensures that the oldest part is being processed first and it also supports pull scheduling.

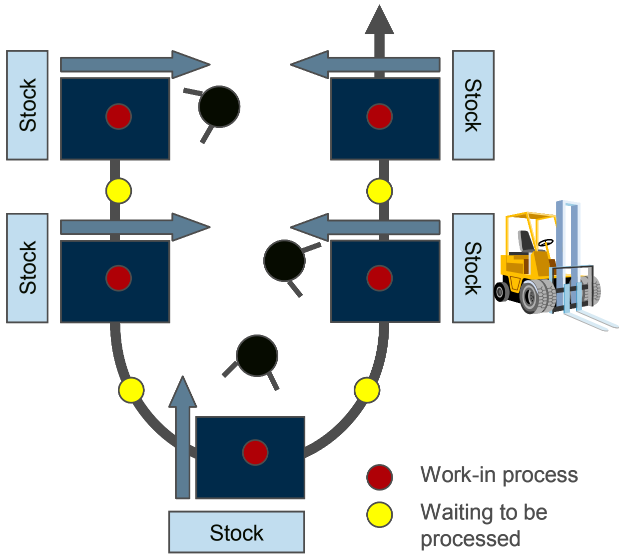


Buffers & Work in Progress

Strive towards a design of the production system that facilitates for a production with a batch size of one part. This will reduce the Work In Process (WIP), increase cash flow and make defect detection easier.

Also, strive towards designing the system so that operations run with no more than one product between operations in order to reduce WIP and ease the process of tracking defects back through the process.

Both of these points strongly affect the material façade and the need for space next to the production line.



Appendix B – Interview guide

1. Facesheet

Name:
Age:
Gender:
Years at VCC:
Work title:

2. Introduction questions

What is the main responsibility of your department?
With a short description, what is your work assignment? What specifically is it that you do?

3. Placing the aspects

Take a look at the different aspects and place them under a suitable heading. Start with the aspects that you think is most important from your point of view.

Why did you place the aspect under the specific heading?
Can you please describe what should be included under the aspect?
Can you please motivate if and why the aspect is relevant when developing a production system?

4. Additional aspects

Can you think of any additional aspects, not covered by the already existing ones? Please try to come up with five new aspects.

How would you motivate the aspect and its placing?
Can you please describe what should be included under the aspect?
Can you see any connection to an already existing aspect? If yes, how do they correlate?

5. Implementation

Can you think of any helpful but rarely used document at your department?

- If yes, why do you think this is the case and what factors could be changed in order to increase the usage of the document?
- If no, what do you think is the reason that the documents are successfully used?

If you were the creating guidelines, how would you deliver them in order to secure the successful usage of them?

If you were the one receiving the guidelines concerning your day-to-day activities, what factors do you think would affect your usage of the guidelines?

Appendix C – Interview description

The purpose of this research is to find general guidelines that can help the work process for developers, making their projects to develop production systems easier and also to standardise and simplify the projects. The study is interested in a high level perspective, with a focus on the possibility to generalise the work process.

This is an interactive interview. After the initial questions concerning standard personal information, the interviewee is asked to place several post-its under six different headings. On each post-it there is an important aspect to consider when developing a production system. Examples of what the aspects consists of are level of automation, operation sequence, investment policy, safety etc. The aspects should be placed under the headline it has the closest connection to from a production development point of view. The headings and their meanings are described below.

