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Automotive Manufacturing Engineering Process Development

A case study of CEVT to determine a critical path and improve process efficiency

Master's thesis in Quality and Operations Management

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Cover:
The Lynk & Co 01. Entirely developed by China Euro Vehicle Technology AB, the subject of this study.

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Abstract

A manufacturing engineering function acts as the link between R&D and manufacturing, and it must accommodate and balance the needs and requirements of both. In the automotive industry, requirements can change rapidly, and the function must be able to manage such change efficiently.

With increasing market volatility, there is a constant demand to shorten development lead time and manage changes occurring in the development process. Strict requirements and demanding customers increase complexity, requiring the collaboration of people in different fields of knowledge to successfully meet the market demands. CEVT, acting as an innovation center for the Geely Group, need to continue to improve their development speed and flexibility to stay competitive in the market.

The purpose of this study is to investigate possibilities and deliver concrete suggestions for lead time reduction within a manufacturing engineering function without compromising the output quality of the processes. Increased flexibility has previously been identified as a possible prerequisite to reduced lead time. To fulfill this purpose, three research questions were established. The first question aims to determine the critical path of the manufacturing engineering development process. The second question examines barriers to a more efficient manufacturing engineering process, focusing especially on the critical path activities. The third and final research question explores how the process can become more efficient and flexible.

To answer the aforementioned research questions, the method applied uses qualitative data. The data is mainly derived from interviews with people in the organisation, both engineers, managers, and field experts. Existing process maps and descriptions along with useful data from the CEVT intranet are also used to establish a comprehensive view of the current situation.

The study shows that the virtual analysis of manufacturability is the primary bottleneck activity of the process. It is the activity that is the most dependent on parties outside of the manufacturing engineering function and where efficient collaboration is essential. Inadequate communication, insufficient use of best practices, and cultural differences are identified as barriers in that they generate double or unnecessary work. Whereas the cultural differences mainly are important to be aware of, communication and work practices can be improved. Three possible areas of identified and discussed. A culture and mindset emphasising the benefits of continuous and direct communication need to be established. Work practices must be better adapted to the reality of the process and organisation. A more holistic organisational restructuring is also examined considering the interdependencies of manufacturing engineering and R&D. Important to underline is that the study focuses on improvements and not what already functions well within the organisation.

Keywords: manufacturing engineering, critical path, agile product development, automotive industry, process efficiency, flexibility, cultural differences, communication.

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This Master's thesis was conducted during the spring of 2020 to conclude five years of engineering studies at Chalmers University of Technology. It has given us the chance to apply our developed skills to a very interesting organisation and subject, and we can honestly say that we have learnt a lot.

At CEVT, we were welcomed with truly open arms and their support has been vital to the project. We encountered several very helpful and friendly individuals to whom we owe our greatest gratitude and who have inspired us throughout the project. In particular, we would like to thank Gigi Cheung, our supervisor, who has guided us and who was always there to answer our questions; Charlie Berner, with whom we have had a lot of good discussions, especially in the beginning; and Natalie Andersson and Marija Bozic, without whose input the project would not have possible.

We would also like to acknowledge the people outside of the CEVT manufacturing engineering organisation who have taken the time to talk to us. The meetings with Mr. Kim and Dr. Matz at Geely in China were particularly encouraging.

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Axel Ihrfelt & Johan Johansson
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Abbreviations

BIW	***Body-In-White*** – A Manufacturing Engineering function responsible for the second assembly phase where the body of the car is produced.
CAD	***Computer-Aided Design*** – Digitally-based design and creation of technical drawings.
Community of Practice	A role or topic-based group of people sharing ideas and best practices.
FMEA	***Failure Modes and Effects Analysis*** – A standardised method for predicting possible failures, evaluating their consequences and suggesting appropriate measures to avoid them.
KPI	***Key Performance Indicator*** – A metric used to measure the performance of an organisation or activity.
ME	***Manufacturing Engineering*** – A function at CEVT responsible for ensuring the manufacturing feasibility of new products developed.
PSS	***Product System Structure*** – An organisational structure of adjacent parts with large dependencies grouped together.
TCF	***Trim & Car Final*** – A Manufacturing Engineering function responsible for the final step of the assembly process in which the car is completed.

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1. Introduction

This chapter introduces the reader to the context of the automotive industry, vehicle development, and the particular setting of the company to be examined, CEVT. It includes a brief description of the manufacturing engineering function. The aim of the study and a specification of the issue are also presented.

1.1. Background

Vehicle development is an expensive and intricate process, requiring people with extensive technical knowledge in many different fields to collaborate in creating a car, or parts thereof. Strict legal requirements concerning for example safety and emissions, combined with demanding customers, increases complexity and drives development lead time. In a competitive market where customer requirements changes constantly and technological advancements are rapid, companies need to have development lead times comparable to or better than their competitors (Clark & Fujimoto, 1989). To reach the market as quickly as possible, car companies are always looking for ways to improve their speed and flexibility in the development phase.

The automotive industry is characterised by heavy R&D expenditure, accounting for over 25 percent of total R&D investment in Europe in 2018 (ACEA, 2018). The industry is facing several challenges and trends that will have an impact on the global automotive market. Kuhnert, Stürmer, and Koster (2018) argue that the car of the future is electrified, autonomous, shared, connected, and yearly updated. For example, changes in the behavior of users and manufacturers will lead to an increase in mobility options in the form of car-sharing concepts. Competition here will come from both traditional car manufacturers who can offer subscription models for their cars, and ride-hailing services like Uber (Kuhnert et al., 2018). To face these trends, investments of an estimated 400 billion USD over the next five years is required (Ewing, 2019). Other challenges changing the competitive reality include rigorous fuel efficiency and emission policies (Ewing, 2019), as well as increasing pressure from Chinese car manufacturers (Kuhnert et al., 2018). The entire industry is currently being realigned, and car manufacturers all over the world need to accelerate their product development to not fall behind (Kuhnert et al., 2018).

The substantial investments required to survive in the increasingly competitive market has led to many carmakers forming alliances to share development costs (Ewing, 2019). The projects in these alliances can focus on developing new technologies and drive systems for electric and autonomous cars, but they can also be aimed at delivering new car models to market. Even though smaller collaborations are commonplace, large-scale alliances are considered essential for the success of carmakers in this transformative era (Ewing, 2019). Many of the largest car manufacturers in the world are part of larger groups, including the Volkswagen Group with brands like Audi, SEAT, and Porsche (Volkswagen AG, n.d.), Hyundai which also owns Kia

(Hyundai Motor Group, n.d.), as well as Fiat Chrysler Automobiles (Fiat Chrysler Automobiles, n.d.). This is also true for the target of this study, CEVT.

China Euro Vehicle Technology AB (CEVT) is an innovation center fully owned by the Geely Group (CEVT, n.d.). The Gothenburg-based company works with modular development, advanced virtual engineering, and software development to deliver new technology to all of the Geely Group brands, including Volvo, Polestar, Geely, Proton, and Lotus. Their primary customer, however, has throughout its existence been Geely Auto Group. Having a separate company doing R&D for the entire group based on modular technology allows for specialisation and centralisation of competence in combination with the efficiency of economies of scale. One of the biggest deliveries of CEVT was the Compact Modular Architecture, a platform now used in the Volvo XC40 and other compact cars built by the group (CEVT, n.d.). The R&D organisation of CEVT has also fully developed the Lynk & Co 01 and 02, two models from an entirely new brand launching in Europe in late 2020.

Manufacturing Engineering (ME) is a function at CEVT responsible for ensuring the manufacturing feasibility of new products developed. Charlie Berner (personal communication, 2020-01-22), a module team director at the function, explains that the ME process is complex and integrated, requiring communication and information from all parts of R&D. Berner exemplified this by stating that most of the work of the function is done before the construction of physical parts in virtual analyses, where ME through several six-week iterations verifies data and software models in collaboration with R&D. Due to increasing market volatility, Berner stresses that this and all other processes are in constant need of reducing lead time and managing late changes.

Later stages of ME development, such as assembly instructions and other processes involving physical parts, have according to Berner (personal communication, 2020-01-22) partly been moved outside of CEVT to be conducted by the group car companies themselves. He states that it is in these later stages that changes become increasingly expensive, as the changed tools and parts may have to be re-ordered. Berner therefore explains that it is critical to be efficient in the early stages of parts development to keep costs down.

1.2. Aim and Specification of Issue Under Investigation

This thesis project aims to investigate possibilities and deliver concrete suggestions for lead time reduction within the ME function without compromising the output quality of the processes. The function has previously identified increased flexibility as a possible prerequisite to reduced lead time which is why the project is in part focused on examining that idea.

To provide concrete and tangible suggestions to reduce lead times, the project is conducted in a set of sequences. It is first necessary to understand the system and process as it functions today. This information is then used to identify which activities are critical to the overall lead times of the process. Once these activities are identified, it is possible to analyse what drives lead times in the process. The final step is then to provide improvement suggestions.

With the limited time frame and resources available for this thesis project, it is important to focus the efforts where the potential for improvement is the greatest. Certain activities within the process are likely to influence the overall lead time more than others and those activities must be identified for the final suggestions to be meaningful. For this purpose, an analysis of the critical path is conducted. This requires a profound understanding of the process, including important tasks and activities. Through such an analysis, it is possible to prevent ME from wasting resources in improving activities not hindering the process.

The process of reducing lead times in the ME process does not stop after locating the problem, it is also necessary to investigate the reasons behind excessive lead times and delays in the process. Identifying the root cause is an important step in effectively providing solutions to the issue. Initial talks with Berner (personal communication, January 22, 2020) indicates that a possible cause is the lack of complete and often tardy information from different functions of R&D that is required in the ME process. This incomplete information hinders ME from performing thorough enough analyses, requiring costly rework and leading to project delays. There may be other causes of the problem as well, and this is examined and analysed further during the project.

The ME process is constructed so that the first phases are virtual, meaning that no physical equipment is built or needed. It is first later in a project that actual tooling is ordered and produced. Consequently, the costs of making changes to designed equipment are much larger later once the process becomes physical. To avoid higher costs due to changes required in the later stages of the development process, it is critical to create high quality solutions in the virtual phase. This is according to Berner the idea (personal communication, January 22, 2020), but it is not always the case.

Any changes made in order to reduce the lead time of the process must be done with output quality in mind. Throughput speed in one activity should not be increased carelessly, driving development costs in later stages. Changes are possible at a low cost in the virtual phase and dealing with change efficiently is a possible way to assure high output quality. In a previous master's thesis conducted at CEVT ME (Gyllenhammar & Yousif, 2018), agile methodology was identified as a way to create a higher level of flexibility by responding better to changes. This assumption is to be examined further in the study.

The research questions this report aims to answer therefore are:

1. *What is the critical path of the manufacturing engineering development process at CEVT?*

2. *What are the barriers to a more efficient manufacturing engineering process, with specific regard to the identified bottleneck activity?*

3. *How can the identified bottleneck activity be improved to reduce lead times and make it more flexible without compromising quality?*

2. Theoretical Framework

The purpose of this chapter is to provide an overview of previous research conducted and to enhance the understanding of important aspects of the topic. The framework is built upon relevant literature collected iteratively during the project and it acts as the foundation for the analysis of the results of the case study as well as the discussion. The chapter covers several themes, with the structure and connection to the research questions illustrated in Figure 2.1. Together, the themes provide the reader with a comprehensive view of the theory needed to understand the results and conclusions of the study.

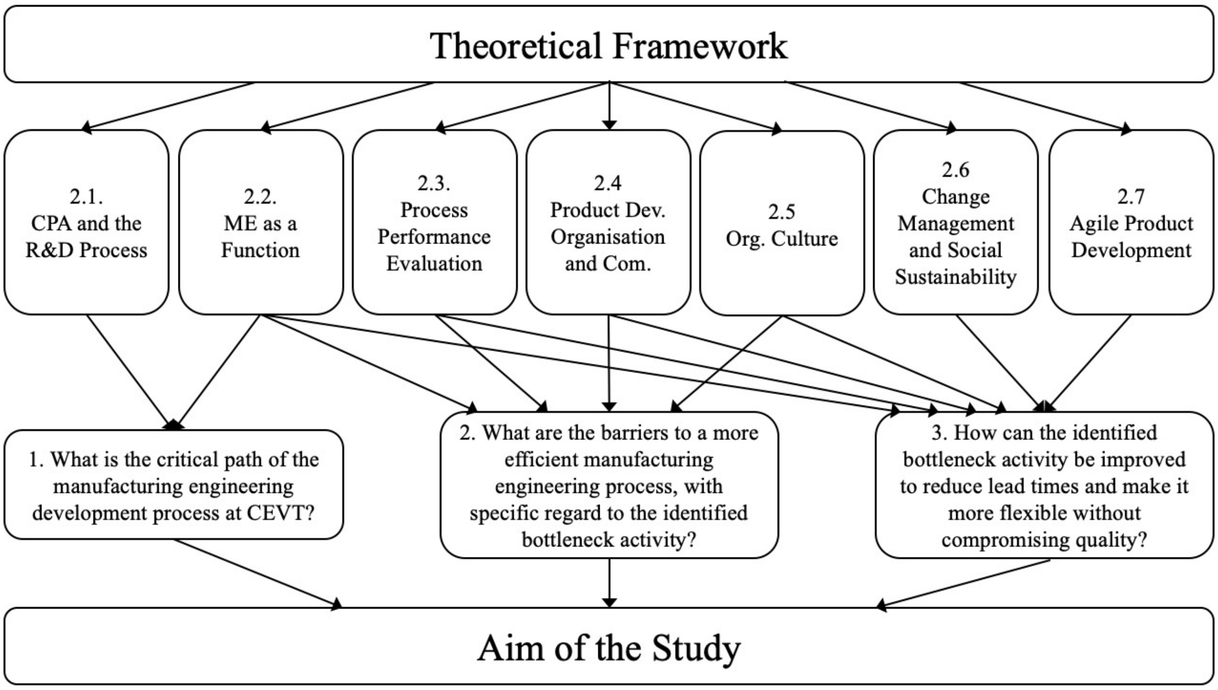

Figure 2.1. Theoretical framework and how it relates to the research questions.

2.1. Critical Path Analysis and the R&D Process

The purpose of this subchapter is to present the critical path analysis method as well as the general concepts of the product development process. It highlights the fundamental features of a process and describe the research and development activities of an organisation. The origin, purpose, and procedures of the critical path analysis is also described.

2.1.1. Process Fundamentals

Holweg, Davies, De Meyer, Lawson, and Schmenner (2018, p. 31) describe a process as a transformation containing sequential activities turning inputs into outputs. The purpose of any process is to produce the desired output (Holweg et al., 2018, p. 32) and the most fundamental metric of a process is its productivity, i.e. the ratio of its outputs to its inputs (Holweg et al., 2018, p. 34). The inputs of a process can be either resources transformed into outputs or resources required for the transformation process itself (Holweg et al., 2018, p. 33). Materials are usually of the former kind, while capital and labour are of the latter. Processes also occur in a certain context which will affect the way they are conducted. Events in both the external and internal environment must be taken into account (Holweg et al., 2018, p. 34).

An important aspect of any process is what is called process efficiency, which can be defined as the amount of effort required to achieve a business outcome (Integrify, n.d.). To increase process efficiency, it is possible to either increase the throughput with the same resources or have the same throughput but using fewer resources. Verbruggen, Sutherland, van der Werf, Brinkkemper, and Sutherland (2019) take a different approach and define process efficiency as value added time divided by total lead time of a particular process. When process efficiency is increased, it correlates directly to the reduction of waste, i.e. activities that do not add value to the product to be delivered. A significant feature of an inefficient process is waiting, including both the wait for preceding process steps to be completed and the wait for the right information to be delivered. Waiting can increase the process throughput time significantly and consequently, it is important to find ways to reduce it (Verbruggen et al., 2019).

When improving a process, it is necessary to understand the process, and the relationship between the design and operation of the process and its performance, in detail (Slack & Lewis, 2017, p. 253). The better this relationship is understood, the easier it is to improve the process itself. The elements important to grasp include the real purpose of the process, the constraints to the process, and the strengths and weaknesses of the process as it looks today (Integrify, n.d.).

2.1.2. Research and Development

Research and development are all the activities that companies conduct to innovate and to create new products and services, or to improve existing ones (Kenton, 2020b). The output of the research and development process are offerings to be introduced to the market. In general, successful R&D is what allows companies to stay ahead of their competition, and without it, they must find other ways to create income. Companies in technological industries are among those that spend the most of their revenue on R&D since their competitive advantage depends on rapid cycles of new product launches (Kenton, 2020b).

Wheelwright and Clark (1992, p. 2) describe three driving forces as to why research and development has become increasingly important in the contemporary world. Firstly, the increased importance of world trade and more accessible markets has created intense international competition. The number of high-level competitors has grown, and these competitors are more aggressive, creating a less forgiving and more demanding market environment. Secondly, customers are much more exigent than before and require more personalised offerings, creating fragmented and more demanding markets. They expect high-performance solutions adapted to their particular problems and needs. Thirdly, technologies today are diverse and rapidly changing, creating the need for technological and scientific knowledge to develop and choose among the many options available (Wheelwright & Clark, 1992, p. 2). Many new technologies have the potential to, and have previously, fundamentally changed businesses and the nature of competition. With a tougher environment and accelerating technological development, effective and efficient R&D is more necessary than ever for companies to survive.

Product development can in general be seen as a funnel, with ideas and knowledge entering on the wider end, and finished products leaving on the narrow end (Wheelwright & Clark, 1992, pp. 111-112). The ideal development process starts by identifying many ideas, selecting the most promising for further development, and focusing resources to bring them into the market. Reality is a lot less straightforward, with new information and input from different stakeholders arriving continuously, requiring changes and iterations to be made repeatedly (Wheelwright & Clark, 1992, p. 115). For the development funnel, there are two main challenges that all firms face, but that are hard to combine. Firstly, companies need to widen the mouth of the funnel to receive as many new ideas as possible to be evaluated (Wheelwright & Clark, 1992, p. 113). Secondly, companies must narrow the neck of the funnel to reduce the list of active projects and to focus the limited resources on only the most promising ones.

The product development process is often organised in a series of stages, of which a simplified example can be seen in Figure 2.2 below. What is defined as a stage, and what activities that are included in each stage, varies from company to company (Slack & Lewis, 2017, pp. 287-290). In theory, the traditional development process is structured in a so-called waterfall process. This means that each stage needs to be completed before the next can commence and that the development cannot go back to a previous stage without starting the process over (smartsheet, n.d.). In this theoretical setting, changes are not easily accommodated, but expensive and difficult to correct (smartsheet, n.d.). It is important to emphasise that the stages presented never are entirely sequential and that as with the development funnel concept, the reality is much more complex (Slack & Lewis, 2017, pp. 287-290). For the scope of this project, the most interesting stages are the latter ones.

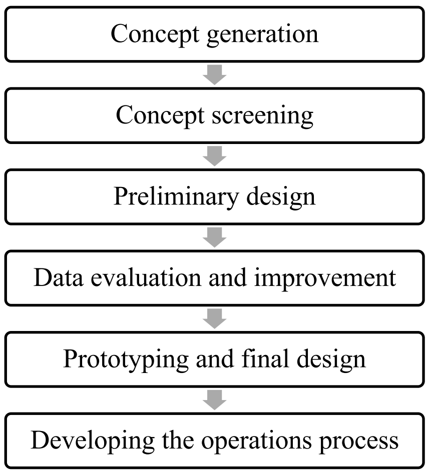

Figure 2.2. A typical 'stage model' for product and service development (Slack & Lewis, 2017, p. 288).

Design evaluation and improvement includes activities evaluating each product part and its contribution to the overall value, and if it could be done differently (Slack & Lewis, 2017, pp. 287-290). Prototyping and final design is about testing a close-to-final product concept to the market, and to collect feedback which is to be used when creating the final design. The final stage, developing the operations process, is about defining how the product is to be manufactured and developing tools and methods for that purpose. It is in this stage that the manufacturing engineering function, the main target of this project, is involved. However, according to Charlie Berner at CEVT (personal communication, 2020-01-22), ME is involved before the final design is set. The ME function is described further in section 2.1.3.

2.1.3. Description of Critical Path Analysis Method

A critical path analysis or method is a project planning tool that is used to identify tasks that are dependent upon other tasks for their timely completion (Kenton, 2020a). The method was first defined in the 1950s in an attempt to mitigate the issue of coordinating many diverse activities towards a common goal (Kelley & Walker, 1959). When conducting a critical path analysis, one should establish the sequence of crucial and interdependent steps that constitutes the process from start to finish, and that determines the overall lead time (Kenton, 2020a). Certain tasks in the process cannot be conducted before preceding steps are finished, and the critical path analysis can help identify such bottleneck activities. The tool is also used to identify non-critical activities that do not necessarily need to be prioritised. Critical path analyses are primarily used in highly complex processes, like product development (Kenton, 2020a).