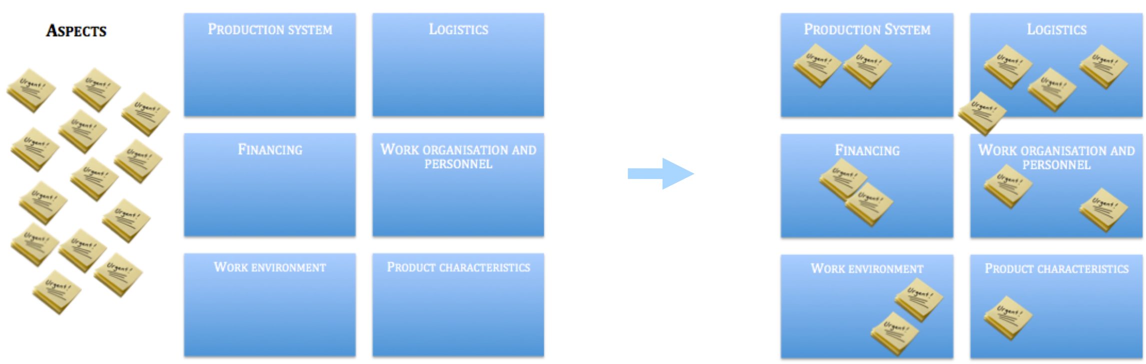
- Production system: *Contains the aspects that concern the stations and the process of production.*
- Product characteristics: *Includes the product oriented aspects.*
- Logistics: *This heading contains aspects concerning the traffic of material.*
- Financing: *Includes the aspects that involve the financial aspects of the production development.*
- Work organisation and personnel: *Treats the relationship between the organisation and the personnel.*
- Work environment: *Embraces the relationship between the workers and their stations.*

When the interviewee places each of the aspects, they are asked to explain their choice, describe what they think is included under the aspect and to motivate if and why the aspect is relevant when developing a production system.

When the discussion about the aspects is finished, the interviewee is asked to come up with 5 new aspects, not covered by the already existing aspects. They are also placed by the interviewee under a suitable headline. Once again, the interviewee is asked to motivate the choices.

At the end of the interview, there are a few questions about the implementation of guidelines and standardised processes.

The picture below clarifies the process of how the post-its should be placed under the headings.



Appendix D – System Aspects checklist by Bellgran & Säfsten (2012)

Production engineering

Production layout
Level of automation (dynamic)
Flexibility
Production volume
Product Life-Cycle
Number of product variants
Cycle time, lead time, change-over time
Availability, reliability
Separation of production processes
Disturbances
Modularisation
Operation sequences
Tolerances
Production process demands
Reliability – equipment
Spare parts
Tool supply
Follow-up system

Material handling

Control principle: push/pull
Work in progress, buffers
MRP-system
Information system
Handling equipment, handling volumes
Material and product flows
Queuing time
Transport, transport time
Inventory capacity, routines
Quality control

Plant and equipment

Plant characteristics: floor, ceiling, pillars, truck roads etc.
Layout planning
Equipment
Stores
Media
Capacity
Personal premises

Financing

Investment level
Method of calculation
Pay-off time for machines/equipment
Offer inquiry
Staff turnover
Absence cost
Profitability demands
Life-cycle cost, Life-cycle profit

Work organisation and personnel

Type of work organisation, team work
Available personnel, personnel structure
Education, training
Competence, personnel flexibility
Information
Attitudes, creativity, adaptability for changes

Work environment

Physical environment
Man-machine, ergonomics
Safety
Noise, vibrations, light
Chemical health risks
Psycho-social work environment
Stress level related to work tasks
Cleaning routines
Work studies

Market – Strategic level

New markets, market demands
Competitors, Customers
Price level, stability, prognoses