When conducting a critical path analysis, the first and most fundamental step is to generate a basic representation of the project or process (Kelley & Walker, 1959). All activities of the process and their relationships are to be described, which can advantageously be depicted in a flowchart or diagram. For each activity, it is necessary to determine what immediately precedes it, what immediately follows it, and what can be done concurrently. For large and complex processes, this mapping can become quite extensive and difficult to grasp. Consequently, depending on the purpose and scope of the critical path analysis, one should choose an aggregation level accordingly (Kelley & Walker, 1959). Some analyses use very detailed activities describing each task while others use more high-level activities.

The second step of a critical path analysis is to assess the duration and effort required for each activity in the process (Kelley & Walker, 1959). This is an essential part of the scheduling of a project, and a necessary step in identifying bottlenecks. The time duration of each activity can either be appointed deterministically, where the duration is known, or non-deterministically, where the exact duration is not known and can vary significantly.

The method as described by Kelley and Walker (1959) is primarily targeting project planning and the allocation and balancing of resources. They continue by describing how the critical path method can be used to assess the project cost, to determine the manpower required for each activity, and to assure effective capital usage. These subsequent steps can all be evaluated mathematically. For the scope of this project, however, the two first steps are the most interesting. Since activities on the critical path directly influence the overall lead time of the process (20/20 Business Insights, n.d.), improvement efforts aiming at reducing the process lead time must focus on those critical activities. If the lead time of one particular activity on the critical path is reduced, or if the activity is commenced earlier, the lead time for the entire project will be reduced (20/20 Business Insights, n.d.). Efforts to reduce the lead time of activities not lying on the critical path will not affect the total lead time at all.

2.2. Manufacturing Engineering as a Function

Manufacturing Engineering is a function within manufacturing firms with the purpose of bridging the gap between product development and the actual production of the products (Matisoff, 1997). The emphasis is on determining the how of the manufacturing process, being responsible for translating the technical aspects of the product into simplified assembly instructions. Non-technical personnel should easily understand the tasks they are to perform. According to Matisoff (1997), it concerns the planning of the manufacturing practices; the research and development of tools, processes, and equipment; and the creation of facilities and systems for cost-efficient production of high-quality products. A particularly important activity of ME is the feasibility studies for the manufacture of new or updated products. One must make sure that the changes made by R&D are producible, and that the quality and cost-efficiency of the process is maintained.

According to Charlie Berner (personal communication, 2020-02-13), the manufacturing engineering function is positioned in different ways within different automotive companies. In some firms, ME is part of the R&D organisation while in others, it is located under manufacturing. Berner states that in Volvo Cars, for example, ME is integrated into the manufacturing organisation and at CEVT, ME is considered an R&D function. The location of the ME function in either the R&D or the manufacturing organisation provides different benefits and disadvantages. The communication with and understanding of the home organisation is enhanced while the opposite is true for the other. Since manufacturing engineering is supposed to bridge the gap between the two organisations, this must be mitigated no matter the location.

The challenges of manufacturing engineering largely relate to the differences between manufacturing and R&D, and how to bridge them most effectively and efficiently possible. Looking at the five performance objectives (quality, speed, dependability, flexibility, and cost) as presented by Slack and Lewis (2017, p. 67), it is evident that what manufacturing and R&D operations strive for respectively differ considerably. Generally, R&D emphasises product flexibility, i.e. the ability to create new products and update old ones (Slack & Lewis, 2017, p. 59), while manufacturing instead wants few product variants to reduce the costs of production. Quality is emphasised by both, but in different ways which can be difficult to combine. Changes by R&D of product specifications that would enhance the features and aesthetics offered might require large changes to the manufacturing processes to maintain them error-free and low-cost processes (Wheelwright & Clark, 1992, pp. 168-169). As the two organisations work towards different goals, many mismatches can occur if cooperation and communication are not working.

According to Wheelwright and Clark (1992, p. 175), there are other barriers that limit integration between what they call upstream and downstream groups, i.e. R&D and manufacturing. Lack of effective communication, not-close-enough relationships, and insufficient understanding of the other side all contribute to solidifying the differences mentioned above (Wheelwright & Clark, 1992, pp. 178-180). The attitudes toward integration are also a hindrance to successful cooperation (Wheelwright & Clark, 1992, p. 184). Mutual trust between the groups must be established, and people must be committed to the success of the other function as well as their own. These barriers must all be mitigated to enhance cooperation between the two functions and acting as an integration mechanism is the raison d'être of manufacturing engineering.

Wheelwright and Clark (1992, pp. 182-183) mention three capabilities that downstream engineers must have to cope with upstream, namely forecasting from upstream clues, managing risks, and coping with unexpected changes. With forecasting from upstream clues, they mean working on problems that have not yet been well defined. This is especially important when upstream input is delayed or not complete. Since forecasting can never be completely accurate, manufacturing must be able to cope with unexpected changes Wheelwright and Clark (1992, pp. 182-183). It involves being able to deal with changes in design by being flexible and excelling in rapid problem-solving. Lastly, managing risks is the trade-off between forecasting and dealing with changes. One must balance the risks of a given change and the benefits of an early start.

2.3. Process Performance Evaluation

In this subchapter, five generic performance objectives are presented, together with the impacts and trade-offs that they have on product development performance. The possibility of overcoming certain trade-offs are also explored, as well as the fundamentals of lead time reduction.

2.3.1. Performance Objectives and Trade-Offs

Product development processes can be examined using the five generic operations performance objectives as presented by Slack and Lewis (2017, p. 67), namely, quality, speed, dependability, flexibility, and cost). They define the objectives specifically for product and service development, and these definitions can be seen in Table 2.1, the objectives are presented as they are defined for product and service development. These objectives all relate to each other, and the traditional approach to the performance objectives is that they come with trade-offs (Slack & Lewis, 2017, pp. 74-76); you cannot excel at all five at once, and operations trying to be good at everything at once end up performing inadequately at everything. This perspective on operations performance suggests that an organisation needs to prioritise between the objectives and that the prioritisation should be linked to its competitive strategy. Another contradictory perspective is that trade-offs are not necessary and that the success of many companies arises from their ability to improve several performance aspects simultaneously. Combining the two, there is a need for companies to position their processes to achieve the appropriate balance between the performance objectives, but that a process can be improved to overcome trade-offs (Slack & Lewis, 2017, pp. 74-76).

Table 2.1. Performance objectives for product and service development (Slack & Lewis, 2017, p. 287).

Quality	Error-free designs that fulfil market requirements
Speed	Fast development from concept to launch
Dependability	Designs delivered to schedule
Flexibility	Designs that include the latest ideas
Cost	Designs produced without consuming excessive cost

Quality is, according to Slack and Lewis (2017, p. 293) difficult to define for a product development process, although it is easy to see the difference between high and low-quality processes. They do, however, define a high-quality development process as one that creates error-free designs that meet the demands of the market. The process should require as little rework as possible and create products that capture the customer requirements accurately (Slack & Lewis, 2017, p. 297). The second performance objective, speed, is about having processes enabling rapid development from concept to launch (Slack & Lewis, 2017, p. 293). The need for fast product development has become increasingly prominent in most industries as a result of the rapid and diverse technological advancements described by (Wheelwright & Clark, 1992, p. 2). Being faster than one's competitors can bring several benefits, like enabling a possible early market introduction, a later development commencement, and more frequent product and technology introductions (Slack & Lewis, 2017, p. 293). The fourth performance objective for product development, dependability, is according to Slack and Lewis (2017, p. 294) about delivering product designs according to the pre-set time plan. To achieve this, the changes that inevitably occur throughout a development process need to be handled to avoid negative effects on the lead time (Slack & Lewis, 2017, pp. 294-295). The fifth objective, flexibility, is therefore needed to be dependable. It is defined by Slack and Lewis (2017, p. 295) as the ability of the development process to cope with external or internal change. Flexibility in development is especially important due to the trends of more volatile markets and the increasing complexity and interconnectedness of products and services (Slack & Lewis, 2017, p. 295). Flexibility can also help to mitigate development risks as changes can be dealt with in a better way (Slack & Lewis, 2017, p. 295). The last operations performance objective presented by Slack and Lewis is cost, which they for product development define as the production of designs without consuming excessive cost (Slack & Lewis, 2017, p. 297). All of the other development performance aspects relate to cost in some way, and improved performance in one of them might have a positive impact on costs.

When examining the performance objectives of product development processes, there is a discussion regarding the existence of a trade-off between flexibility and efficiency, especially from an organisational point of view (Adler, Goldoftas, & Levine, 1999). Efficiency normally requires high levels of standardisation, formalisation, and specialisation, and such organisational structures hinder the more fluid process required for flexibility (Adler et al., 1999). Certain authors argue that firms must choose between what they call dynamic effectiveness through flexibility or static efficiency through a more rigid structure. Boyer and Lewis (2002), for example, find that organisations increasingly consider all performance aspects as vital for success, but that decision-makers still see the need to make trade-offs. They argue, however, that the trade-offs appear more subtle than before. Nonetheless, according to

Adler et al. (1999), the empirical evidence for the flexibility-efficiency trade-off is weak, and there are several examples of firms that have been able to do both.

Adler et al. (1999) exemplify the ability to overcome the presumed trade-off between flexibility and efficiency with a Japanese automotive company, Toyota, which is famous for its lean practices. Toyota has been able to shift the flexibility-efficiency trade-off for its production system repeatedly and over time. Although most of their findings relate to production and manufacturing, there is one identified mechanism in particular that applies to development processes, namely, meta-routines. Meta-routines are standardised procedures for changing existing routines and for creating new ones, which directly increases efficiency for a given level of flexibility. By having standardised methods of dealing with situations where change is needed, the organisation can increase efficiency without compromising flexibility. Additionally, to achieve sustained work on overcoming the flexibility-efficiency trade-off in the long term, Adler et al. (1999) stress the fundamental role of good leadership. High-level management should continuously advocate for the combined importance of flexibility and efficiency so that short-term pressures on performance does not lead to the reestablishment of excessively rigid and standardised processes.

Another example of a method to perform well in both efficiency and flexibility is the agile methodology, which is described in detail in subchapter 2.7. In particular, the Scrum framework as described by (Schwaber & Sutherland, 2018) is designed to surmount the efficiency-flexibility trade-off, also incorporating creativity. Agile product development is, in short, about creating empowered self-organising cross-functional teams that are responsible for their own value creation (Beck et al., 2001). They are allowed to structure their work, as long as they meet the pre-set objectives, which should lead to better and simpler processes.

The previously described objectives relate closely to performance measures as a way of evaluating a process. The process performance measures used by an organisation commonly include aspects of the process that have been deemed particularly important to achieve superior results (Slack & Lewis, 2017, p. 46). According to Catasús, Ersson, Gröjer, and Wallentin (2007), there is a link between the measures used and what actually is managed by the organisation. However, they also emphasise the link between mobilisation and what becomes carried out. If an organisation emphasises one particular process aspect and apply measures to evaluate it, this is what the organisation will achieve, possible at the expense of other aspects. If the measures applied do not capture the core issue, it might result in unintended consequences.

2.3.2. Lead Time Reduction

Development speed and short lead times are increasingly important in product development processes (Kuhnert et al., 2018). As with flexibility, Japanese car manufacturers have long been hailed for their comparatively short product development cycles. Clark and Fujimoto (1989) identified three structural characteristics that provide the Japanese firms with advantages in planning and engineering lead time. Firstly, and most importantly, they have developed internal organisational capabilities for quick and integrated problem-solving. They argue that product development itself is constituted by a series of problem-solving cycles that are to be repeated until the product requirements have been met. Process lead time is shortened by shortening individual cycles, eliminating cycles, reducing the number of iterations, and creating conditions where upstream and downstream cycles can overlap effectively. Secondly, Japanese firms tend to have a close relationship with suppliers, ensuring strong supplier engineering capability. In doing so, they can maintain a narrower project scope while still having many unique parts. Thirdly, they innovate through smaller, more incremental technology changes that can be introduced more frequently. Although each development step is smaller, the technology innovation rate can be higher in the long run.

R&D activities or stages, as illustrated in section 2.1.2, can be arranged according to two different approaches, sequential or simultaneous arrangements (Slack & Lewis, 2017, p. 292). The sequential, or step-by-step, approach is the traditional product development arrangement where one stage needs to be completed before the following one can start. This is also the approach utilised by Kelley and Walker (1959). With the sequential approach, each step is clearly defined, and development resources of each stage can be entirely focused on the tasks to be completed. Using a simultaneous arrangement, activities in consecutive development stages are conducted concurrently and a subsequent stage can start before a preceding one is completed. This approach requires a lot more communication and coordination between the stages but enables the organisation to compress the overall development lead time substantially, and reduce costs (Slack & Lewis, 2017, p. 292).

2.4. Product Development Organisation and Communication

In this subchapter, the organisation of the product development process is to be explained. It first examines the two main types of organisational structures, project and function, and the continuum in between, and how it affects the product development process. Furthermore, it highlights the need for cross-functional communications and different ways of enhancing the integration of upstream and downstream functions.

2.4.1. Product Development Projects and Teams

Slack and Lewis (2017, pp. 303-306) argue that the effectiveness of product development organisation can be assessed according to two criteria, namely, specialisation and integration. These two criteria often lie at the opposite end of a line, and it is difficult to achieve both a high degree of specialisation and integration. Specialisation is important due to the need for profound knowledge and technical understanding in the development process. Integration is necessary since products are made up of subsystems, and the development requires the coordination of developers and engineers from all over the organisation. It is also essential to assure that the technical solutions created reflect the market priorities of the organisation. According to Kniberg and Ivarsson (2012), integrated product development organisations tend to foster generalists rather than specialists.

Within a product development organisation, the management of development activities can be centered around the various organisational functions that contribute to development or around the development project itself (Slack & Lewis, 2017, pp. 303-306). According to Slack and Lewis (2017), which approach that should dominate is an important question for the organisation, and the matrix organisation is a compromise between the two. In Figure 2.3, the different organisation structures possible are shown on a continuum from a pure functional organisation to a pure project organisation. In a purely functional organisation, all personnel associated with the project are based exclusively in their functional groups, and all communication and coordination between functions are conducted through the functional managers. In a pure project organisation, on the other hand, all resources and personnel that are needed to conduct the project are allocated together, with a project manager leading them. In between the two extremes lies the balanced matrix organisation, where the project manager and the functional managers together oversee the project and its required resources on an equal basis.

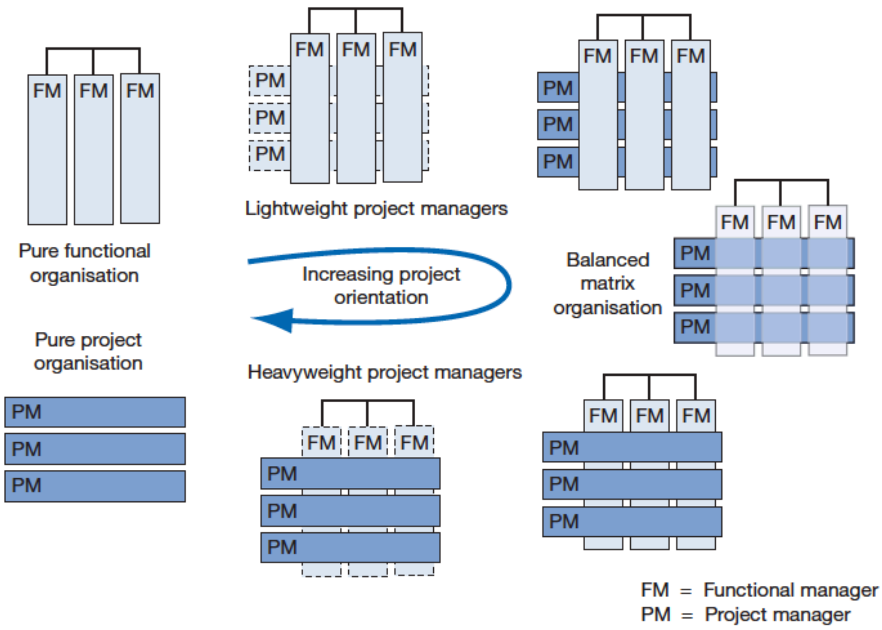

Figure 2.3. Organisation structures for design processes (Slack & Lewis, 2017, p. 305).

It is, according to (Slack & Lewis, 2017, pp. 303-306), widely acknowledged that structures closer to the project end of the continuum are more efficient forms of organising. For example, a study shows that heavyweight teams, with only a loose functional structure, have shorter development lead times and better product competitiveness. This is, however, true mostly for very complex development projects. Matrix organisations tend to be better when dealing with both simple and complex projects. It is necessary to find a balance between the technical knowledge coming from functional specialisation and the cross-functional integration coming from a more project-oriented structure. Slack and Lewis (2017, pp. 303-306) argue that most companies that move towards a more cross-functional structure do so to break down the walls between functions, i.e. to assure good communication.

2.4.2. Communication within an Organisation

To achieve outstanding development, effective action from all major functions in a business is needed, including engineering and manufacturing (Wheelwright & Clark, 1992, p. 165). In the case of designing and manufacturing a product, the problems that occur in the two functions are similar and very much linked together (Wheelwright & Clark, 1992, p. 175). The upstream design choices regarding dimensions, tolerances, interfaces, surface characteristics, and materials, are all becoming input for the downstream production process planning (Wheelwright & Clark, 1992, p. 176). The integration of these two groups determines the effectiveness of the integration in the development of the product.

A critical element in the upstream-downstream communication is the patterns of communication. Wheelwright and Clark (1992, p. 176) define four dimensions of communication, richness, frequency, direction, and timing, that determine the quality and effectiveness. The dimensions and the corresponding range of choice are presented Table 2.2. The range of choice represents opposites in integration, where the right column is preferable, enabling collaboration and feedback.

Table 2.2. Dimensions of communication between upstream and downstream groups (Wheelwright & Clark, 1992, p. 177).

Dimension	Range of Choice	
Richness of Media	**Sparse**: documents, computer network	**Rich**: face-to-face, models
Frequency	**Low**: one-shot, batch	**High**: piece-by-piece, on-line, intensive
Direction	**One-way**	**Two-way**
Timing	**Late:** completed work, ends the process	**Early:** preliminary, begins the process

To enable successful cross-functional integration, the key issue is to which extent the work of two groups is done in parallel (Wheelwright & Clark, 1992, p. 176). Wheelwright and Clark combine the communication patterns in Table 2.2 with different approaches to parallel activities, creating four modes of upstream-downstream interaction, shown in Figure 2.4. On the first mode, the serial mode, the downstream group waits until the upstream group has finished its design. The information flow is one-way and the over-the-wall thinking does not support a mutual, timely adaptation of product and process design (Wheelwright & Clark, 1992, p. 180). In the second mode, called early-start-in-the-dark, the communication is still conducted in one-way batches (Wheelwright & Clark, 1992, p. 179). The processes seem to be concurrent, but the lack of information transfer from the upstream group hinders the integration of the problem-solving cycles in the two organisations.

In the third mode, the two organisation move towards real integration (Wheelwright & Clark, 1992, p. 179). Communication occurs much earlier than in the previous modes and involves preliminary, fragmental information. There is however a gap between the start of the part design and the manufacturing process design. The downstream organisation gathers insights, and participates in the design process, but waits for the completion of the design before starting their problem-solving. The last mode of communication is where the two organisations utilise integrated problem-solving. Here, the downstream engineers use the insights gathered in the early dialogue to get a head start on their work (Wheelwright & Clark, 1992, p. 179). The feedback provided by the downstream organisation reflects the current work and attempts to implement the upstream design.

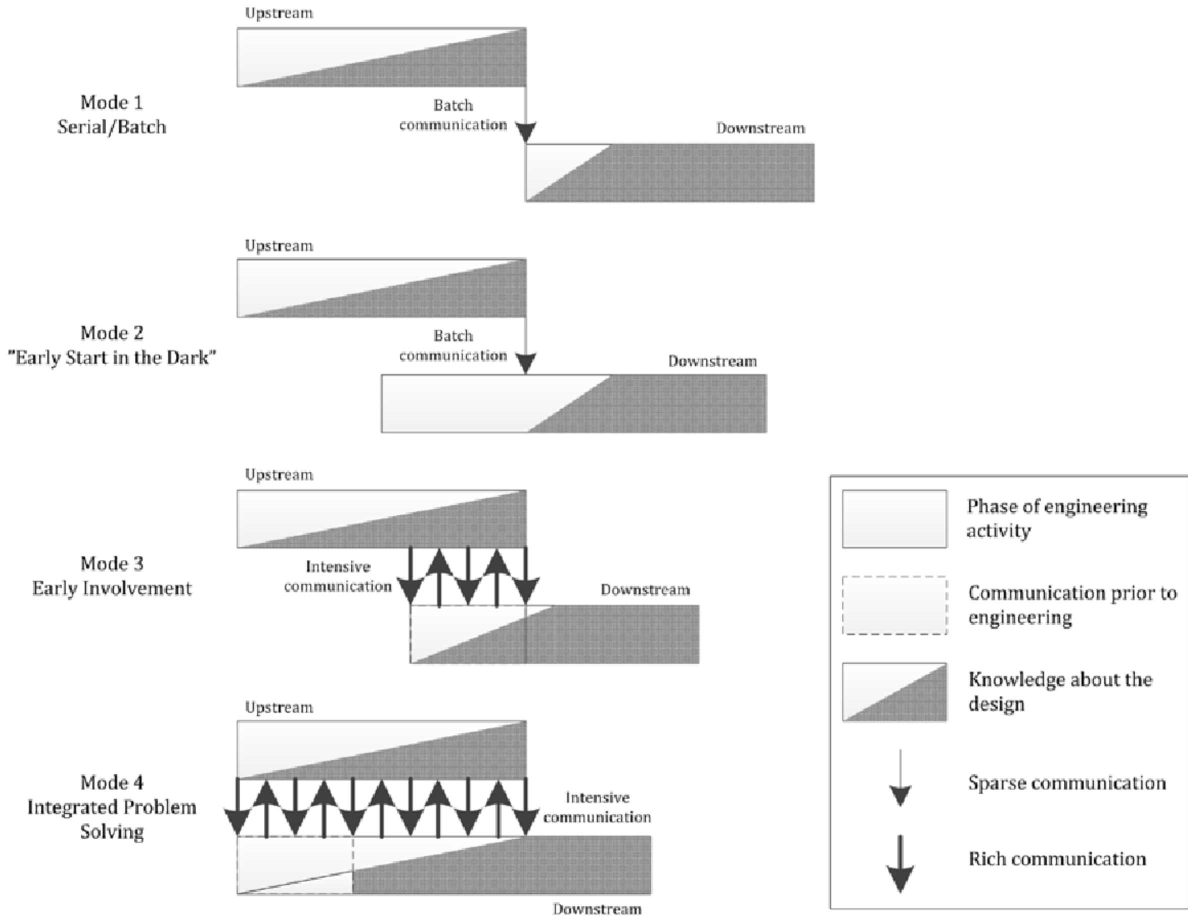

Figure 2.4. Four modes of upstream-downstream interaction (Wheelwright & Clark, 1992, p. 178).

Setting up an organisation for integrated problem solving is a demanding process (Wheelwright & Clark, 1992, pp. 180-182). The upstream group must be knowledgeable about the downstream constraints and capabilities, create downstream-friendly solutions, and be quick to solve issues and disagreements between the groups when they inevitably occur. The downstream group, meanwhile, must be able to forecast based on upstream clues, manage the risk of these forecasts, and be flexible and skilled enough to handle unexpected changes.

Apart from these mentioned capabilities, the deployment of integrated problem solving is dependent on the overall attitude and relationship between the upstream and downstream groups (Wheelwright & Clark, 1992, pp. 184-185). People must be willing to share preliminary information and to work in an ambiguous environment, while also trusting each other to cope with changes to the product. Effective integration is also built on shared responsibility for the results of processes. With shared responsibility, the goals of the upstream and downstream groups can be aligned, better enabling systems thinking and avoiding suboptimisation of the end product (Wheelwright & Clark, 1992, pp. 184-185).

2.5. Influence of Organisational Culture

When trying to understand the functioning of a workplace, it is necessary to understand the influence of culture. Hofstede and Hofstede (1991, p. 5) define culture as "the collective programming of the mind distinguishing the members of one group or category of people from others”. National culture has a clear incidence on the culture of an organisation (Hofstede Insights, 2019b), and considering CEVT being a Chinese company in a Swedish context, the differences between Swedish and Chinese culture are necessary to take into consideration. Six dimensions of national culture are presented that distinguish countries from each other (Hofstede Insights, 2019b). The scores on the dimensions are all relative and are consequently only meaningful by comparison. The dimensions are power distance, individualism, masculinity, uncertainty avoidance, long-term orientation, and indulgence. The dimensions are presented and explained in Table 2.3 below.

Table 2.3. Dimensions of national culture (Hofstede Insights, 2019a) (Hofstede Insights, 2019b).

Power Distance (PDI)	The degree to which the less powerful members of a society accept and expect that power is distributed unequally. How a society handles inequalities among people.
Individualism versus Collectivism (IDV)	The degree of interdependence a society maintains among its members. In an individualistic society, individuals are expected to take care of only themselves and their close families, while in a collectivistic society, people belong to groups that take care of them in exchange for loyalty.
Masculinity versus Femininity (MAS)	The fundamental here is what motivates people. Masculinist societies are at large more competitive while feministic are more consensus-oriented. The former value achievement, heroism, assertiveness, and material rewards for success while the latter value cooperation, modesty, caring for the weak, and quality of life.
Uncertainty Avoidance (UAI)	The degree to which the members of a society feel uncomfortable with uncertainty and ambiguity. How a society deals with the fact that the future can never be known.
Long-term versus Short-term normative orientation (LTO)	How societies prioritise between maintaining links with their past and dealing with the challenges of the present and future. A long-term oriented society encourages thrift and efforts in modern education as a way to prepare for the future. A short-term oriented society maintains time-honoured traditions and norms while viewing societal change with suspicion.
Indulgence versus Restraint (IVR)	The extent to which people try to control their desires and impulses. Weak control is defined as indulgence, and such societies emphasise the satisfaction of basic and natural human drives related to enjoying life and having fun. Restraint societies suppress the gratification of needs and regulate it through strict social norms.

Multicultural work environments come with benefits for any organisation in terms of for example enhanced creativity and broader thinking (Orbium, 2019). However, they come with challenges too. When examining the Swedish and the Chinese national cultures according to the Hofstede dimensions, with the scores presented in Figure 2.5, it is visible that they differ greatly. For many of the dimensions, Sweden and China even take opposing positions. These differences will influence the cooperation and communication between people coming from the two countries. The ways of working will not be the same and those differences must be dealt with effectively. In a text on Hofstede Insights (2019b), Hofstede argues that national culture cannot be changed, but that one should understand and respect it.

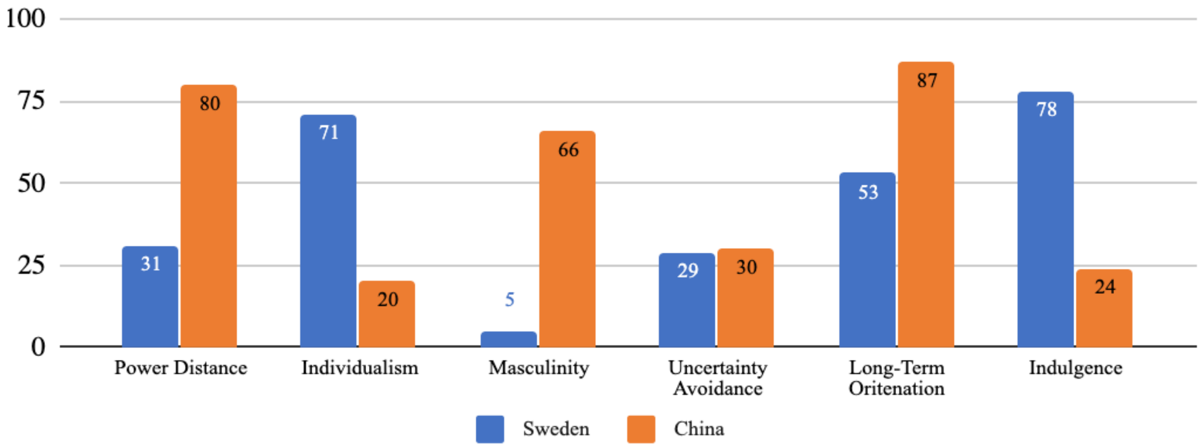

Figure 2.5. National culture comparison of Sweden and China (Hofstede Insights, 2019a).

If one starts by looking at power distance, the PDI score of China is much higher than that of Sweden. This indicates that Chinese culture is much more hierarchical than Swedish, and organisations have more formal processes in which everyone has a place (Hofstede Insights, 2019a). Additionally, decision-making tends to be centralised and communication is indirect and selective. In Swedish culture, the opposite tends to be true. Hierarchies exist for convenience only and leaders are to be accessible and of a coaching type (Hofstede Insights, 2019a). Power is decentralised with employees expecting to be consulted on decisions, and communication is direct and participative.

According to Meyer (2014), the East Asian hierarchical structures include two types of responsibilities. A lower-level person has a responsibility to follow the leader regardless if s/he believes the leader is right. The leader is not to be challenged, even in cases where it is obvious that s/he is wrong. Simultaneously, the higher-level person has a responsibility to protect and care for those further down. Meyer (2014) also cites one Swedish manager, contrasting the Chinese leadership style, who says that rather than providing the employees with a direct answer to a question, it is better to let them resolve it themselves.

For the individualism dimension, Sweden has a much higher IDV score than China. Sweden is a fairly individualistic society, where management is the management of individuals and employment is a contract based on mutual advantage (Hofstede Insights, 2019a). China, contrarily, is a highly collectivist society where people act in the interest of the group. Employees are more committed to personal relationships than to the task and the organisation. They form cooperative relationships with close colleagues but can be cold or even hostile to outsiders (Hofstede Insights, 2019a).

Sweden is, according to an article on Hofstede Insights (2019a), the world's most feminine society, in stark contrast to China. In Sweden, work-life balance and the inclusion of everyone is important, and managers strive for consensus. Conflicts are resolved through long discussions where people need to compromise to reach consensus. In Chinese organisations, there is a need for achievement and to excel, and people tend to live to work (Hofstede Insights, 2019a). Many Chinese sacrifice family to work and leisure time is in general not very important.

Regarding uncertainty avoidance, Swedish and Chinese cultures score similarly, indicating there are no significant differences between the countries. Countries with a low UAI score tend to favor practice over principles and people believe there should not be more rules than necessary (Hofstede Insights, 2019a). However, how this is expressed in a country can differ.

The position of Swedish national culture on the long-term-short-term orientation scale is very much in the middle, indicating that it does not have a clear preference (Hofstede Insights, 2019a). China, however, like other East Asian countries, is among the most long-term oriented societies in the world. In such societies, which are also called pragmatic societies, people strive for sustained and slow results, are persistent in achieving those results, and are more accepting of change (Hofstede Insights, 2019a). Traditions are adapted to changed conditions and what is the truth depends on the situation, context, and time.

For the last dimension, indulgence, Swedish and Chinese cultures also take very different positions, with Sweden being a society of indulgence and China one of restraint. Swedish culture encourages people to follow their impulses and desires to enjoy life and have fun (Hofstede Insights, 2019a). People in indulgent cultures also tend to be more positive and optimistic. Contrarily, people in restraint cultures like the Chinese are more restricted by social norms and tend to be more cynical and pessimistic (Hofstede Insights, 2019a). They are concerned with maintaining order rather than acting as they please.

2.6. Change Management and Social Sustainability

Change management is defined by Moran and Brightman (2001) as "the process of continually renewing an organisation's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers." According to Lewin, the father of organisational change theory, successful organisational change requires changing the behaviours of the individuals and social groups that constitute the organisation (Burnes, 2004). To do so, one must first create an understanding of these social groups; how they are formed, motivated, and maintained (Burnes, 2004). Change management involves other aspects as well. It is, for example, about being able to introduce changes while conserving the elements that work well within the organisation (Rondeau & Bareil, 2009). Change management is also about successfully handling change coming from multiple directions, as top-down or bottom-up, from without or within (Autissier, Johnson, & Moutot, 2015).

Rondeau and Bareil (2009) identify three primary challenges for managers when supporting change initiatives, namely, the legitimisation, the realisation and the appropriation of the change. Firstly, legitimisation is about instilling the need to change within the entire organisation and making people understand what actions need to be taken. For this phase, it is necessary to have a sustained dialogue about the situation and to deal with the imbalances of simultaneously working and changing. Secondly, realisation is the phase of deploying new practices and ways of working corresponding to the transformation needing to occur. According to Rondeau and Bareil (2009), it is in this phase important to continuously visualise the change to keep the entire organisation up to date with what is taking place. Lastly, appropriation is about making sure that the people affected by the change adopt these new practices into their natural way of working. Here, managers must accompany their teams in the modification of their behaviour and habits, and sometimes also exercise leadership.

Related to the challenges of conducting and implementing change is social sustainability. According to the Royal Institute of Technology (KTH) (2018), it involves the well-being, justice, power, rights, and needs of the individual. It deals with the ability of all people to fulfil their needs, goals, and dreams at a global level while simultaneously meeting the ability of the planet. The development process has a clear link to the ways people are working within the organisation and any change there will have an impact on the individual employee. Consequently, it is very important to involve the people working with the process in the project to assure that the proposed changes are feasible and do not influence their wellbeing negatively in any way. Nevertheless, a better process could improve their situation as well.

2.7. Agile Product Development

In this subchapter, the idea, benefits, and challenges of agile product development is presented. Firstly, the Agile Manifesto is described, along with the basics of Scrum methodology and how it differs from Lean methodology. Thereafter, agile implementation and challenges are discussed by presenting prerequisites, cases of implementation in a hardware setting, and difficulties that arise from scaling agile beyond a team level.

2.7.1. The Agile Manifesto

The term Agile software development was first coined in 2001, as a group of software industry leaders tried to find common ground among several concurrently emerging development methodologies (Highsmith, 2001). They all felt that documentation-driven, heavyweight software development processes were becoming outdated and that an alternative had to be established. The term agile, the ability to adapt and respond to changing circumstances, was chosen as it was felt representative of the capabilities needed to operate and succeed in the turbulent and uncertain environment that is software development (Agile Alliance, n.d.). The idea of agile development can be described by the Agile Manifesto, in which four statements and twelve principles lay the foundations for the way of thinking and approaching the methodology (Beck et al., 2001). The statements are presented below in Figure 2.6 along with a description of the manifesto.

We are uncovering better ways of developing
software by doing it and helping others do it.
Through this work we have come to value:

Individuals and interactions	over	processes and tools
Working software	over	comprehensive documentation
Customer collaboration	over	contract negotiation
Responding to change	over	following a plan

That is, while there is value in the items on
the right, we value the items on the left more.

Figure 2.6. The four statements of the Agile Manifesto (Beck et al., 2001).

According to Beck et al. (2001), by focusing on individuals and interactions over processes and tools, the emphasis is that people, not processes, are responsible for delivering value. Trusting developers to deliver the desired output is more effective than having rigid structures to control the work. Letting teams self-organise leads to better and often simpler designs and processes than having them be predetermined by managers. As long as motivated individuals have the environment and support that they need, the projects are more likely to be successful. The trust in developers' communication and output also leads to valuing working software over processes and tools, believing that motivated, empowered individuals get the work done if they are trusted to do so (Beck et al., 2001). The software should be delivered early and frequently, establishing a continuous value flow to the customer, as customer focus is of utmost importance in all projects and at the core of development. The cadence of the project must be sustainable for all parties, keeping it at a reasonable pace and not introducing big spikes in work hours.

Both internal and external alignment is critical in projects. To achieve internal alignment, businesspeople should join in daily for meetings with the development teams to reflect on progress, potential higher-level issues, and possible strategic questions (Beck et al., 2001). Quickly resolving issues keeps the projects running with fewer stops, allowing a smoother cadence. To evolve both as a team and as individuals, regular reflections should be held on how to be more effective(Beck et al., 2001). Face-to-face communication is preferred within the teams as it is considered the most effective and efficient way to share information. The external alignment should also occur frequently, where changes in the project can be suggested and welcomed even at a late stage of development, as well-grounded changes can enable higher customer value in the end (Beck et al., 2001). To adapt and embrace change is one of the fundamentals of agile software development, as the market and environment are uncertain, competitive, and changing at a rapid pace (Agile Alliance, n.d.).

2.7.2. Scrum as a Way to Organise Development Work

Scrum is a process framework used since the 1990s to manage complex work on products (Schwaber & Sutherland, 2018). Using agile as the mindset, Scrum centers around continuous improvement and helps teams to start building agile principles into everyday work (Drumond, n.d.). The framework describes the scrum team and the roles, events, artifacts, and rules associated with it and is illustrated in Figure 2.8.

A scrum team is a self-organising and cross-functional team consisting of a product owner, the development team, and a scrum master (Schwaber & Sutherland, 2018). A cross-functional team has all competencies needed to perform work independently of others not part of the team. This model is designed to optimise flexibility, creativity, and productivity.

The product owner is responsible for optimising the value resulting from the development team's work, using a product backlog as the primary tool (Schwaber & Sutherland, 2018). The product backlog is the sole responsibility of the product owner. It contains a ranked list of items to be done next by the development team, taking the customer, deadlines, potential value, and other perspectives into consideration. Every item should increase the functionality of the product and be considered a small, vertical slice of the system that supports incremental development (Scaled Agile, 2019b). The idea of agile vertical slicing and how it differs from the waterfall model is illustrated in Figure 2.7. For a product owner to be successful, the entire organisation must respect their decisions, as no one else can force the development team to work on different tasks (Schwaber & Sutherland, 2018).

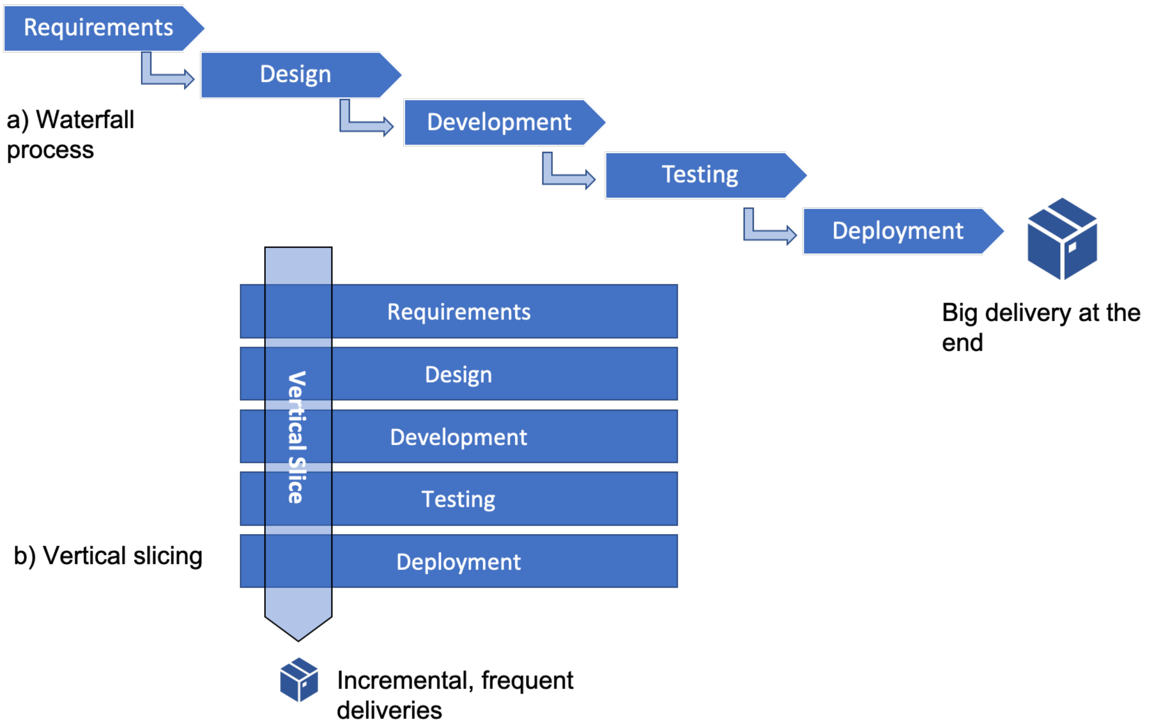

Figure 2.7. Illustration of the difference between Waterfall and agile vertical slicing.

While the product owner decides what the development team is supposed to do during each increment, the team itself decides how the tasks are to be performed (Schwaber & Sutherland, 2018). This self-organising leads to synergies that optimise the team's effectiveness and efficiency. Each scrum team also has a scrum master, who works as a servant-leader for the development team and as a facilitator and expert of the Scrum practices. By removing and impediments for the developers, the scrum master keeps the workflow high and consistent (Schwaber & Sutherland, 2018).

The heart of Scrum is the sprint, an iterative increment of a month or less where the development of the predetermined tasks take place (Schwaber & Sutherland, 2018). The content of the sprint is decided at a planning meeting, where input from the product backlog, the previous increment, and projected capacity leads to items being selected and placed in the sprint backlog. Every item in the sprint backlog needs to have a shared, agreed-upon definition of done. This is critical to ensure transparency in the work. During the sprint, no changes are made to the sprint backlog. During the sprint, a daily stand-up meeting is held in the development team where they discuss the state of the work and forecasts for the coming day (Schwaber & Sutherland, 2018). The purpose is to optimise collaboration and transparency of the progress.