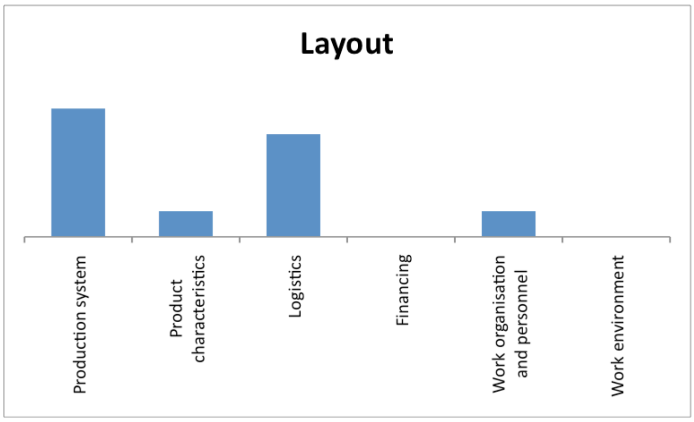
Company – Strategic level

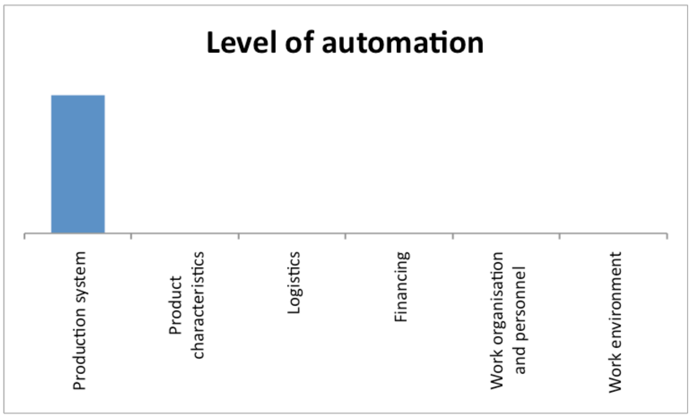
Company strategy, future plans
Investment policy
Resources, competences
Core activities
Make or buy strategy

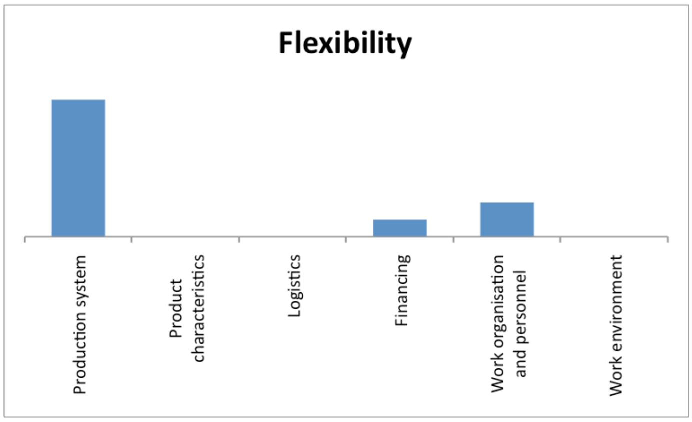
Product concept

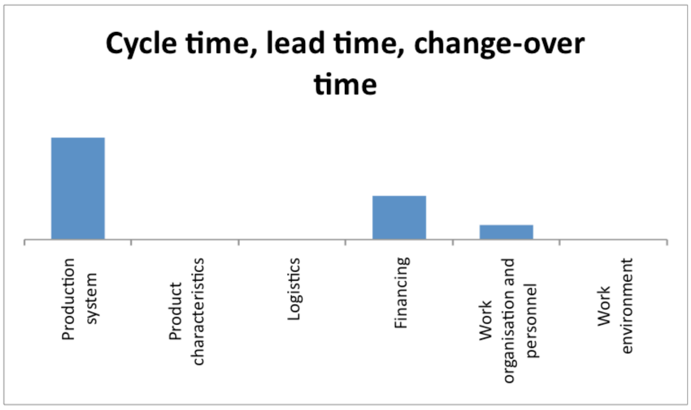
Price
Quality, Design
Product mix, product complexity
Delivery time, delivery precision
Customer adaptation

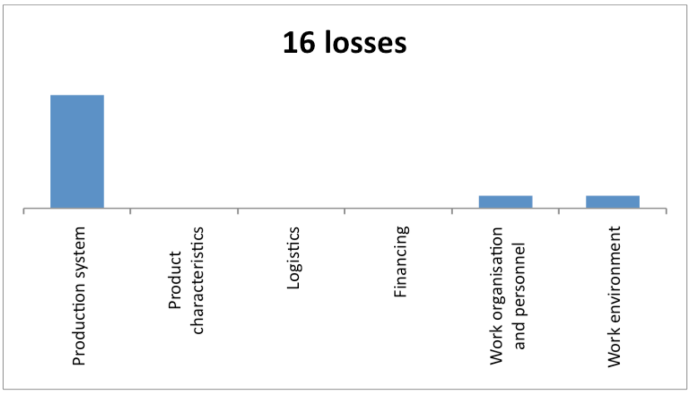
Appendix E – Interviewees' placements of aspects