Each sprint ends with a sprint review and retrospective (Schwaber & Sutherland, 2018). During the Review, the work done over the last increment is demonstrated and discussed together with stakeholders, to find potential improvements for the coming sprint. The product backlog is reviewed along with the timeline, budget, potential capabilities, and marketplace, to ensure the strategic alignment of future increments. After the review, the retrospective is an opportunity for the scrum team to identify lessons learned and use them for future improvements (Schwaber & Sutherland, 2018). The focus for the retrospective is on people, relationships, processes, and tools, rather than the output or deliverables developed.

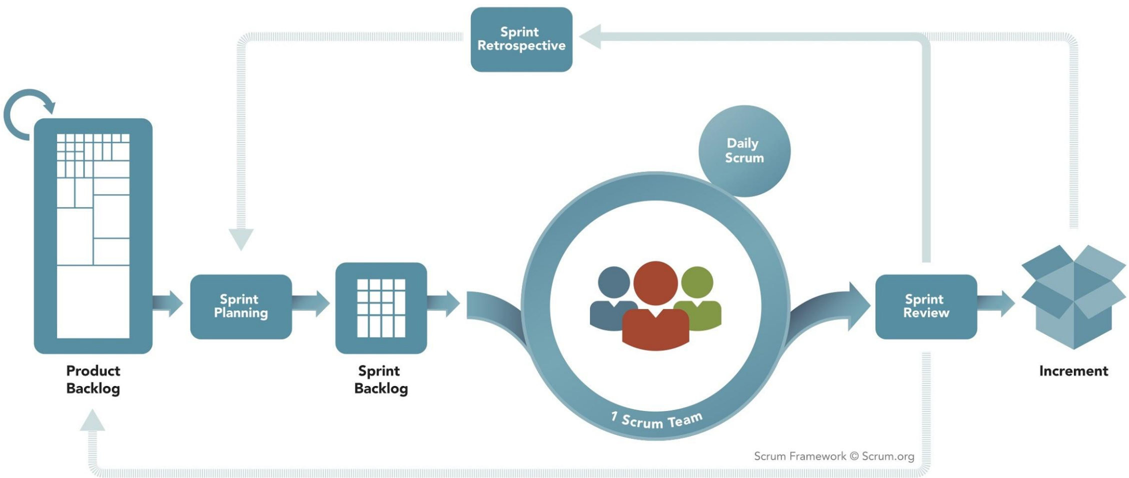

Figure 2.8. Simplified illustration of the Scrum framework (Scrum.org, n.d.).

2.7.3. Differences between Lean and Agile Product Development

Another popular development method used in both hardware and software is lean product development. It originated from the Toyota Production System which was further developed to not only encompass production but also product development (Rachaelle, n.d.). The focus of lean is to eliminate waste, and it tries to achieve this by managing processes (Brasel, n.d.). The difference from agile can be seen in several different areas. While lean development was adapted from the lean production ideas and therefore centered around processes, agile has always been focused on the people involved in the development and their interactions (Educba, n.d.). In lean development, the idea is that by doing a process over and over again, producing the same output, the process improves and waste is eliminated (Educba, n.d.). In agile development, the difference is that each new development cycle is about creating something entirely new, very much separate from prior products developed (Educba, n.d.). The novelty of each new development iteration in agile creates the need for managing uncertainty and integrating it into the development process through rapid customer feedback (Brasel, n.d.). This thinking makes agile more suitable for settings where the requirements are dynamically changing, more so than lean development (Educba, n.d.).

To establish a long-term agile culture in a company, metrics and KPIs must be re-designed to fully achieve business agility (Sanders-Blackman, 2019). For instance, traditionally, quality in software development was measured by the number of bugs fixed (Sanders-Blackman, 2019). This can then lead to the expectation of perfect products and processes and the discredit of anything less than that (Sanders-Blackman, 2019). Metrics themselves can also result in people playing the number game, i.e. finding ways to make their metrics look good (Sanders-Blackman, 2019). Agile metrics instead need to be people-centric, recognising that people drive the outcome, and focusing on the team's performance and the success of the product instead of individual capacity (Sanders-Blackman, 2019). The hard, quantifiable metrics traditionally used are not all bad, but softer metrics using subjective data and interactive responses to determine effectiveness create a necessary balance (Sanders-Blackman, 2019). Sanders-Blackman (2019) argues that different, softer definitions of success are needed to measure progress in a better, more agile way. Examples of legacy definitions and more agile definitions are presented in Table 2.4 below.

Table 2.4. Examples of agile success criteria compared to legacy success criteria (Sanders-Blackman, 2019).

Agile Definition of Success	Legacy Definition of Success
Measure how well value was delivered	Measure how well the plan was followed
Measure if quick feedback was received and adjustments were made quickly	Measure if changes were avoided and the solution was sold as-is

Mehri (2006) argues that the lean practices at Toyota may not be as innovative as often thought. He argues that creative thinking is restrained under a rigid management culture tied firmly to the Japanese culture, limiting the design process of product development. Part of the problem emerges from the fact that many engineers work in relative isolation with directives coming from management, instead of collaborating within the team (Mehri, 2006). The ideas, which can give outstanding results in regards to production lead time and quality, might work due to the hierarchical culture it operates under, and stifle creativity as a result (Mehri, 2006).

2.7.4. Implementation of Agile Product Development

To successfully implement an agile transformation, many different aspects need to be taken into consideration. One of the most important factors that affect the success of the implementation within software development is the management's involvement (Livermore, 2007). Just as in almost any development project, having the backing required from management improves the chances of succeeding. This can be especially important in a large transformation. Rigby, Sutherland, and Takeuchi (2016) stress that the greatest impediment to agile implementation is the behavior of executives. Learning to lead the transformation will enable a company to achieve profitable growth.

Mattias Khaki, agile coach at CEVT (personal communication, 2020-02-06), stresses two important factors that are critical in the implementation of agile methodologies, namely adopting the correct mindset and culture, and achieving clarification and simplification of the roles and common language. According to Khaki, the first factor is the most important one. In contrast to what many people think, he argues that agile methodology is mindset and only 20 percent tools. Without a culture that emphasises and embraces change, trust, and the ability to question decisions and processes, no agile implementation will have lasting results. If the first factor can be seen as aligning a company to embrace change, the second factor is more about getting everyone on the same page in terms of how the change will affect the work. Khaki explains that a common agile terminology is needed within the organisation to be able to educate people and eventually have constructive conversations about evolving and fine-tuning the new methods. In terms of role clarification and simplification, Khaki argues that in the beginning of an organisational change, everyone needs to be understanding of their new role and the corresponding responsibilities. According to him, the best way of doing this is to make clear, simple role definitions based on the output that each role is expected to produce. This clarifies responsibilities but also leaves people free to self-organise the execution of tasks, in line with the agile methodology.

When implementing agile, it is important to take into consideration the conditions or context that the organisation is operating in (Rigby et al., 2016). Since the methodologies evolved from software development, the implementation will be most effective in those working conditions most resembling software innovation. Rigby et al. (2016) mention five conditions or dimensions that need to be investigated and used as a foundation for the decision of whether to invest in the implementation or not. Each condition has a favorable and unfavorable state denoting whether the situation is suitable for agile methodologies or not. Many of the favorable conditions can be found not only in software development, but also in for instance product development and strategic planning activities (Rigby et al., 2016). The conditions are market environment, customer involvement, innovation type, modularity of work, and impact of interim mistakes, and are presented in Table 2.5 below.

Table 2.5. The Right Conditions for Agile (Rigby et al., 2016).

Conditions	Favorable	Unfavorable
Market Environment	Dynamic environment where changes in customer preferences and solution options are frequent	Market conditions are stable and predictable
Customer Involvement	Close collaboration and rapid feedback are feasible Over time, the customers know better what they want	Constant collaboration with the customers is not possible From the outset, requirements are clear and will remain stable
Innovation Type	Problems are complex with initially unknown solutions and an unclear scope Specifications might change, and creative breakthroughs and time to market are important Cross-functional collaboration is vital	Current work is similar to previous work with believed clear solutions. Work plans and detailed specifications can be forecast with confidence and are followed Problems can be solved sequentially in functional silos
Modularity of Work	Incremental developments have value and use for the customers Work can be broken down into parts and conducted in rapid, iterative cycles Late changes are manageable	Customer testing of the product is not feasible until everything is complete Late changes are expensive or impossible
Impact of Interim Mistakes	They provide valuable learning	They may be catastrophic

In addition to these five dimensions, Rigby et al. (2016) also stress that an agile transformation requires training, behavioral change, and possibly new information technology. All of these aspects of course require resources in terms of time and money, and executives must weigh the investments against the anticipated payoffs of the transformation.

2.7.5. Adapting Agile to Hardware Development

Agile methodologies were first developed in the software development business, at first presumed most suited for small and non-critical software projects (Punkka, 2012). Since the early 2000s however, the frameworks have been applied in a larger range of settings, from larger distributed programs and critical, real-time embedded systems, to most notably, non-software development. Gustavsson and Rönnlund (2013) present in a study that agile methods in hardware development can be positively valued by teams, without them experiencing negative work-related effects. Even though software and hardware share many similarities, for instance the complexity and the combination of functional (user-facing) and non-functional (nob-user-facing) requirements, several differences between them affect the implementation of agile methodologies (cPrime, n.d.). Hardware is harder to change than software once developed since physical components cannot be refactored after manufacturing. Therefore, the cost of change is higher for hardware development and rises toward the end of the development cycle.

cPrime (n.d.), a full-service consultancy firm in agile/Scrum transformation services, mentions four major advantages of agile for hardware compared to the traditional waterfall development model. Firstly, the adaptability of the project can increase, as small, testable deliveries can provide greater flexibility to plan, control, and change scope on short notice. In the same study as mentioned in the paragraph above, Gustavsson and Rönnlund (2013) argue that the flexibility of the process could still be obtained while the output increased from the project team. More frequent, early testing and discovery increase the ability to address the high cost of change associated with hardware development. Secondly, the time to market can potentially decrease as high-value requests can be developed and delivered more quickly. The visibility of the work is also greatly increased, as transparency allows for more people to be aware of a project's progress. Lastly, more frequent customer testing and feedback allow for a higher probability of meeting customer needs.

Embedded systems, a computer system combining processing, memory, and peripheral devices, demand the integration of multiple perspectives to avoid sub-optimisation of the result. This is since changes in one area or parameter likely affects other parts of the project (Punkka, 2012). As a result of this, continuous planning, refinement, and consequently collaboration, involving every affected area, is needed throughout the project. If continuous planning and changes are needed, then the requirements at the start of the project are likely to be wrong, vague, or lacking in detail. This leads to the conclusion that up-front planning in this setting is irrational and ineffective (Punkka, 2012). Similar settings, including automotive development, can also be seen as a complex environment where systems thinking is critical and collaboration is needed to avoid suboptimisation of the final product.

One similarity for all kinds of complex projects is that learnings are required, and trial and error arguably is the most effective way of learning (Punkka, 2012). In addition, the efficiency of learning increases as the trial cycles speed up. Technology has dramatically lowered the costs of prototyping and testing for hardware, as well as the cost of changes. This enables hardware developers to test earlier and more frequently, not only using testing for validation but also experimentation. Rework due to a failed test can instead be seen as valuable learnings, guiding the way to a working solution (Punkka, 2012).

Even though technology has lowered the cost of testing, there is, according to Punkka (2012), still a cost of money and time associated with it. If the possibility of running more test cycles is utilised, it could turn out to be an increased cost for the project as a whole. He argues, however, that this front-loaded cost increase works more like insurance and helps to avoid bigger money and time-consuming delays at later stages of development, where changes and rework are much more costly. The thinking is illustrated in Figure 2.9. The time cost dimension is where up-front prototyping has the biggest relative effect, according to Punkka (2012). This is since more test cycles not only improves new technology but also internal processes and the relationship with suppliers. The opposite is then true when this is not applied since suppliers and other stakeholders can be surprised by the late rework, leading to long lead times for parts or input from suppliers.

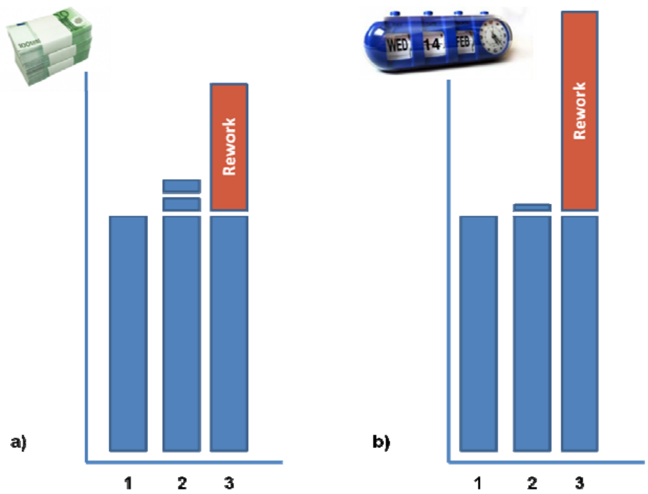

Figure 2.9 The (imaginary) true cost of prototyping; a) monetary cost and b) calendar time (Punkka, 2012). The bars represent 1. Traditional project estimate; 2. Added cost/calendar time caused by up-front prototyping during the project; 3. Added cost/calendar time caused by the rework at the end of the project without up-front prototyping.

A study on agile hardware development was conducted at a large-scale German car manufacturer and mobility services provider by Hilt, Wagner, Osterlehner, and Kampker (2016). The environment of the study was the technology predevelopment department for electric powertrain components, and a project investigating the assembly process of the battery module. Predevelopment concerns the testing of possible new innovative technologies in companies. Challenges in the department derive from high complexity, low level of carry-over, and a relatively low structure Hilt et al. (2016). The authors had in earlier studies on predevelopment identified communication barriers regarding requirements, tasks, and progress as major obstacles for overcoming these mentioned challenges.

In the study by Hilt et al. (2016), no major alterations were needed to be made to the agile practices regarding task management, as they are regarded as independent of the product. Minor alterations mentioned were a shorter planning period of two weeks, effort estimated in hours instead of arbitrary points, and a reduction of the stand-up meetings from daily to twice a week. More substantial changes had to be made to the agile practices of incremental and test-driven development. The authors defined increments as all information generated by the project, including drawings, computer-aided design (CAD) models, supplier evaluations, and patents, since the final product, the production system, was the set of knowledge gained (Hilt et al., 2016). For predevelopment, tests were understood as any type of validation of increments, including tensile tests and assembly simulations. Lastly, in contrast to software development, where functions are added and might work independently of the final product, this approach is harder to implement in a hardware environment and was after testing ultimately dropped from the project.

The authors did not manage to implement a fully agile project but instead combined agile aspects with the existing structures and circumstances of the company (Hilt et al., 2016). The results from the study showed that by separately implementing, combining, and adapting agile aspects in a predevelopment stage, communication over department interfaces, inefficient task prioritisation, and management of changing requirements was improved (Hilt et al., 2016). The methods were introduced and iteratively adapted to best fit the project. According to the participants in the study, the most beneficial method was the common alignment in the definition of done for every task, which made the work more effective. The authors assume that further value can be realised in larger projects by methods designed to increase the transparency of progress.

2.7.6. Challenges in Scaling Agile Development

At the South East European test conference 2018, Safe Journey (2018) identified several challenges when conducting an agile transformation at scale. Apart from challenges regarding knowledge of agile methodologies and management commitment, the delegates at the conference listed that coordination challenges across teams and technical excellence were among the top issues (Safe Journey, 2018).

To conduct an agile transformation that spans multiple teams, departments, or even an entire organisation, it is necessary to in some form scale the team-based framework (like Scrum) to encompass more complex organisational structures. The dependencies and longer planning horizons of larger projects increase the need for collaboration and alignment beyond the boundaries of individual teams. Coordinating multiple teams can be challenging in large-scale projects, where common guidance is critical (Francino, n.d.). Frameworks for scaling agile provide tools for using the foundation of team-based Scrum to a larger setting (Francino, n.d.). The general idea is that several agile teams can work relatively independently throughout the sprints by collaborating between larger increments. This allows for dependencies to surface and be resolved while ensuring a common alignment in the project. In Large Scale Scrum (LeSS), the activities of Scrum are simply scaled up to a team-of-teams level (Heusser, 2015). Planning ahead of a sprint, daily meetings during, and retrospectives after are all conducted both on a team level and on an aggregated level with team representatives (Heusser, 2015). Since only one product is developed, all teams share a single product backlog, managed by a single product owner (Heusser, 2015). The framework is illustrated in Figure 2.10.

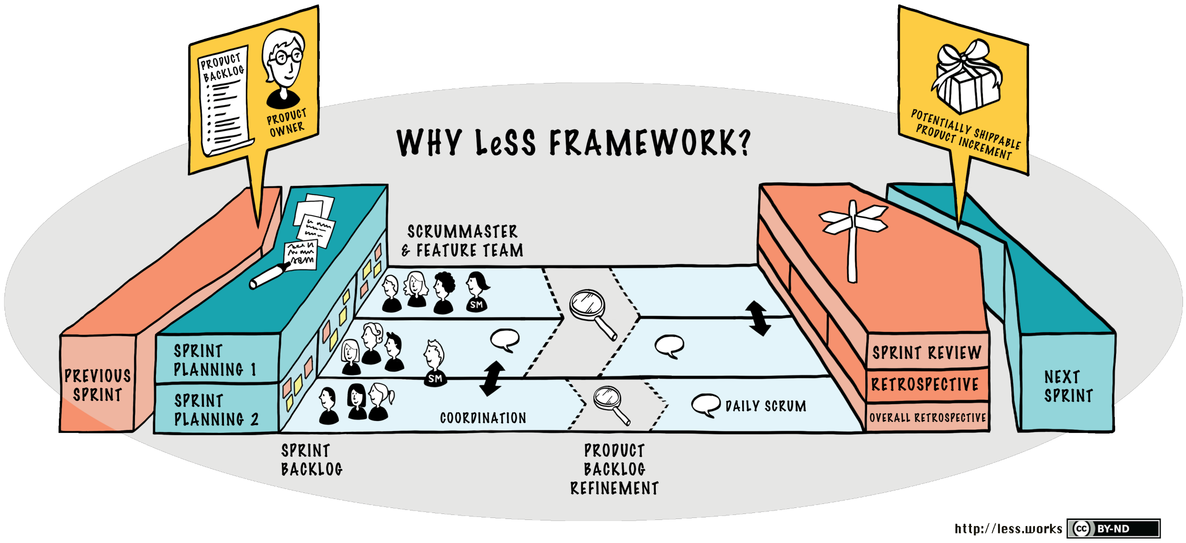

Figure 2.10. LeSS framework (The LeSS Company B.V., n.d.)

In very large organisations, where more than eight teams are required, the larger LeSS Huge framework divides the work into several requirement areas, where each area is served by a LeSS framework (The LeSS Company B.V., n.d.). The single product owner's backlog remains, but an area backlog and a responsible area product owner are added for each requirement area (The LeSS Company B.V., n.d.). The LeSS Huge framework is illustrated in Figure 2.11.

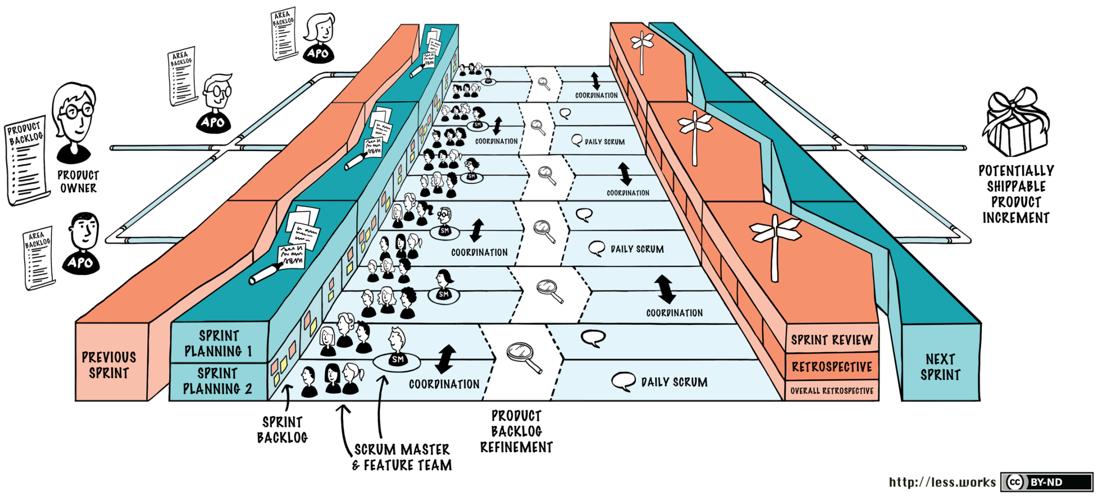

Figure 2.11. LeSS Huge framework (The LeSS Company B.V., n.d.)

Another popular framework for scaling agile is the Scaled Agile Framework (SAFe). SAFe also tries to solve the coordination issue by applying the Scrum ideas in higher levels of the company (Francino, n.d.). Above the team level which contains the scrum teams is the program level (Francino, n.d.). Here, several teams combine into a release train, which iterates every five sprints, where the combined deliveries of the teams are released (Francino, n.d.). A sixth, innovation planning sprint is also added to allow teams to innovate, inspect, and adapt (Francino, n.d.). Roles and processes are defined at the program level, which allows for consistency and collaboration across the project (Francino, n.d.). A program backlog exists, where deliverables sized for an entire release train to complete within the five-sprint increment are placed (Scaled Agile, 2020). These are called features and are then broken down to several smaller deliverables which can be implemented by single teams during a sprint (Scaled Agile, 2020). More levels can exist above the program level in different constellations, to suit different sizes of projects and companies.

Regarding the issue with loss of technical excellence, the problem can originate in the tendency of cross-functional teams to foster generalists, according to Johannes Berglind Söderqvist, Ph.D. student at the Department of Innovation and R&D Management at Chalmers University of Technology (Personal communication, November 19, 2019). According to him, the role of teams as a base for the individual instead of a function in the traditional line organisation leads to a focus on product delivery instead of knowledge gain. This can lead to a loss of economies of scale, where the best current practice and knowledge is not being shared with others working on the same kind of problems (Kniberg & Ivarsson, 2012).

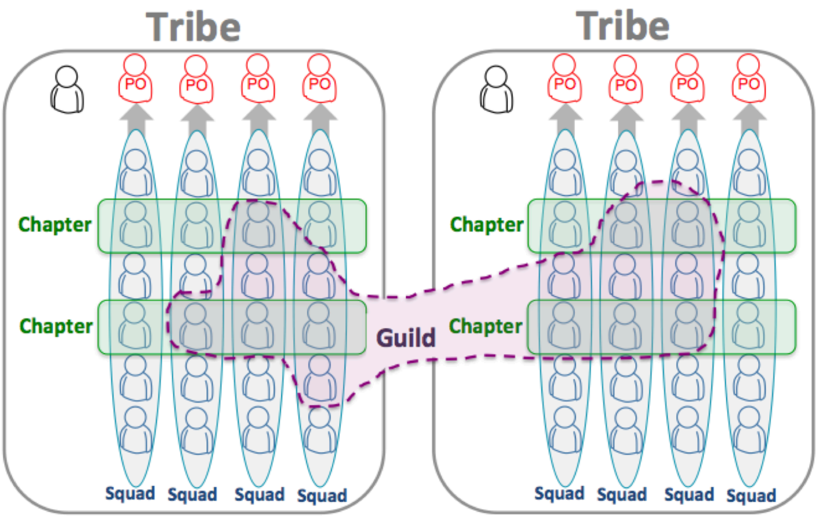

Figure 2.12. Organisation of Spotify in chapters and guilds (Kniberg & Ivarsson, 2012).

To solve the challenge of technical excellence, the building of knowledge and specialisation traditionally handled by the line organisation is instead taking place in a community of practice (Johannes Berglind Söderqvist, personal communication, November 19, 2019). A community of practice is "a group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly." (Wenger-Trayner & Wenger-Trayner, 2015). It consists of three traits, namely a shared area of interest, a shared body of knowledge, and a self-selected group of individuals who care about the topic. They can either be role-based, for scrum masters or test engineers, or topic-based, addressing for instance continuous integration or built-in quality (Scaled Agile, 2019a). Spotify uses a structure of communities of practice as illustrated in Figure 2.12. They organise teams that work in related areas in tribes (Kniberg & Ivarsson, 2012). The developers within these tribes holding similar competencies are grouped in communities of practice called chapters. The chapter is the driver of technical expertise, with a chapter lead facilitating and supporting the sharing of knowledge. The company also utilises communities of interest called guilds; a more organic and wide-reaching constellation where anyone is free to join if the topic feels interesting (Kniberg & Ivarsson, 2012).

3. Methodology

This chapter includes a description of the methodology used when conducting this study. The overall structure of the study as well as the type of study will be described, followed by an explanation of the literature study and data collection used. It also includes a discussion of the ethical aspects of the study.

3.1. Setup of Study

In the following paragraphs, the processes related to project initiation and problem formulation is presented.

3.1.1. Initiation and Commencement of Study

The project was announced in October 2019 by Gigi Cheung at the CEVT Manufacturing Engineering Department. The current project team applied and was called to an interview in early November. The project team was selected to conduct the study and while it had continuous contact with Cheung for the rest of that year, the project itself was not initiated before mid-January 2020. A meeting was held between the project team, Cheung and Charlie Berner, module team director, to assure the proper commencement of the study.

The project initially faced some struggles as the outbreak of Covid-19 prevented Cheung from returning to work after a vacation to Hong Kong and was quarantined for two weeks. The project team therefore primarily worked with Berner until Cheung was able to return in week seven. Continuous communication has however been conducted over email and Skype.

Except for CEVT, there are other stakeholders in the project that needed to be taken into account. Since this is a master thesis project to complete the M.Sc.Eng. programme of Quality and Operations Management at Chalmers University of Technology, a certain academic niveau is required. The team stays in close contact with the Chalmers supervisor Alvar Palm to assure this level is attained. Palm is also helpful in the process of finding a feasible purpose and scope for the project. The project team was also one of the stakeholders. It had its own thoughts and ideas regarding the scope of the project, wanting to assure the conformance to their skills while also providing new challenges.

3.1.2. Purpose and Problem Formulation Process

Considering how the problem was well defined by CEVT already at its announcement, the process was partly more focused on aligning this purpose with the academic demands that exist for a master thesis, including generalisability. However, the scope of the study also needed to become more precise, and the project team quickly realised that the scope could be shifted to assure a better and more profitable result.

The first few weeks of the study was spent on efforts to profoundly understand the situation as it is today. This was done through repeated interviews with key colleagues at CEVT as well as through studying the process maps available at the CEVT intranet. One of the tasks stated in the original project description was to identify the critical path of the Manufacturing Engineering process to better understand where to apply measures to shorten its lead times. After the preliminary interviews, the project team was even more convinced that understanding the system as it is today is necessary to identify areas of improvement. Consequently, the first research question focuses on providing a profound understanding of the current manufacturing engineering process.

Using the information gathered answering the first research question, the second research question looks at how to make the process more flexible to reduce lead times. This issue was mentioned in the original project description in different wording. The preliminary interviews provided knowledge about incomplete information and communication as a possible reason for delays which is why the focus is looking at ways to manage such issues.

3.2. Methodological Approach

The study is based on data collected from interviews and CEVT processes as well as theory. The data collected is primarily be qualitative and consequently, the approach and analysis is mainly of a qualitative kind. The objective is to combine theory with observations from reality and use both sources of knowledge to draw conclusions. According to Wallén (1996, p. 46), this corresponds to an abductive methodological approach. Furthermore, the study follows the patterns of a case study in which a specific situation or process is studied without the involvement of the investigators themselves in the actual process Wallén (1996, p. 115).

3.3. Data Collection

The data collection is primarily, if not almost exclusively, of a qualitative type. This qualitative data is mainly collected through interviews with relevant people within the organisation, as well as by studying the CEVT intranet. Due to the situation with Covid-19 and the two-month closure of the CEVT Gothenburg office, the project has been affected in that fewer spontaneous meetings and discussions have been possible. Certain meeting with external parties which could have provided useful information to the project also needed to be cancelled. In general, however, the people at CEVT have been very helpful and accommodating to the project, and the necessary data collection has been possible. Meetings with Geely in China were also conducted and used as a sounding board to the findings of the project.

An important aspect of the data collection process is to assure the validity of the data. It is usually divided into internal validity, examining the structure of the study, and external validity, examining the results and finding other possible explanations as to why they have been obtained (Shuttleworth, 2008). Validation is conducted continuously throughout the study by the project team. Since interviews, in combination with data from internal systems, are the primary sources of information, much of the validation work involves comparing the information obtained to assure their consensus. It is also, however, important to observe the situation from different perspectives and the information collected might vary. Through continuous contact with the

CEVT supervisor, Gigi Cheung, the validity of the interviews is assured. Certain aspects of the qualitative data are also validated using external references and literature. To further evaluate the validity of the study, and to receive a truly external perspective of the study, the project team takes advice from the Chalmers supervisor, Alvar Palm.

Another important concept in data collection is reliability, which is defined by Shuttleworth (2008) as the ability to reproduce the results of a study. The reliability of a study is influenced by the reliability of the collected data as well as the processing of this data. Since most of the data is of a qualitative type, it is not possible to assess its validity quantitatively. Instead, the reliability is assured by describing in detail how the interviews were conducted and how the information provided was processed.

3.3.1. Interviews

The interviews can be divided into two phases. The first phase is of a more explorative kind where the goal of the interviews is to develop a better understanding of the organisation, their challenges, and possible solutions. These interviews have mostly been of a semi-structured kind, which according to Davidsson and Patel (2011, p. 82) implies that the interview is constructed of a couple of pre-set questions around which a discussion is conducted. Since the goal was to develop an understanding rather than receiving answers to particular questions, this was seen as the most appropriate method for this phase. Three interviews have also been of an unstructured and open kind, where no questions are prepared in advance (Academic Work, 2020). In such an interview, much of what is discussed is decided by the interviewee. The interviewees in the first interview phase were selected after recommendations by and discussion with our supervisor at CEVT. They were deemed to be able to provide a broad overview of the current situation and challenges of the ME function. The interviews that have been conducted in the first interview phase are presented in Table 3.1, together with the interviewee's role and type of interview.

Table 3.1. People interviewed during the first exploratory interview phase.

Department	Role	Type of interview
ME	Unit Project Leader, Shared Tech	Semi-structured
ME	Unit Project Leader, Running Change	Semi-structured
ME	System Manager, Geometry	Semi-structured
ME	System Project Leader, Trim & Car Final (TCF)	Semi-structured
Emerging Technology	Agile Coach	Unstructured
ME	Module Team Director, Geometry and Projects	Unstructured
ME	Process Development Manager	Unstructured

Once a sufficient understanding of the situation had been developed and the actual analysis had commenced, the interviews became more detailed and specific. Here, the interviewees were referred to us by people from the first phase, but some were also people who showed an interest in the thesis work. Relevant experience in the process phases identified as most interesting to examine further was a criterium for the interviewees. Some people from the first phase were interviewed again in the second, but under a different pretext and with different questions. These interviews lay on the spectrum between structured and semi-structured interviews, and the goal no longer is to explore, but to receive answers to specific questions. To have a discussion was however encouraged also in this later stage. The interviews that have been conducted in the second interview phase are presented in Table 3.2, together with the role of the interviewee and type of interview. The interviewees within ME were selected together with the supervisor Cheung to provide a complete understanding of the two most prominent ME units. After these interviews, the project team realised the need to include the perspective of R&D as well. Consequently, with the help of the ME interviewees, relevant people in the R&D organisation were identified and contacted.

Table 3.2. Interviews conducted in the second interview phase, not including people interviewed again.

Department	Role	Type of interview
Digital Manufacturing & Servicing	Manufacturing Method Developer	Unstructured
ME	System Engineer, Body-In-White (BIW)	Semi-structured
R&D	System Manager, Body-In-White	Semi-structured
ME	System Project Leader, Trim & Car Final (TCF)	Semi-structured
R&D	Unit Project Leader, Body-In-White	Semi-structured

After the interviews of the second interview phase, multiple follow-up questions were asked to clarify and develop the information obtained. Additionally, to assure the accurate depiction of the interviews in the report, the respective citations were sent to the people concerned for confirmation. Feedback was collected and some minor alterations were made to the text to explain certain aspects better.

During the interviews, one team member was primarily responsible for asking questions while the other took notes. The interviews were not recorded to assure an open setting in which the interviewee could speak freely. To analyse the collected information, the most important aspects were highlighted and continuously discussed with the project supervisor. Purely personal opinions expressed were considered but to assure objectivity, such statements were compared to other information collected.

3.3.2. Other Qualitative Data

In addition to the interviews, the project time conducted weekly meeting with the CEVT supervisor to discuss the progress. Sometimes during these meeting, supplementary relevant information was collected. The project team also had recurrent meetings with Geely in China and Germany to develop an understanding of their work and to receive feedback on the study.

CEVT has over its existence developed an extensive database describing the organisation and the processes occurring within. Accessible through the CEVT intranet, the database has proven to be a useful tool in the efforts of the project team to understand the situation as it is today. The product development system, and especially the manufacturing engineering processes, have been given much attention and is described further later in the study. It is however important to remember that this database is CEVT property and that it cannot be shared in its entirety in the final report.

3.4. Ethics

Research ethics is a concept looking at the impact of a particular study on people and the environment. In a broader sense, it also involves research fraud and things related to that (UHR, 2016).

The ethics in this project primarily involves the people being interviewed, as well as the organisation behind them. It is important to assure that the interviews are not intrusive and that the interviewees are comfortable with the questions asked. The usage of the data collected in the interviews should reflect what was communicated and conclusions drawn by the project team should be well supported.

Additionally, since one focus of this project is to provide suggestions for how to improve a particular process, it is important to take into consideration the ethical aspects of such a change. Bamford and Forrester (2003) talk about individual and organisational resistance to change and how many different factors influence to what degree an individual embraces change. Changing processes within CEVT inevitably have an impact on the work of the individual and it is necessary to assure that this impact is of a positive and improving kind.

4. Introduction to Manufacturing Engineering at CEVT

The purpose of this chapter is the provide an introduction to the subject of this study, namely, the manufacturing engineering function of CEVT. The chapter is divided into two parts. First, the organisation of the ME function will be illustrated. Second, the manufacturing engineering process will be presented, providing both an overview and a more detailed description of the constituting activities.

4.1. CEVT ME Organisation

CEVT is, as described in chapter 1.1, a development centre fully owned by Geely Group, with the responsibility to conduct part of the research and development for several companies of the group. The purpose of having a separate R&D company is to encourage specialised and centralised competence in combination with the efficiency of economies of scale. With the other Geely Group companies maintaining their separate R&D organisations as well, the new product development process requires extensive coordination also between the organisations.

The organisation of manufacturing engineering is at CEVT located under R&D, but functions as a separate organisation with a distinct structure. The organisation is led by the vice president for manufacturing engineering, located below the senior vice president for all hardware research and development except that of electronics in the organisational hierarchy. The members of the manufacturing engineering functions are organised according to areas of responsibility, corresponding to the manufacturing process in the factories. This structure is shown in Figure 4.1, also depicting the sequence of the manufacturing process steps.

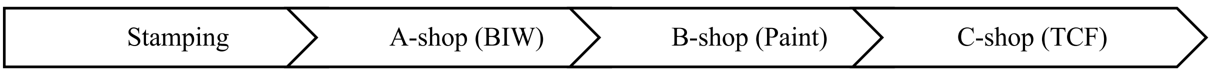

Figure 4.1. Manufacturing process layout, corresponding to the manufacturing engineering organisation.

In total, within ME there are five different functions. Body-in-White (BIW) and Trim & Car Final (TCF) have the most analyses to conduct and have the most engineers allocated. TCF is responsible for the final step of the assembly process, also called C-shop, in which the car is completed. It is the largest function with most parts to evaluate. Since it examines the final assembly phase, it is dependent on the work of other functions. BIW is responsible for the second assembly phase, or A-shop, where the body of the car is produced. The emphasis is upon the joining of parts rather than the number of parts, and it still requires extensive analyses.

The three other ME units are smaller but are still conducting analyses essential to the process. Stamping is responsible for the first manufacturing phase where metal sheets are pressed into the shapes that are to be assembled to form the car. Paint is responsible for the third phase, where they look at how to apply different types of paint and anti-corrosive coating to the car. Lastly, in addition to the functional areas of responsibility presented in Figure 4.1, there is also the geometry function. This is a much smaller group working dispersed over several projects. They work together with both BIW and TCF to assure that the parts fulfil the pre-set tolerance limits.

In addition to belonging to a unit based on their area of responsibility, the individual engineers are organised according to the product system structure, or PSS. There is a large number of parts in a car and to reduce the organisational complexity, they are categorised according to their role and placement in the car, in what are called function groups. Similar function groups are then grouped to form a PSS. These still have some dependencies with other PSSs, but they are not as numerous as within the structure. This way of organising the work of individual engineers according to the PSS is used by R&D as well. The ME engineers can be responsible for more than one PSS, or parts of one, but the parts they are responsible for all relate in some way.

The engineers of the ME units have traditionally primarily belonged to their functional groups. However, due to recent restructuring, the organisation has moved from a more functional structure to a more project-based structure. In this new organisational structure, the responsibility for resource allocation and budgeting has been moved from the function to the project. Still, however, the engineers belong to a function corresponding to their area of responsibility. Under the new structure, some ME engineers are collocated with their R&D counterparts to improve collaboration. The projects tend to be extensive, covering the development of an entire car, although some are updates of pre-existing ones. The projects tend to be realised over a long period, often spanning years.

Manufacturing Engineering at CEVT is part of the much larger new product development system of the Geely Group and works in close collaboration with the ME function at Geely. The tasks are divided between the two organisations so that activities involving the factories to a greater extent are conducted by Geely, while activities requiring more R&D involvement are located at CEVT. Previously, more activities were located at CEVT, but as the Geely ME organisation has become more mature, it has become possible to allocate more activities there.

4.2. CEVT ME Process

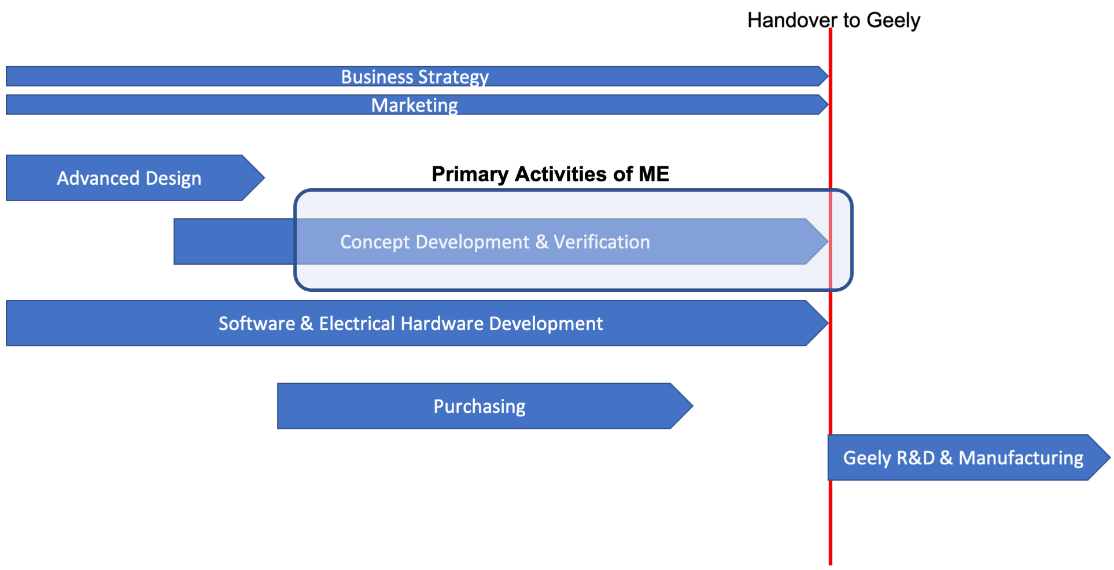

Figure 4.2. Simplified process map of the CEVT organisation with primary activities of ME highlighted.

The development process of the manufacturing engineering function at CEVT consists of six primary activities and is closely related to other functions both within CEVT and externally at Geely. Taking a holistic approach to an entire project at CEVT, it is possible to put the ME activities into a bigger perspective. The position of the ME activities in the overall product development process is presented briefly in Figure 4.2 above. ME has connections both upstream and downstream, and there are other activities conducted by other functions occurring concurrently.

4.2.1. Overview of CEVT ME Process

As described in section 2.1.1, Holweg et al. (2018) define a process as a transformation containing sequential activities turning inputs into outputs. This definition can be used as a foundation to describe the manufacturing engineering process at CEVT. The purpose of this chapter is to provide an overview of the process by describing the overall inputs and outputs, as well as the transformational activities occurring.