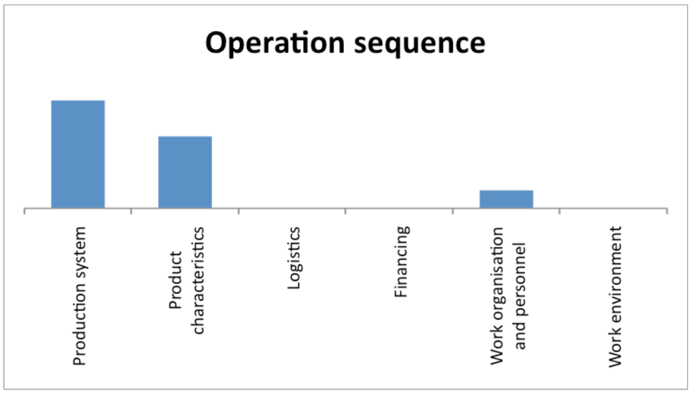


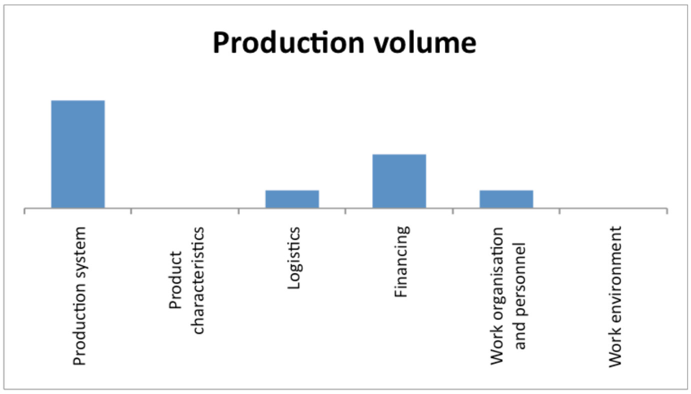


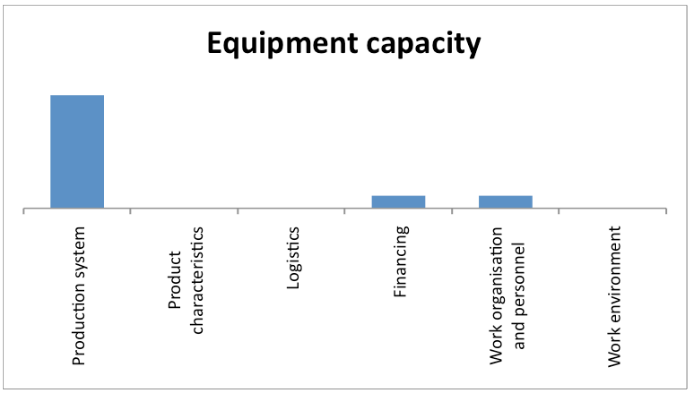


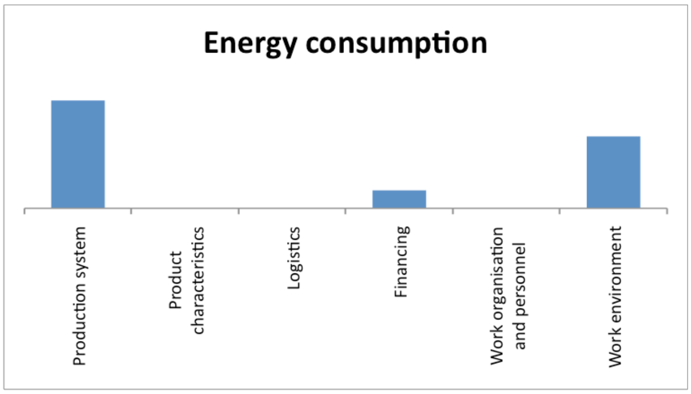


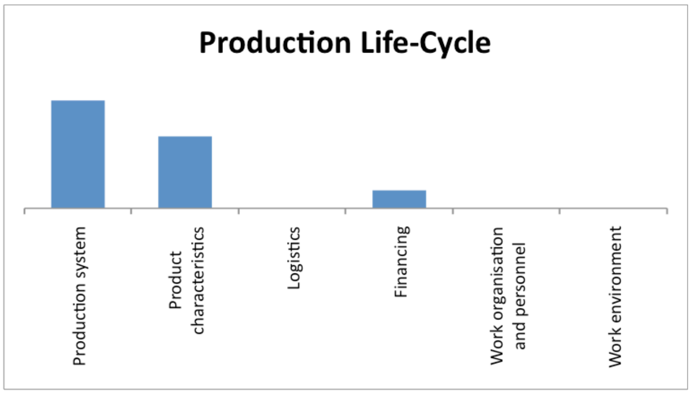


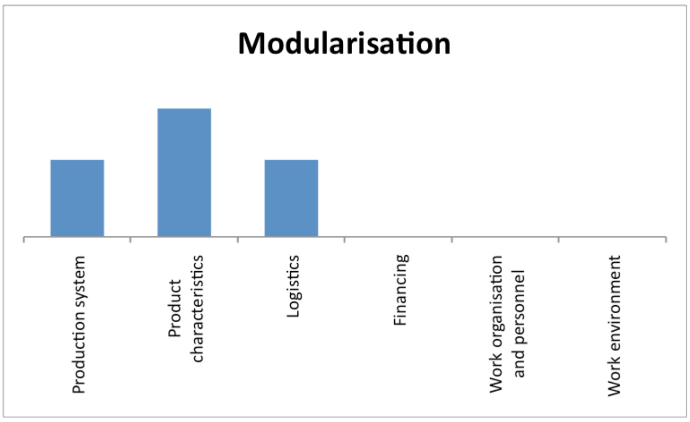


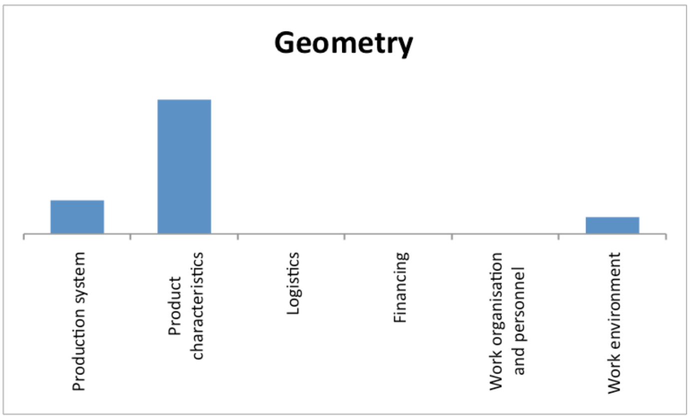


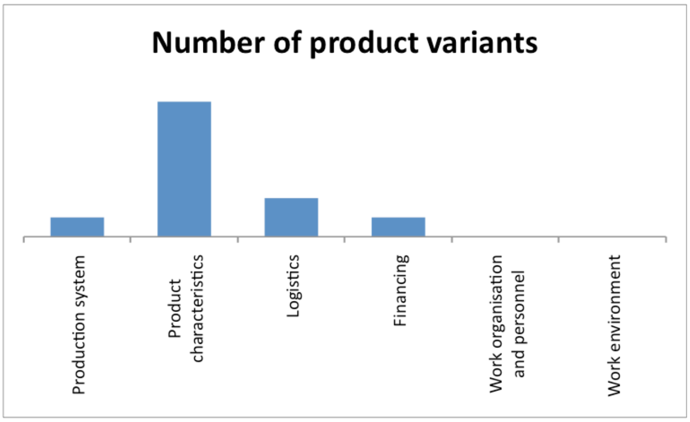


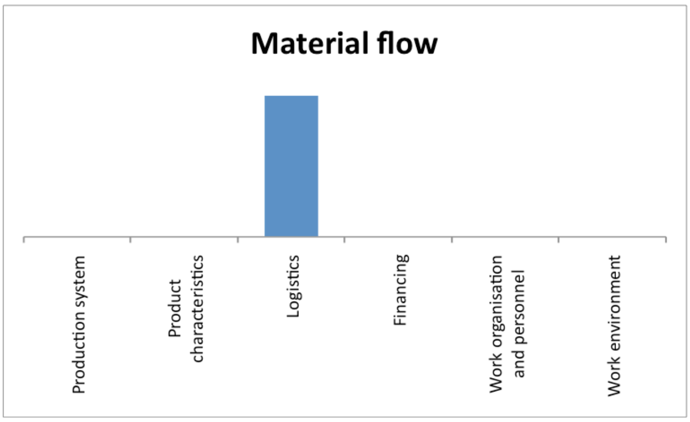

Energy consumption
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

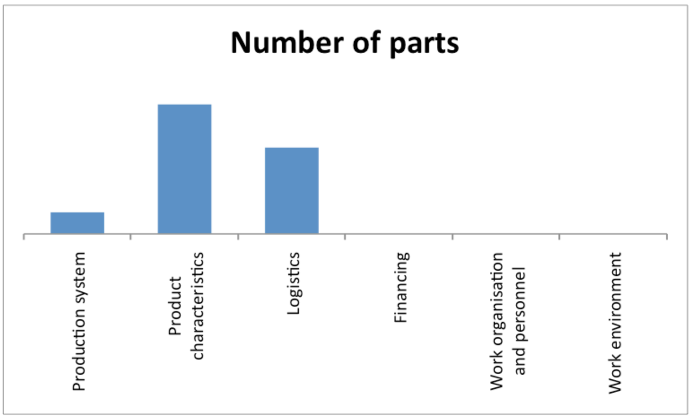