Input

The input of a process can be divided into the resources being transformed, and the resources required for the transformation process. For the transformation resources, the main inputs for ME are the virtual designs and specifications developed by the developing functions of CEVT R&D. As the bulk of ME's work is conducted by testing, simulating, and modifying drawings in a virtual environment, these models are essential for enabling an efficient and effective process. By not engaging with physical prototypes for as long as possible, the cost and time of change are greatly reduced.

To ensure manufacturability, requirements, restrictions, and guidelines from a production point of view are critical inputs that enable the ME process. These are used as a baseline that the process aims to fulfill. For instance, ergonomic tests and simulations examine load, angles and reachability to ensure a comfortable and sustainable assembly of the vehicles. Other types of purchasing and legal requirements combine to create an intricated process where a holistic perspective is needed to avoid suboptimisation.

The development process is characterised by the need for continuous improvement and learning. Knowledge builds constantly throughout the projects and over time builds a knowledge base, both for the individual employee and current development projects as a whole. Therefore, annual work and lessons learned through earlier challenges create a powerful resource required in the transformation process. This input is used to avoid pitfalls and increase the efficiency and effectiveness of the work.

Output

The purpose of the manufacturing engineering function at CEVT is to assure the manufacturability of the vehicle designs developed and to deliver assembly instructions to the Geely Group factories in China. The activities conducted by ME at CEVT are part of a much larger new product development context where most Geely Group companies and their respective manufacturing organisations are involved. The responsibilities of CEVT essentially end after the virtual ME analysis and the subsequent activities necessary are conducted by the individual Geely Group companies. While the general ME process outputs are described here below, the outputs of the individual activities conducted are examined in chapter 4.2.2.

Staring by examining the first purpose mentioned of ME at CEVT, to assure vehicle manufacturability, the primary customers are the product development functions. ME is supposed to deliver part-specific feedback on the design released provided by R&D, assessing the intended assembly and signalling if a part is difficult to assemble. This is currently delivered iteratively, with a new assessment conducted after each design release. Included as output here is also to deliver a process risk assessment, an FMEA, which will be described more in detail in chapter 4.2.2.

The second type of output is more directed toward the factories and the ME organisations of other Geely Group companies, namely, the delivery of assembly instructions. These assembly instructions are created continuously throughout the process as design evaluations are finalised and deemed ready to be transferred to one of the other companies. Once the information has been passed on, it is difficult for ME at CEVT to make any changes if needed. Although the Chinese organisation can make the required changes as well, the goal is to change at little as possible after the responsibility has been handed over.

Connected to the second type of output is the handover of projects to Geely in China. As described in chapter 4.1, ME at CEVT is only responsible for part of the manufacturing engineering process and the tasks involving the factories to a greater degree are managed by Geely. As a result, there needs to be an official handover for when a project, or parts of a project, are transferred from CEVT to Geely. This is done separately for each ME unit, and documents are specifying in detail what is to be discussed and gone through for each delivery. It is, however, also possible to include additional aspects of the project in the delivery if deemed necessary by one of the parties. Once the formal handover is complete, the involvement of CEVT is limited. In a situation where not all of the requirements are met, or if there are disagreements, there is a plan for how such a situation should be managed and escalated.

Transformation

The transformation is the sequence of activities that turn inputs into outputs. Within the manufacturing engineering function of the CEVT new product development system, there are six distinct process phases, which can be seen in the synoptic process mapping shown in Figure 4.3. The activities of these process steps often occur concurrently and are integrated into each other. Each phase and its relationships to other both functional and external activities will be described in chapter 4.2.2.

When manufacturing engineering at CEVT first becomes involved in a project, the ME function commences by conducting two activities concurrently. Firstly, they establish a list of requirements that ME have on the vehicle to be developed, something done by the other R&D functions as well. Secondly, they create a Bill of Processes, which is a detailed plan explaining the various manufacturing and assembly processes that need to be conducted. Linked to the establishment of requirements, and conducted subsequently, is the activity of system selection. Here, all R&D functions evaluate the different systems solutions suggested and provide feedback to the vehicle integration function.

The other three manufacturing engineering activities at CEVT are performed concurrently throughout the remainder of the project process. It is within these three activities that the bulk of the ME work is conducted. The virtual analysis of the manufacturing process is the most important one and occurs once the first design concept release has been made by R&D. The assembly of part is analysed in detail and feedback is given to R&D. The virtual analysis is conducted iteratively in cycles, and the feedback provided to R&D is used in the subsequent cycle. In parallel to the virtual analysis, ME conducts a Failure modes and effects analysis, or FMEA, of the process to identify risks and enact preventive measures to mitigate them. Also, simultaneously, ME creates production and inspection instructions.

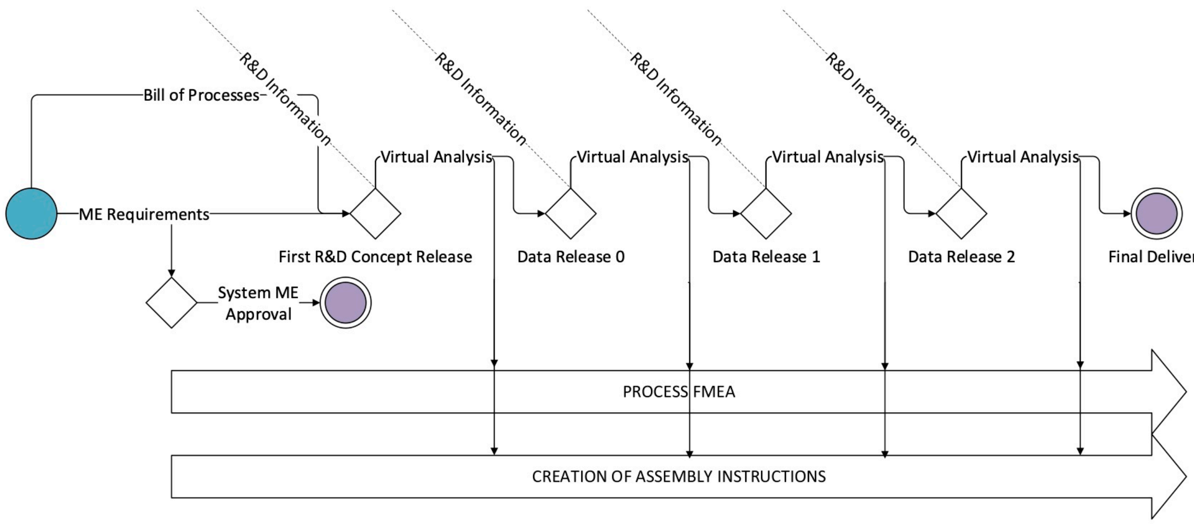

Figure 4.3. The ME development process at CEVT, with activities specified.

The ME work correlates to a set of gates that are common for the entire CEVT organisation. The virtual analysis work is commenced after the design concept release by R&D. This design data is updated in cycles with a new virtual analysis conducted after each new release. The virtual analysis work ends with a final data judgement after which the ME organisation at CEVT transfers the majority of its responsibilities. After the final data judgement, the development becomes much more physical.

In addition to the activities conducted by manufacturing engineering at CEVT, many other activities linked to ME are conducted by other organisations of the Geely group. The ME organisation at CEVT is mainly responsible for the earlier stages of development, where no or few physical parts have been constructed or ordered. After the delivery of vehicle designs and assembly instructions, the ME organisation of the customer (often Geely) itself is responsible for the factory layout and tool planning for the manufacturing. This division of labour is a result of the special position of CEVT as an innovation and R&D center owned by Geely Group, serving internal customers. The related activities have a strong connection to ME at CEVT and a holistic view is critical to avoid suboptimisation of the manufacturing process. Continuous information sharing and collaboration regarding these activities are taking place concurrently with the main activities at CEVT ME, but the customers are responsible and own those linked activities.

4.2.2. Activities of the CEVT ME Process

Below, the six primary activities conducted by the manufacturing engineering function in a development project are presented. All product development activities at CEVT is structured according to a product development system. A process development manager at ME explains that the system was originally modelled after the one used at Volvo Cars. Geely and CEVT released their own, updated version of the system in 2017, adapted to better suit the organisations in the Geely Auto Group. Today, it is used in all of the Chinese Geely brands. According to the manager, the product development system is updated and aligned occasionally to best fit the work practices.

Bill of Processes

The Bill of Processes is a tool that illustrates the operation sequences at the plant, and it is used as an aid to develop and refine the production systems. It should ensure that production lines are balanced and optimised and that the product and the related processes are compatible. In a project, bills of processes are conducted at different levels of detail, with the bill created becoming gradually more specific and extensive as the project progresses. The first level, or level 0, is simply looking at the plant layout while the last level, or level 3, corresponds at large to the assembly instructions created in a separate activity. Only the bill of processes of level 1, corresponding to the logical level of each shop, needs to be created before the virtual analysis work can commence. Higher-level bills are created later, by CEVT or Geely ME.

One of the purposes of the bill of processes is to support the reuse of assembly processes across plants. Consequently, in general, for a new car development project, an existing bill of processes is used as a foundation which is then gradually adapted to the new car to be developed. In many of the projects at CEVT, the new car is to be produced in a factory where other cars are already being produced. In that case, CEVT ME becomes dependent on a pre-existing bill of processes from Geely China to create its own. According to the system engineer at BIW, the collection of that information tends to be a time-consuming activity, and the process is normally faster when they are allowed to create it independently.

For the creation of the bill of processes necessary for the virtual analysis, the work is done concurrently with the establishment of the ME requirements. According to a system project leader and a system engineer interviewed, the creation of ME requirements does, however, take longer than the creation of the first levels of the bill of processes. Additionally, the bill of processes created is not directly fed into the virtual analysis at first but is used by R&D as a form of requirements.

ME Requirements
ME Requirements is a process whose purpose is to deliver requirements to R&D to ensure manufacturing feasibility, to prevent problems in production, and to facilitate improvements in development. These requirements can be seen as the rules R&D has to abide by when developing the car from a manufacturing point of view. ME then verifies the abidance during the development process. Each ME engineer is responsible for creating the requirements for the parts she is in charge of. Not all requirements need to be created from scratch for each project, but many can be carried over from previous experiences. This is especially true when the output of the project is the first car built on a new platform. The process then takes less time to complete. If the project is developing a car on a platform where there is already a car previously developed, the process is more time-consuming. This is because a negotiation needs to take place between CEVT ME and Geely ME to decide which set of requirements are to be followed and updated, the one that CEVT uses or the one adapted by Geely. It is necessary to establish how similar they are to each other and if they then can be combined in any way. Additionally, when developing a new platform, the development of ME requirements is a highly time-consuming activity.

The development of ME requirements takes place concurrently with the creation of the first levels of the bill of processes, described above, and it is the long process of the two. The requirements take on average two to three days for each ME engineer to develop and handshake with the corresponding R&D engineer. The entire process can however take up to two weeks for each function, as the system project leader responsible for the requirements facilitates the meetings and attends them all.

System ME Approval
In the early stages of a vehicle development project, a lot of different design alternatives can be under consideration in parallel. Among other things, engineers need to evaluate what parts can be carried over from previous projects and which ones need to be newly developed. Using the product system structure, described in section 4.1, parts are grouped in systems according to function areas to reduce complexity. The System ME Approval process is the evaluation of a potential system alternative from a manufacturing point of view. This is then used as feedback to best decide which system to select move forward to further development.

The evaluation that takes place is owned by ME but mostly conducted by R&D. The R&D functions evaluate their respective parts from a set of criteria, and ME then decides if the system solution can be considered approved or not. Any detected deviations or items deemed not okay should be followed up by R&D as the project progresses. Apart from using the output to guide the system selection, the process's results are also used for FMEA analysis to detect potential failures in later stages of development, described in detail later in this section.

Virtual Analysis of Design Manufacturability
A big part of vehicle development at CEVT is concentrated around the virtual analyses, where vehicles under development are evaluated to verify that requirements are fulfilled. Conducting analyses on using virtual verification tools like CAD measurements, simulations and CAE

evaluation without subjecting physical objects to testing saves time, money and increases the flexibility of the processes. There are a lot of different requirements related to vehicle development, both from internal and external stakeholders. In total, five different analyses, excluding internal analyses of R&D, are conducted by different departments corresponding to different kinds of requirements. The evaluated areas are geometric compatibility, perceived quality, geometric quality, serviceability evaluation, and manufacturing evaluation. CEVT ME is responsible for the fifth one, where the manufacturing feasibility is ensured. The analysis uses the ME requirements and Bill of Processes as input required for transformation, and the models and data from R&D as the transformative resource. In addition to those process outputs, standards common to all projects and suggestive guidelines are also used to make the analysis as comprehensive as possible. Each new release from R&D results in a new iteration of the analysis, and the output from the analysis feeds back to R&D as change requests for the designs.

The two major types of projects conducted at CEVT are platform or architecture-related projects, called shared tech, and projects related to specific car models. The two types of projects often relate since car models in development are supposed to be running on the shared tech being developed concurrently. Shared tech projects are scheduled so that the final virtual R&D release of the platform design serves as input for the car projects' virtual analysis. Since the car models' body and technology are all connected to the platform through various interfaces, and the platform is supposed to be a common base for several models, platform designs cause restrictions in car model development.

According to a ME BIW engineer, a data release is normally made on a Friday by R&D, and the ME engineers start their virtual analysis of the data the following Monday. The time needed to conduct a complete analysis varies between five and seven weeks and depends on the number of parts that need to be analysed. During the ME virtual analysis, change requests are created for parts that are not approved. A change request is a document with issues for different areas that are identified during analysis. These documents form the basis for the work to be conducted after each virtual analysis iteration. A weekly decision meeting is held with R&D to decide on what actions are to be taken with the issues found. ME and R&D can have different opinions, and different criteria such as time and cost are used to decide on a solution.

When ME has completed the virtual analysis, the results are presented at a design verification meeting, with short presentations from each unit highlighting the biggest issues. R&D and ME work more or less together to resolve each problem, with R&D beginning to resolve issues before ME has completed the analysis. The result of this problem resolution process might be an update to the existing part, an entirely new part, or that the issue is resolved in another way. If a change is made, the part needs to be revised again. This process is repeated for each release, with new evaluations, and consequently new change requests created and resolved. An overview of such an iteration is shown in Figure 4.4, with the meetings with R&D to be described further.

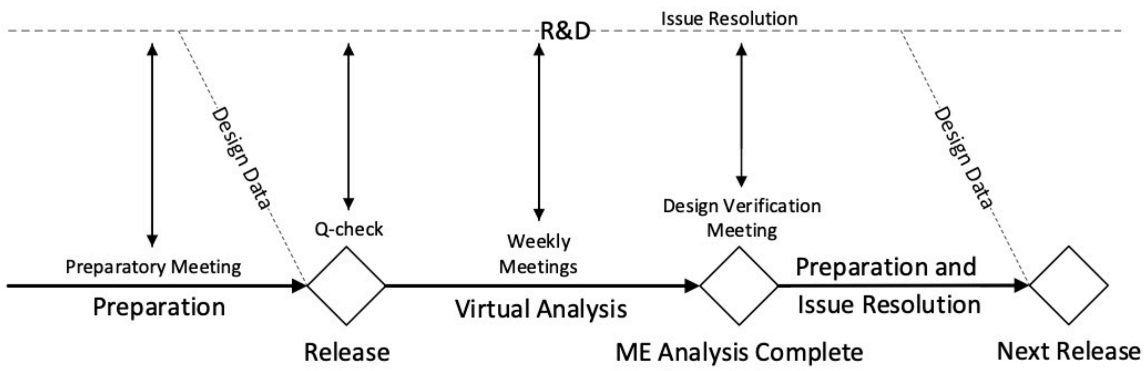

Figure 4.4. An iteration of the virtual analysis of the manufacturability.

The change-request documents are used to register and communicate issues on designs, and to keep track of their status. Ideally, according to the process development manager, they should all be dealt with and closed before the transfer to Geely. However, within the organisation, some people experience that the creation of such documents is mainly for the benefit of Geely. A system manager states that extensive documentation is not the most efficient way to handle non-conforming parts, instead a more continuous communication with R&D is preferred. Geely uses the number of created change requests as some type of performance measure. At CEVT, however, it is the share of approved parts that is used as a KPI for the virtual analysis.

For each iteration of the virtual analyses, i.e. after each design data release, there is a set of criteria used to evaluate each part. For the analysis conducted on the first data release, or the concept release, the criteria are unique and more superficial. For the other iterations, however, the criteria do not change very much. The criteria used are also different for different functions within ME, corresponding to their responsibilities.

In the analysis process, the idea is that R&D should release a close-to-complete concept in the beginning and that ME should identify issues in this design concept and together with R&D resolve them. Each subsequent iteration should identify more issues to be resolved, but the design concept at its core should not change very much. This is not the case in reality, according to an ME Body-In-White engineer, and quite large changes are often made to the design also in later stages which must be dealt with. After the data release leading up to the final iteration of virtual analysis, in theory, R&D is not supposed to make any more alterations to the designs. This is nevertheless often the case, forcing additional release cycles that affect not only CEVT ME but all involved departments, prolonging the project. These late design changes are often derived from Geely top management, overruling previous CEVT R&D decisions.

The process as described in internal documents is fairly sequential, as seen in Figure 4.4, with data and information being transferred back and forth between R&D and ME. Three days after a release, a meeting is held to determine if the released data is complete and mature enough for a virtual analysis to be conducted. During this meeting, called Q-check, there is not much discussion of discovered issues held between R&D and ME. There is however a meeting, called engineering release confirmation, that has been implemented by teams to improve the communication between the two departments during the analysis process. This meeting is held by the ME project leader two weeks to two days before R&D is set to release a new set of data for ME to analyse. The purpose of the meeting is to walk through the problems that until then have been found regarding the manufacturability of the designs and present the engineering areas' expected status for the upcoming release event. This aligns the two departments better in their work. With ME sharing the biggest errors found before a release, R&D can be more prepared for the changes that have to be made and also have more time to modify the designs for the next release. The engineers at TCF also take part in a weekly vehicle integration meeting, where the current status of the virtual analysis is presented together with Vehicle Integration. Vehicle Integration is the unit in R&D that is responsible for ensuring the final packaging of the complete vehicle and is among other thing responsible for that R&D actually releases the design at the set events. Little to no discussion is held is this meeting, it is mostly a presentation from Vehicle Integration that TCF listens to.

The data released by R&D at the beginning of each iteration of analysis is frozen, meaning that the data is not changed during the analysis. However, the ME Body-In-White engineer describes that changes to the design might occur between releases as well, creating updated versions, or what is called the *latest published*. Engineers working on the frozen data release and not taking the latest published into account will consequently work on outdated data. The update is not automatically made available to the engineer who must be attentive to avoid double work. Additionally, if the change occurs late in an iteration and the analysis is not possible to fully complete, and the timeline is not changed due to such a change, the part will be transferred with errors to the next release iteration.

A Process Development Manager at ME explains that a system is currently being implemented within the ME organisation to increase the visualisation of the progress the analysis conducted after each release. In this system, it is possible to look at each part to see if the evaluation has deemed it ready or not, and what aspects of the evaluation that are not approved. The criteria that are used by each ME unit to evaluate each phase are also visualised, as well as their respective status. The system is updated continuously, allowing users to see the progress in almost real-time. Every ME unit has a system page for each analysis iteration, but they are all collocated in the company intranet.

It is also possible to expand the view to see the status for each function group and each PSS, as well as the overall ME project status. Using the system, one can quickly obtain an understanding of the project and see what tasks and evaluations remain. Additionally, connected to the system is the status of the change requests created, creating traceability between part evaluation and the evaluation of issues identified. This supplementary change request tracking system provides ways to escalate problems if an adequate solution is not found.

A developed car is rarely entirely new, and many features of the previous version can be used in a subsequent one. A manufacturing method developer at CEVT describes that when a new car development project is commenced at ME, there are usually several such carry-over parts, parts that are the same and serve the same purpose in both versions. In the virtual analysis, it is usually not necessary to evaluate carry-overs since they have already been evaluated in a previous project, provided they have not been affected by any other changes in the manufacturing process. If the ME organisation knows in advance which parts that are new and need to be evaluated, and not, it is possible to avoid conducting unnecessary analyses. This information is provided by R&D, but in a much later stage in the process than when it is first needed.

Process FMEA

FMEA is an abbreviation of Failure Modes and Effects Analysis and is a standardised method for predicting possible failures, evaluating their consequences and suggesting appropriate measures to avoid them. The PFMEA, an FMEA for processes, is conducted to analyse and improve the manufacturing process. At CEVT ME, the goal is to identify and correct potential failures in an early phase to avoid the consequences of problems and changes. It includes the methods of design for manufacturing and assembly and should enable proactive improvements to the process. Consequently, the output is recommended actions to mitigate the identified risks. It includes more than manufacturing feasibility and ergonomics, with for example the risk human errors being evaluated.

The PFMEA is conducted by both ME at CEVT and Geely with the earlier steps being conducted by CEVT, corresponding to what occurs before the project handover. At CEVT ME, the analysis is supposed to be conducted concurrently with the virtual analysis, but this is not always the case. The CEVT part of it is supposed to completed before in time for the handover with a PFMEA status report being delivered. The PFMEA is also closely linked to project quality assurance and robustness engineering, activities not conducted by ME. Potential design and process risks might be discovered by either analysis, and such information should be communicated by either organisation to the other.

Creation of Assembly Instructions

For each new car model developed, a set of instructions needs to be created to describe the sequence of assembly at the factory. Each part also needs inspection instructions to guide the factory worker in the assembly process to check for abnormalities in the parts. The input for the instruction creation process is the Bill of Processes and the PFMEA analysis. The purpose of the process is to describe all of the information needed to perform the assembly and control operations for a part or product. It should fulfill the quality, efficiency, ergonomic and functional requirements set during the development process.

This process is only partly owned by CEVT ME with Geely overtaking more and more of the process. If the process is owned by CEVT, complete instructions are delivered to Geely at the handover of the designs after the virtual analysis. The complexity and time required to complete these instructions can vary between ME units. One factor affecting the process is the number of parts a particular function is responsible for and how those parts are assembled. Some ME units have also to a varying degree transferred the responsibility for creating these instructions to Geely in China. This is another factor that greatly affects the time required and the complexity of the instructions. Some units create more shallow assembly instructions in a more visual format, while others create more detailed documentation.

5. Findings and Analysis

In this chapter, the background information of chapter 4 and the theoretical framework is combined with empirical findings of the conducted interviews to analyse the process and organisation of CEVT ME. The chapter is divided into three parts, reflecting the three research questions. The two initial parts are of a more descriptive type while the last part is more prescriptive. In the first part, the ME development process and its activities are examined to identify the critical path. The second part further analyses the process to identify barriers to increased efficiency primarily targeting the bottleneck activities identified. The third and final part of the chapter aims at identifying ways to make the process and organisation more efficient by applying suitable methodologies.

5.1. Critical Path of the Manufacturing Engineering Process

As mentioned in section 2.1.3, the critical path method is used to identify bottleneck activities that affect the overall lead time of the process. This indicates which activities should be targeted for process improvements. The sequence of activities within the ME organisation that affect the internal process lead time is analysed using information collected from interviews with ME personnel. Additionally, according to the process development manager, one can look at the entire product development process of CEVT to identify which ME activities that directly influence the overall process lead time. The critical path will thus be examined from two perspectives differing on scope.

5.1.1. The Critical Path from an Internal ME Perspective

Examining the internal ME process chronologically, as described in section 4.2.2, the first two activities are the development of ME requirements and the creation of the first level of the bill of processes. The two activities occur concurrently and are an important step also for the work of R&D. As further mentioned in section 4.2.2, the creation and confirmation of ME requirements is a process that takes around two weeks with each ME engineer requiring two to three days. The work for each ME engineer is conducted sequentially since the project leader needs to be present at all meetings. The creation of the first level of the bill of processes is a faster process, especially a pre-existing one can be used. This activity is usually commenced at the same time as, or slightly before, the ME requirements and is thus finished before ME requirements as well. Consequently, out of those two activities, the development of ME requirements is on the critical path of the internal development process. This is as presented in section 4.2.2 also true in a situation when the activities are dependent on information that needs to be collected from Geely in China.

After the first design concept release, three activities in the ME process occur more or less concurrently. These activities are the virtual analysis of manufacturability, the process FMEA, and the creation of assembly instructions. As explained in section 4.2.2, the bulk of the ME work is conducted in this phase and it is a major determinant to the overall process lead time. In general, it is the tasks related to the virtual analysis that require the most effort. According to the system engineer at BIW and system project leader at TCF, the faster an engineer can complete her analysis, the sooner she can commence resolving issues. Furthermore, they argue that the lead time of each iteration is dependent on the individual engineer. According to the new product development system, the virtual analysis should take approximately six weeks, but in reality, some engineers can complete their evaluations a lot faster. The system engineer and manager claim that such engineers have better communication with R&D. Nevertheless, they argue that for all ME engineers, the tasks related to virtual analysis lies on the critical path, but the individual disposition of those tasks differs.

According to the system project leader at TCF, the creation of assembly instructions can also be an extensive process, especially for the TCF unit. Instructions need to be created for each part, and consequently, the time required increases linearly with the number of parts. The system engineer at BIW states that the TCF unit is responsible for the largest number of parts and it is, consequently, the unit where the creation of such instructions takes the most time. According to the system project leader, the time required to create the instructions is also individual-dependent and it is influenced by the experience of the ME engineer. An experienced ME engineer often works proactively, continuously creating and updating the instructions as the project progresses. Other engineers, however, wait until the end of the virtual analysis to create all of their assembly instructions. For such engineers, the activity can become a bottleneck. According to the system project leader at TCF, if an engineer is late, it results in overtime rather than the postponement of the transfer to Geely.

However, according to the module team director, the plan is to transfer the responsibility of assembly instruction creation to Geely, with only some preparation work will remain as CEVT ME. This corresponds to the current practice in the BIW unit which according to the system engineer creates less detailed instructions that require less time to complete. This allows the activity to run more in parallel to the virtual analysis and it is not on the critical path.

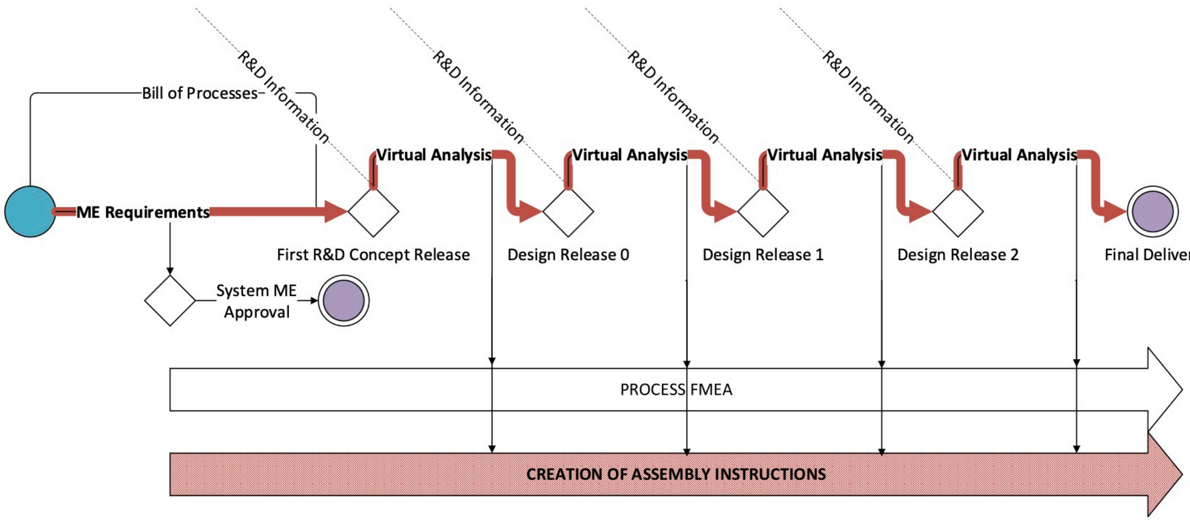

Figure 5.1. The ME development process at CEVT with the critical path marked in red.

Using the process map presented in section 4.2.1, and the activities identified as driving lead time internally, the critical path of the ME process is presented in Figure 5.1. above. This mapping does not include the perspective of the entire development process and the activities driving overall lead time. This perspective will be presented in the following section.

5.1.2. The Critical Path from a Holistic CEVT Perspective

By adopting a more holistic perspective of the product development process at CEVT, it is possible to identify a critical path for all development activities. In a document provided by the process development manager, the sequence of activities that are drivers of lead time for an entire project is presented. This critical path includes all CEVT function as well as the purchasing and manufacturing departments at Geely. This document shows that the activity of verifying designs and concepts, i.e. the five virtual analyses presented in subchapter 4.2, are a substantial driver of project lead time. If the objective is to reduce the lead time for an entire project at CEVT, the entire project progression needs to be considered.

Considering the impact on the overall lead time of new product development at CEVT as well as the internal ME process, it is evident that the ME activity most associated with the critical path is the virtual analysis. The document provided shows that the establishment of ME requirements does not affect the overall lead time of a project. The same is true for the creation of assembly instructions, however time-consuming for individual engineers. Consequently, if the ME process is to be made more efficient, the effort should be deployed to the activity of virtual analysis and the tasks related to that.

5.2. Barriers to a More Efficient and Flexible Process

The activity identified in the previous subchapter as the primary driver of lead time in the ME process is the virtual analysis of manufacturability of the product designs provided by R&D. All people interviewed in the ME organisation, but in particular the unit project leaders, emphasise that changes and updates to designs occur recurrently throughout the ME process and influence ME work. The ME organisation must incorporate the sometimes-sudden changes in its analyses to avoid outdated evaluations. Consequently, ME must be attentive to changes, and flexible in how to incorporate them into their evaluations. It should be noted that the function has improved in this regard over the years and are in many aspects regarding flexibility performing well.

As described in section 2.3.1, flexibility and efficiency have traditionally been seen as a trade-off. Efficiency normally requires high levels of standardisation, formalisation and specialisation which conflict flexibility. Through lean and agile product development, however, companies have been able to bridge this trade-off. At CEVT ME, the concepts of flexibility and efficiency go closely together as the ability to deal with changing information and requirements directly influences the overall process efficiency. The system engineer and the system project leader state that the need to manage continuous change is particularly important in the virtual analysis.

As mentioned in the previous subchapter, certain engineers are able to conduct their virtual analysis faster than others. The system project leader at TCF and the system engineer at BIW both emphasise that the efficiency of the process is highly dependent on the individual engineer. The less efficient engineers tend to require more unnecessary double work in their evaluations. The first section of this subchapter will, therefore, present differences in work practices between individual engineers and how they can be categorised. The subsequent subsections will explore other issues related to process efficiency identified in interviews with CEVT personnel.

The system project leader at TCF and the system engineer at BIW argue that a key issue in the ME process is communication with CEVT R&D. As described in section 4.2.2, several scheduled meetings are held between R&D and ME before, during and after the virtual analysis. They state, however, that not all engineers communicate and collaborate equally well with R&D and that this affects the efficiency of their work. Another aspect related to this is how the work practices described as the most efficient by the system project leader and engineer does not reflect the formal process structure illustrated in subchapter 4.2. Certain engineers follow the sequential process specified while other have deployed a more continuous approach.

5.2.1. The Influence of the Behaviour of the Individual ME Engineer

The system engineer at BIW and the system project leader at TCF both emphasise that there are differences between individual ME engineers in the way they work and the way they interact with their R&D counterparts. The system engineer and project leader also state that the work of an ME engineer can be done independently for the most part, which is why the impact of the individual is especially influential. This becomes most prominent comparing the time required to conduct the virtual analysis. Through the interviews with the system engineer and project leader, it is possible to identify two extremes. One extreme conducts the tasks more proactively and has more continuous communication with R&D. This type of ME engineer is henceforth be called a proactive engineer, and the work process of such an engineer can be seen in Figure 5.2. The other extreme is more reactive in her work and does not communicate as much or frequently with the R&D counterpart. This type of engineer is called a reactive engineer, whose work process is shown in Figure 5.3. All ME engineers lie somewhere between these two extremes in how their work is conducted. Common to all is that they attend the formal meetings specified in section 4.2.2.

The most distinctive feature of the proactive engineer is the continuous communication and collaboration she has with R&D. The system engineer at BIW and system project leader at TCF explains that the proactive engineer, shown in Figure 5.2, commences her work in a virtual analysis iteration before the actual data release from R&D has occurred. By accessing designs that have already been completed, available on the CEVT intranet, some evaluations can be conducted in advance. Additionally, the system engineer describes that by communicating closely with the R&D counterparts, the proactive engineer can receive information on changes and updates that will be made but that has not yet been made available. The proactive engineer can then work pre-emptively with evaluations and as a result, the scheduled data release does not become as important. To them, according to the system engineer, the virtual analysis becomes a mainly administrative activity.

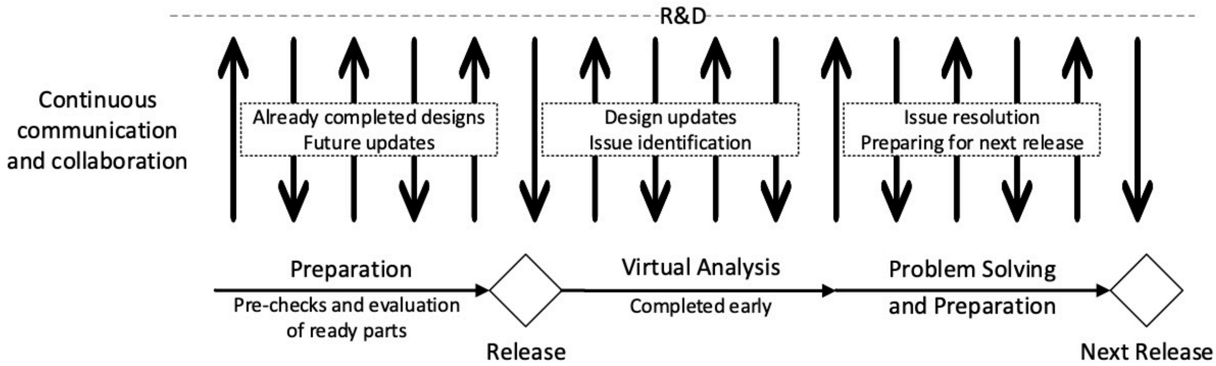

Figure 5.2. The work of a proactive engineer in the virtual analysis showing the communication flow with R&D but excluding formal meetings.

The system engineer at BIW describes how the continuous communication with R&D continues throughout the virtual analysis for the proactive engineer. It allows the engineer to remain informed on any design updates to parts occurring in between releases. The engineer can, as a result, avoid conducting an evaluation of the same part twice. The system project leader at TCF additionally describes how the proactive engineer does not wait until formal meeting to discuss identified issues to R&D. According to the system engineer, the proactive engineer can complete the virtual analysis faster and consequently, begin resolving problems identified together with R&D sooner. In the time between the end of the virtual analysis and the next release, the engineer continues the close interaction with R&D to prepare for the next release. By doing so, the system project leader argues that the engineer can assure that R&D develops compatible solutions to issues that have emerged while also identifying possible future issues. Parts that have been collaboratively designed generally require less rework in subsequent iterations. The project leader explains that for ME engineers working more proactively, the in theory relatively rigid, sequential process flow becomes more or less blurred out, and instead most activities are being conducted in parallel and continuously. It is, for example, the proactive engineer that creates and updates the assembly instructions continuously as described in section 5.1.1.

The reactive engineer does, according to the system engineer at BIW and as illustrated in Figure 5.3, not engage in many discussions with R&D before the data release takes place. Consequently, she is not as likely to anticipate what the release will include. The reactive engineer also tends to wait until the actual release has been made before she commences the evaluations. By not doing much preparatory work and waiting until the data has been formally released, the system engineer explains that the reactive engineer must use the full five-to-seven-week period to complete the evaluations. This is significantly longer than what the proactive engineer requires. Additionally, since interaction with R&D is limited during the analysis, the reactive engineer does not become aware of all design updates. Nor does R&D counterparts become aware of issues directly. The system project leader at TCF argues that lack of discussion, collaboration, and anticipation lead to the work being conducted more sequentially.

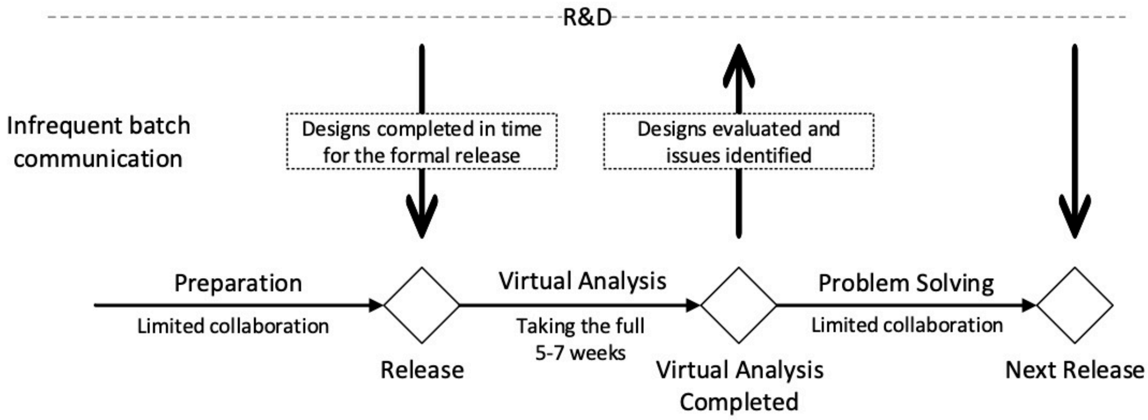

Figure 5.3. The work of a proactive engineer in the virtual analysis showing the communication flow with R&D but excluding formal meetings.

There is, explains the system engineer at BIW, no significant difference in the output quality of the proactive and reactive engineer. Both can complete their evaluations within the period set for the analysis for the entire organisation, and deliver adequate analyses to R&D. The system project leader at TCF stresses that what sets them apart is the speed in which the analysis is conducted, as well as in flexibility, where the proactive engineer has a clear advantage. The proactive engineer is also better at harmonising her work with the R&D counterparts and avoid rework. More time can also be spent on tasks related to the virtual analysis, like the resolution of issues identified.

5.2.2. Impact of Communication Between ME and Other Parties

As described in section 2.4.2, communication is of the utmost importance in product development projects. Upstream and downstream groups are dependent on each other's work and they must be successfully integrated for product development to be efficient. According to the module team director, CEVT ME acts as a link between R&D at CEVT and ME at Geely in China, with communication needing to be seamless in both directions. For the virtual analysis, as is further elaborated in section 4.2.2, the main counterpart is the internal CEVT R&D function. Consequently, for that activity, identified as especially critical, communication with them is particularly important. However, the unit project leaders describe how directives originating in Geely R&D also have a major influence on the work of CEVT ME and they must also be communicated smoothly. In general, it tends to be more difficult to retrieve information from Geely, requiring both time and effort. As presented in the previous subchapter, it is evident that communication in certain aspects is inadequate for some ME engineers and that it limits the efficiency of the process. The recurring meetings described in section 4.2.2 are partly facilitating this, but communication still depends on the approach of the individual engineer.

For the virtual analysis, it is possible to identify two different ways in which poor communication creates double work for the ME organisation. Firstly, the system engineer at BIW and the system project leader at TCF describe how CEVT R&D makes updates and changes to designs constantly throughout the process, not exclusively in formal data releases as intended. If the ME engineers do not become aware of such changes, they might need to conduct the same analysis twice on the same part. If they, contrarily, communicate with their

R&D counterparts and realise that an update has been made, they can avoid the double work. Secondly, the system engineer and project leader describe how engineers can anticipate what a release will include if they interact with R&D beforehand. They can then conduct preliminary and preparatory work before the release and, consequently, do the actual virtual analysis faster. If communication is not conducted before the release, the engineer cannot anticipate the content and must conduct all the work needed afterwards. Additionally, changes and demands making past ME evaluations outdated can arrive from Geely R&D in China. According to the unit project leaders, they tend to be less frequent but can be more intrusive than the ones originating internally in CEVT. They are also more difficult to anticipate and are communicated top-down.

The quality and effectiveness of communication can, as described in chapter 2.4.2, be determined using four patterns or dimensions. Considering the need for good communication between CEVT ME and its counterparts to avoid redundant double work, it is important to evaluate how it functions today and where improvements can be made. The in section 5.2.1 identified differences between proactive and reactive engineers invite a more detailed analysis of their respective communication patterns. For the patterns, one side is preferable for successful integration, enabling collaboration and feedback. A summary of the CEVT ME positioning, using proactive and reactive engineers, on the four dimensions is seen in Table 5.1.

Table 5.1. The position of ME engineers on the dimensions of communication.

Dimension	Proactive	Reactive
Richness of Media	Face-to-face communication	Primarily through designs and documents
Frequency	Receives design updates continuously	Receives design updates when formal releases are made
Direction	Two-way throughout the process	One-way if not invited to meetings
Timing	Early and preliminary before releases	Later, when formal releases are made

The first dimension, the richness of media, favours face-to-face communication over documents and other physical sources. According to the process development manager, most design work is available on the intranet for CEVT ME engineers to access, also before formal design releases and updates. Nevertheless, the system project leader at TCF and system engineer at BIW emphasise that the engineers who communicate directly with their R&D counterparts conduct their work better. If engineers only look at what is available on the intranet, it is more difficult for them to anticipate changes. Additionally, the system engineer states that published updates might not be seen since no notice is given. Face-to-face communication is needed for engineers to be efficiently made aware of what has been changed or is about to change. Yet interestingly, according to the system project leader, it tends to be the same engineers that actively look for updates on the intranet that also communicate face-to-face with their R&D counterparts.