Production Life-Cycle
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

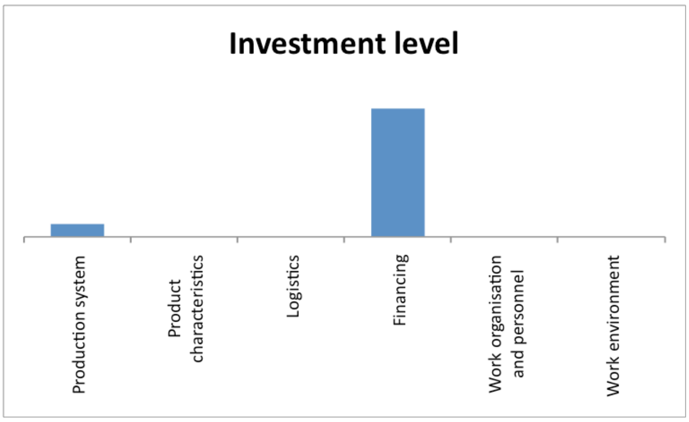

Modularisation
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

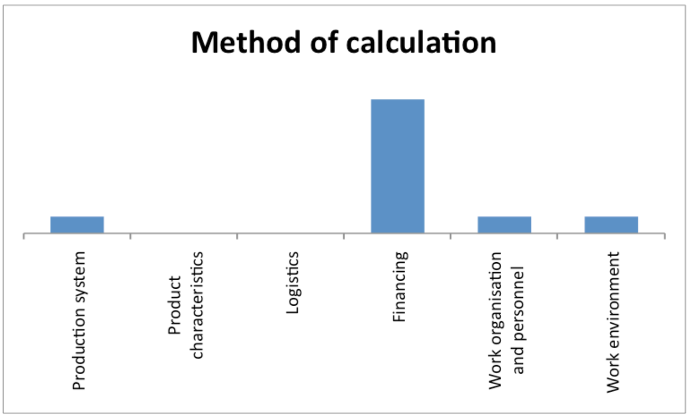

Geometry
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

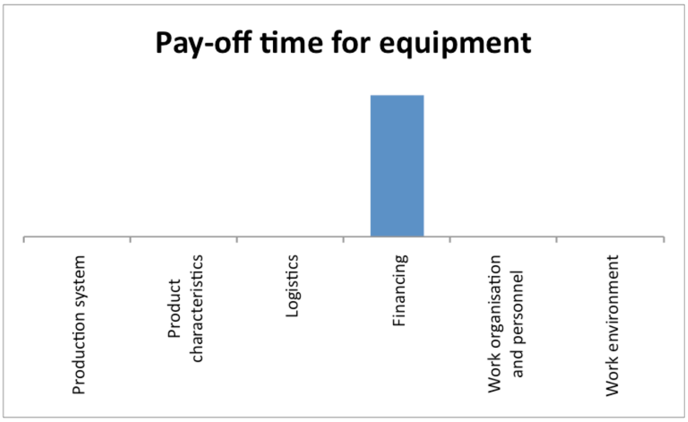

Number of product variants
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

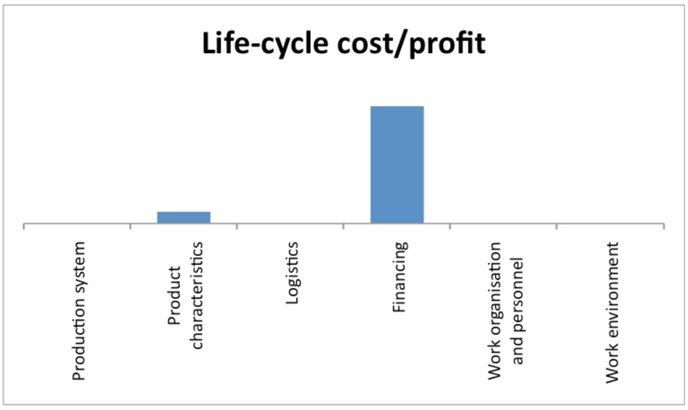

Material flow
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

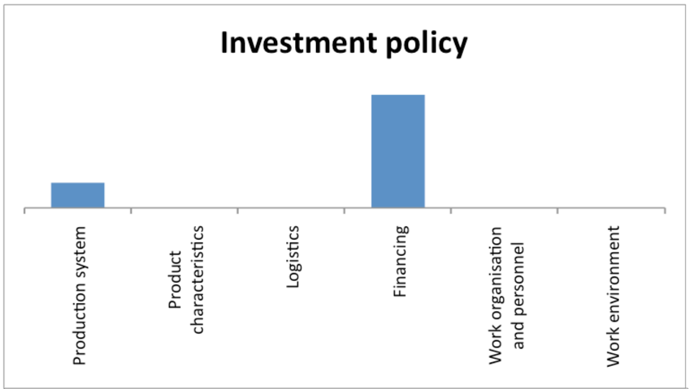

Number of parts
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment


Investment level
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

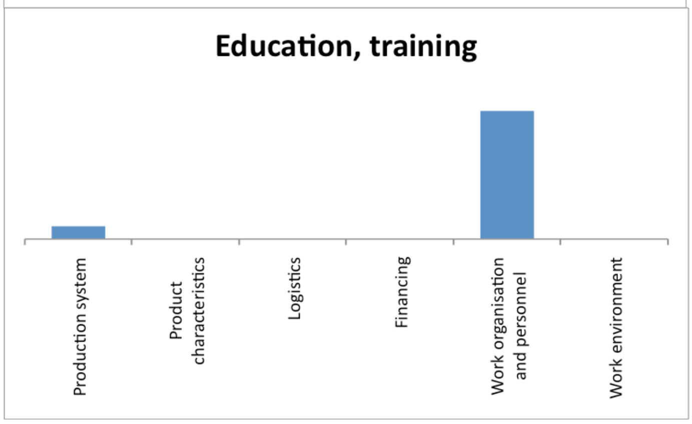

Method of calculation
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

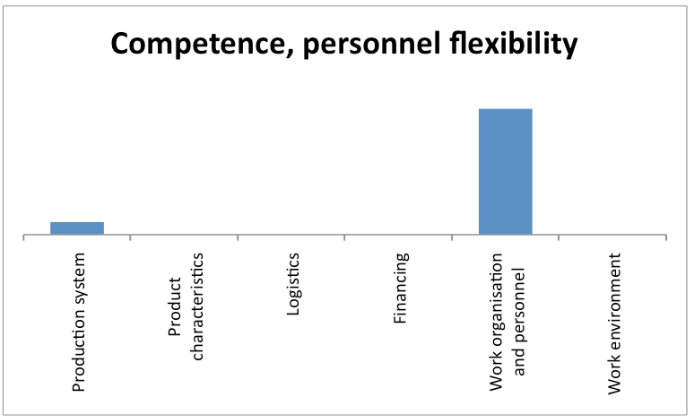

Pay-off time for equipment
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

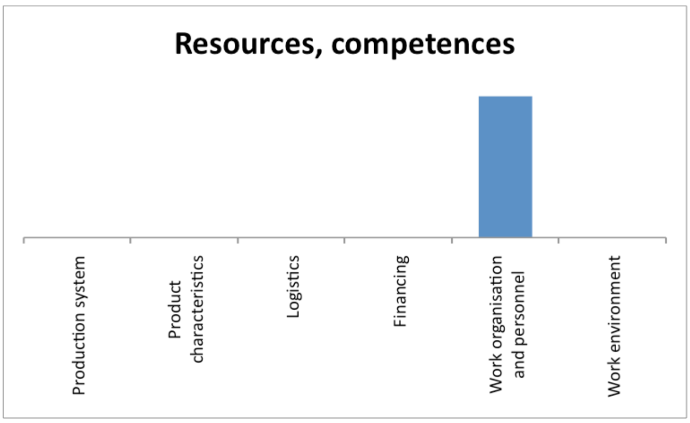

Life-cycle cost/profit
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

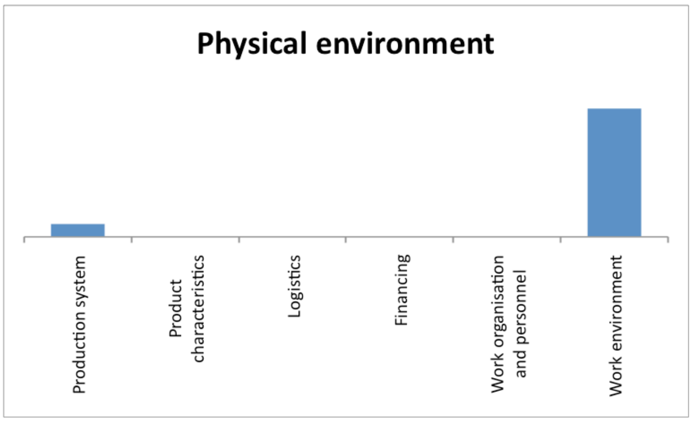

Investment policy
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

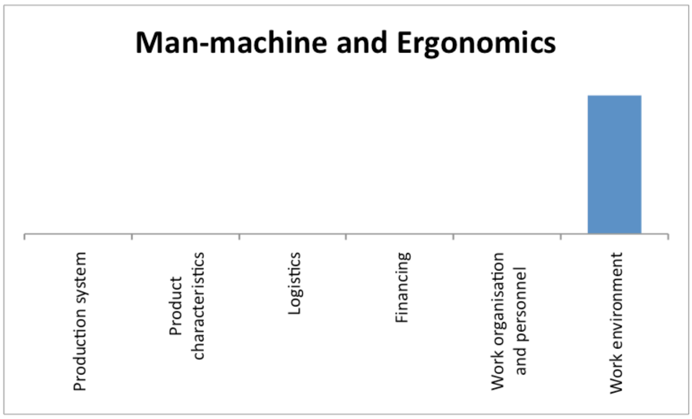

Make or buy strategy
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment

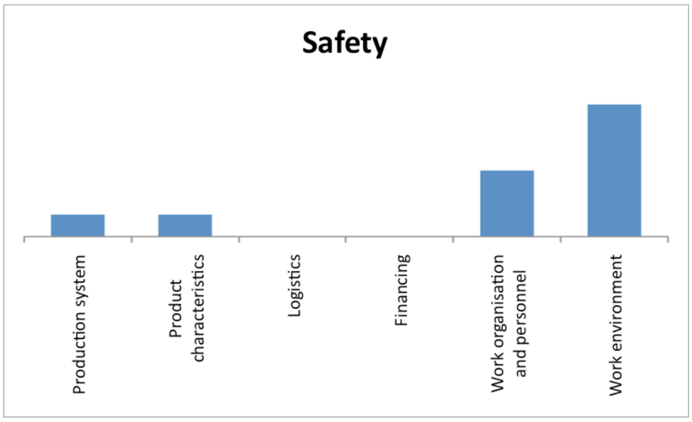

Education, training
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment


Competence, personnel flexibility
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment


Resources, competences
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment


Physical environment
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment


Man-machine and Ergonomics
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment


Safety
Production system
Product characteristics
Logistics
Financing
Work organisation and personnel
Work environment