Frequency is the second dimension and emphasises the need for intensive piece-by-piece rather than one-shot batch communication. The formal process structure described in subchapter 4.2 encourages batch communication in the virtual analysis work through the design data releases. As highlighted in section 5.2.1, the proactive engineers however receive design updates continuously through close communication with R&D. As a result, they can conduct evaluations on the latest design data, and this data is conveyed as soon as possible. Engineers who only receive the information needed to conduct their evaluations through the formal releases might, as previously mentioned, work on outdated designs. The unit project leader at R&D BIW recognises that the responsibility for this lies on both sides and that the R&D engineer must notify her ME counterpart when an update has been made.

The third dimension is the direction and it underlines the benefits of two-way communication over one-way. Considering R&D is both a supplier and a customer to the virtual analysis, as described in chapter 4.2, the communication flows both ways when delivers are made. Nevertheless, whether it is two-directional during the analysis process depends on the individual engineer. As described by the system engineer at BIW, the proactive engineers, depicted in Figure 5.2, conduct continuous two-way communication with R&D. The communication flow of reactive engineers is much more one-directional, as shown in Figure 5.3. The system engineer also states that some groups attend weekly engineering meetings where updates are communicated and discussed. The benefits of two-directional communication are emphasised by the unit project leader at R&D BIW as it makes the entire development process more efficient. As they are dependent on each other, it becomes beneficial to both sides. This is further emphasised by the system project leader at TCF in that designs evaluated in a collaborative setting generally needs less rework and that several analyses on the same part are not required. Additionally, the system project leader mentions the handover of a project to Geely is done in a one-shot batch after which it is difficult for CEVT to make changes if needed. If there could be more of a two-directional communication after the handover, with discussions over the proposed changes, this process could become less exigent.

The last dimension involves the timing of the communication, where early preliminary information transfer is favoured over a late transfer, i.e. when the work is entirely completed. By accessing preliminary design data, engineers can anticipate future changes and updates and adapt their work accordingly. The data is normally available to the ME engineers, but according to the system project leader at TCF, only proactive engineers tend to actively pursue it. Related to the timing of communication is also the delivery of information on carry-overs, as described in chapter 4.2.2. The manufacturing method developer argues that better timing of that information would help avoid conducting evaluations of obsolete parts and reduce double work.

5.2.3. Differences Between Formal and Best Practices

As described in section 2.7.1, having rigid structures controlling a process is rarely value-adding if the process is predetermined by people not directly involved in its execution. The risk is that a process described in great detail fails to reflect the actual nature of the work being conducted. This can also hinder the evolution and improvement of the said process. At CEVT ME, process descriptions do not accurately depict the work practices of the of most efficient engineers as described by the system project leader at TCF and system engineer at BIW. Since a clear instruction regarding communication and continuity is missing, the project leader argues that certain engineers maintain more sequential, and less efficient, work practices.

In subchapter 5.1, the ME activity most associated with the critical path is the virtual analysis. This process is, as described in section 4.2.2, in theory a sequential process where information and data are supposed to transfer between ME and R&D in cycles of around twelve weeks. The system engineer at BIW and the system project leader at TCF states that this is not the most efficient way to conduct the work. They, as well as the interviewees from R&D, stress that a concurrent approach with extensive collaboration between ME and R&D is far superior in terms of lead time, flexibility and to some extent, output quality. This corresponds to the work practices of proactive engineers. The sequential work as it is described in theory and, consequently, practiced by the reactive engineer limits the efficiency of ME process.

A consequence of formal work practices not reflecting best practices can be that some engineers follow the descriptions closely and do not adapt their work to better suit the situation. For example, as described in section 5.2.1, ME engineers leaning more toward the reactive way of working wait until a release is made to start analysing the data. Since this is how the process is described in the new product development system, this is officially not wrong even though it is not the best way to do it. The changes to practices made by some engineers and project leaders to optimise the process are according to the process development manager not reflected in the formal process structure. Consequently, lead-time, flexibility and quality improvements can be inhibited by reactive engineers who continue conducting the process as officially prescribed.

Related to work practices is the use of performance measures and KPIs. As mentioned in section 2.7.3, metrics need to be designed to conform to the most efficient way of performing the analysis. More traditional measures tend to not reflect agile ways of working where too much focus on quantitative KPIs can have a counterproductive effect on the progress and results of projects. An example of this stated in section 4.2.2 is how some engineers within CEVT ME experience the use of the number of change requests created as a type of performance measure introduced by Geely. Although CEVT does not use this measure internally at all, it might influence people to create too many such change requests. If the process is to be changed to better correspond to the work of the proactive engineer, the KPIs used should reflect this. As further described in section 4.2.2, CEVT ME currently uses the share of part approved as the primary KPI for the virtual analysis. This is more suitable, as described in section 2.3.1, as it more closely captures the core issue.

In the process description of the virtual analysis process, the initial analysis is supposed to be quite detailed according to the R&D system manager. However, the manager argues, in the early stages of development, the concept developed by R&D is very rough. Designs are preliminary and can be subject to large changes. These early drawings are bound to have numerous issues, especially regarding larger parts with many connections to other parts. The system manager states that consequently, a detailed virtual analysis conducted by ME on an individual part level is, at this stage, not very valuable for R&D since large changes to the rough designs will remove those errors and instead create new ones. The work practice of thoroughly evaluating the early vehicle concepts is therefore not worth the time required to complete them. Generally, according to the system manager, the creation of such detailed evaluations early is the process corresponds to the work practices of reactive engineers.

The system project leader at TCF and the module team direction states that corrections and updates which in theory are supposed to be completed in time for a data release never fully are. Instead, around 30 percent of the function areas have remaining issues that hinder the full and thorough analysis described in chapter 4.2. This dilemma results in a process that is never actually followed since the data is not available in time for the releases to happen. The current work practice of having set releases where data is transferred from R&D to ME might not be the most efficient way of development since this can never be entirely achieved. The ME engineers working more proactively are according to the system project leader already circumventing this dilemma by collaborating continuously with R&D and anticipating future changes. However, for someone working more reactively, receiving incomplete information might hinder the efficiency of the process.

5.2.4. Summary of the Identified Barriers to a More Efficient ME Process

Common to both aspects of the ME process analysed in the previous chapters is that they generate unnecessary supplementary or double work. This work generally originates in changes to designs and other demands which the ME organisation needs to manage. Considering the importance for ME to efficiently deal with changing requirements, these aspects can be considered barriers to a more efficient process. They are summarised in Table 5.2 below. It is important to underline that the way they generate double work differs between individual engineers. These two factors can be seen as the fundamental difference between the proactive and reactive engineers described in section 5.2.1. It is because of these two factors that the reactive engineer is less efficient. Proactive engineers have developed ways to bridge these barriers to improve the process.

Table 5.2. Summary of the identified barriers to a more efficient ME process.

Barrier Factor	Description
Communication	On an individual level, the communication between ME and R&D can be insufficient regarding richness, frequency, direction, and timing
Work Practices	A sequential approach to the virtual analysis is not the most efficient way to conduct it
	Engineers strictly following the process description tend not to be the most efficient ones and might not actively work to find improvements

The communication with other groups, particularly R&D, is of the utmost importance to all ME engineers since they must stay informed on design changes occurring throughout the process and anticipate future updates. By applying that information to their evaluations, they can avoid unnecessary double work generated by evaluating outdated parts. Also, with Geely, richer and more frequent communication would be beneficial to better anticipate the often-significant directives and changes. Regarding work practices, there is a difference between what is specified in formal documents and the best practice used by proactive engineers. Engineers following the specified process strictly and more sequentially tend to be less efficient. They need to spend more time conducting the virtual analysis than engineers who adapt the process to better suit the situation.

5.3. Ways to Improve Process Efficiency

This study aims to provide suggestions on how the manufacturing engineering function at CEVT can reduce its lead times without compromising the output quality. This is also the focus of the third and final research question. In subchapter 5.2, in analysis of the second research question, three aspects that influence process efficiency are discussed and three barriers are identified. These barriers contribute to an inefficient process and are, consequently, aspects that need to be overcome for the lead times to be reduced. When analysing the third research question, the emphasis is therefore on identifying how to mitigate those barriers.

Increased flexibility had before this study been identified as possibly being closely related to increased efficiency in the ME organisation. As presented in subchapter 5.2, the ME engineers encounter changing information, updates and demands throughout the process which they need to deal with. To conduct their work efficiently, they must process such inevitable changes efficiently, without requiring double work. Consequently, CEVT ME cannot be efficient without efficiently dealing with changes, i.e. being flexible. This somewhat contradicts the trade-off between flexibility and efficiency as presented in section 2.3.1, where flexibility for R&D is defined as the ability to produce designs that include the latest ideas. However, in an environment where efficiency depends on flexibility, which as mentioned in section 2.1.2, is true for R&D, it becomes evident that the two go together. CEVT ME cannot be efficient without being flexible.

This subchapter presents how CEVT ME can become more efficient in dealing with changes. As presented in section 2.3.1 and 2.7.1, agile methodology is an increasingly popular way to better incorporate changes in product development, where, as seen in section 2.7.4 conditions tend to be favourable for an agile approach. This is true also for CEVT ME in the case setting, where requirements change rapidly and frequently, close collaboration with the customer is feasible, and incremental improvements have value. The virtual nature of the designs at this stage of development presented in 1.1 enables work to be broken down more easily and for mistakes to be corrected more cheaply. These observations are summarised in Table 5.3 below. Hence, the suggested improvements to the ME process and organisation are based on agile methodology. The strong presence of virtual design in hardware development makes it an increasingly suitable setting for agile practices. As shown in section 2.7.5, agile methods and ideas do not need to be implemented as one and choosing what suits the organisation in question is possible. Firstly, as further mentioned in section 2.7.4, it is essential to have the right culture and mindset in place before implementing agile methods. Therefore, the first section discusses the culture needed for ME to become more efficient and flexible. Thereafter, the second section examines possible changes in practices that might make the process better at dealing with changes. In the last section, a more holistic perspective is taken, and it will investigate how organisational changes can reduce the development lead times.

Table 5.3. Prerequisites for agile development compared to the observation at CEVT

Conditions	Favourable	CEVT Observation
Market Environment	A dynamic environment where changes in customer preferences and solution options are frequent	✓
Customer Involvement	Close collaboration and rapid feedback are feasible Over time, the customers know better what they want	✓
Innovation Type	Problems are complex with initially unknown solutions and an unclear scope Specifications might change, and creative breakthroughs and time to market are important Cross-functional collaboration is vital	✓
Modularity of Work	Incremental developments have value and use for the customers Work can be broken down into parts and conducted in rapid, iterative cycles Late changes are manageable	✓
Impact of Interim Mistakes	They provide valuable learning	✓

The quality of the evaluations conducted by the ME engineers does, from an ME perspective, not vary between the proactive and reactive engineers, as described in section 5.2.1. Proactive engineers, however, are better at harmonising their work with the R&D counterparts and therefore avoid rework. Consequently, they have more time to resolve identified issues, somewhat improving output quality. From an R&D perspective, as argued by the system manager at BIW R&D, the quality of the work of proactive engineers is superior since they increase the output quality in the right places. They focus the effort on areas where increased quality will add value to the product, avoiding excessively expensive parts where limited benefits are gained.

5.3.1. Importance of Culture and Mindset

The culture and mindset of an organisation is, as mentioned in section 2.7.4, the first and most important target of any transformation towards a more agile approach to product development. It refers to aligning the entire organisation to embrace change rather than working against it. As mentioned by the system project leader, and further discussed in subchapter 5.2, changing conditions and requirements are truly intrinsic to the ME process. Additionally, the system project leader at TCF explains that the data to be used in the analyses need to require updates and work by R&D after releases. This is since it is never entirely complete when indented, further stressing the unavoidable omnipresence of change. This dilemma has been constant during the three years the project leader has worked at CEVT, there has not been a single release where every function area has been finished at the set release date. The module team director at ME repeats this, stating that only around 70 percent of all models are completed by R&D on time for all functions. Consequently, rather than trying to avoid changes, the organisation should try to excel in managing them. Although changes are most prevalent in the virtual analysis, they do affect other activities in the process too. The culture and mindset to better handle change will not be exclusive to the virtual analysis but will influence the entire process.

As illustrated in section 5.2.1, the type of engineer labelled as proactive conducts the ME work in a superior way. The proactive engineer can avoid much of the double work otherwise generated by the barriers as described in answering the previous research question. These engineers do not follow the formal processes to the point and have instead adjusted their practices to better suit the needs of the process. They communicate continuously and directly to their R&D counterparts and are, consequently, able to anticipate and better incorporate design changes in their work. Frequent and two-way communication additionally allow engineers to become aware of changes more quickly. This way of working corresponds at large to the agile mindset as presented in subchapter 2.7.1. Interactions are valued over set processes, collaboration with the recipients of the work is emphasised, and they respond to change rather than strictly following a plan. Consequently, it is the already existing mindset of these proactive engineers that should constitute the foundation for a more agile approach within CEVT ME. All engineers need to see the benefits of continuous communication with R&D and a culture encouraging this should be established. The prerequisites exist, as is shown by the success of the proactive engineers described in section 5.2.1, but there must be a will among everybody to make use of them. The current structure does not inhibit people from preparing, but it requires a certain mindset.

In section 2.7.4, it is stated that the greatest obstacle to implementing a more agile approach is the behaviour of management. It is, as further argued in subchapter 2.6, critical that managers themselves accompany their teams in the change of habits and behaviour for change initiatives to be successfully appropriated by the people concerned. If CEVT is to develop a people-centred and more agile culture, management must be on board and lead by example, also over time. As experienced in the interviews with both system and unit project leaders, this appears to be the case at CEVT ME. Management is interested in agile ways of working and tends to be open to new ideas. As explained in section 2.3.1, it is easy that short-term pressure on performance leads to the reestablishment of too rigid processes. Sustained emphasis on the importance of an agile mindset must be assured by management for it to work over time.

When examining the required organisational culture, it is beneficial to compare agile to the other, dominant, paradigm within the automotive industry, namely, lean product development. As described in section 2.7.3, a key difference between the two is the lean focus on processes when agile instead emphasise people and interactions. As has been laid out in section 5.2.3, the process focus has partly limited the efficiency of the ME work, and a shift towards an interaction focus could thus be beneficial. Another difference presented is the way change is managed, where agile is centred around operating in uncertainty and lean has more of a planned approach to change. The unit and system project leaders interviewed describes how changes to the product designs occur constantly throughout the process. as stated in sections 2.7.3 and 2.7.4, agile works better in such situations where requirements are dynamically changing. To summarise, an agile mindset has advantages over lean thinking in the context of CEVT ME.

Another potentially valuable aspect to evaluate is how suitable the discussed culture and mindset is to the inherent national work culture of CEVT, namely, the Swedish. As described in subchapter 2.5, the national culture has a clear incidence of how people conduct their work and confront challenges within an organisation. The current work process of CEVT is as highlighted in section 4.2.2 highly influenced by Geely and, consequently, Chinese culture in which formal processes are emphasised. As further presented in subchapter 2.5, Swedish and Chinese cultures are profoundly different and what functions well in one might be contradictory in the other. As highlighted above, people within CEVT work the best when they are not restricted by predefined processes and adapt their work to better suit the situation. Presented in subchapter 2.5 is that Swedish culture is largely one of less formal structures where people are empowered to work independently. Comparing Chinese work culture to the flat and informal structures of agile development, Swedish corresponds more to the latter. Agile methods might thus be better adapted to Swedish culture than the current process of CEVT ME. As stated in subchapter 2.5, national culture cannot be changed, but it must be respected.

5.3.2. Changes to Work Practices

Many of the suggestions sprung out of the discussion above imply some sort of change to work practices. A change in culture regarding communication, leading to more upstream integration from ME's perspective, will inevitably result in ME engineers working differently with their tasks. Some work practices not as directly connected to culture, but still with a potential for improvement if changed, is described here.

Although agile methods are used as a foundation for the practices suggested below, agile must not necessarily be implemented in its entirety. As can be exemplified by the case of the German car manufacturer presented in section 2.7.5, there are benefits of implementing agile methods also separately. They adapted and combined agile methods to better suit their situation. The pure agile product development approach originates in software development and as described in section 2.7.4, the context of the organisation must be considered as well. Certain agile methods will inevitably be more suitable for an organisation than others. The suggestions are summarised in Table 5.4 and described in the sections below.

Table 5.4. Summary of the suggested changes to work practices.

Suggested Change	Possible Effect
Continuous development instead of separate data releases.	Reduced lead time by increasing responsiveness to change More frequent opportunities for feedback on progress Improve preparation and prioritisation of tasks
Clarified process and role descriptions centred around output and responsibilities	Allow for self-organisation and a more efficient process
Evolutionary analysis, becoming incrementally more detailed	Lead time reduction in the early phases of virtual analysis due to a quicker, more shallow analysis

The sequential nature of the virtual analysis for manufacturability, as described in theory in section 4.2.2 and executed by the reactive engineers as presented in section 5.2.1, has been identified as a barrier to a more efficient ME process. This activity, centred around set data releases followed by an analysis, is the most time-consuming ME activity, and during its execution, other activities can be done concurrently. This is already done to a great extent by the more proactive engineers, as described in section 5.2.1. Presented in the same section is that these engineers are also to a greater extent working more continuously with the virtual analysis, informally adapting the process to more efficiently produce the desired outcome. Instead of waiting for the data to be released, they seek out the latest data as it is released. Instead of completing the analysis and releasing the results in a bigger batch, they make R&D aware of issues as they arise. This has been described as a superior work practice by the interviewees and should, therefore, be strived for and improved upon by the entire function.

In section 2.3.2, it is described that process lead time can be decreased by shortening individual cycles and creating conditions where upstream and downstream cycles can overlap. This is currently how the more proactive engineers work, as presented in section 5.2.1. The system project leader at TCF argues that collaboration toward a common goal achieved by integrating the upstream R&D and downstream ME leads to fast feedback on new designs. As a result of the proactive work practice, the releases do not completely fulfill their intended purpose. Even for the reactive engineer, who the project leader explains waits for the official release of new data to start analysing, the fact that the releases are only around 70 percent complete dilutes their usefulness. Stated in section 2.3.2 is that a simultaneous arrangement between upstream and downstream, although requiring more coordination, can decrease development lead time substantially and reduce costs. In section 2.7.1, it is argued that processes should be defined by their output and let the developers directly involved in their execution reshape and optimise the workflow. Also, in section 2.7.4, it is explained that the best way to make developers understand their role and corresponding responsibilities at the beginning of an organisational change is to have simple role definitions based on the expected output of each role.

With this information, it can be argued that the virtual analysis should be redefined into a more continuous process, where the process definition is clarified, centred around the goal of outputting a car with great quality and high manufacturability. The role descriptions should also be similarly clarified and assigned certain responsibilities in the process, in line with the theory described in section 2.7.1. This would empower the engineers to self-organise and find the most efficient way to deliver the set requirements. It should always be clear what each process and employee is expected to deliver in each stage of development. Even with a more continuous analysis and development process, the release gateways could still remain to serve the purpose of quality control. In this form, the release would become more of an administrative event where the current development status can be reviewed by relevant stakeholders.

The virtual nature of the data at this stage of development presented in section 4.2.2 can additionally favour working in the smaller increments needed in agile development described in section 2.7.2. The case study at a major German car manufacturer presented in section 2.7.5 also indicates that the development of virtual designs and drawings can be considered incremental deliveries in a hardware development project. This information combined indicates that the work tasks can be sufficiently broken down into the desired sprint deliverables described in 2.7.2. More frequent deliveries would enable faster customer feedback on progress.

A continuous development analysis process, including vertical integration between R&D and ME, would better facilitate the preparation and prioritisation of the analysis work, as a collective discussion can align the engineers on the most critical tasks. This continuous, integrated process would also improve the three capabilities, mentioned in subchapter 2.2, that downstream engineers should possess to cope with upstream demands, namely forecasting from upstream clues, managing risks and coping with unexpected changes.

Having a single, continuous analysis process instead of several, similar stages could allow for the development to become more evolutionary in its progression. Just as in the present situation described in section 5.2.3, the early designs will be less detailed in a continuous analysis process. However, by emphasising the preliminary nature of the early concepts, the work of the ME engineer can be better adapted to this. If it is understood that the early concept is subject to large and frequent changes, then the lead time for the early virtual analyses conducted by ME can be reduced. As mentioned in section 5.2.3, an overly detailed and thorough analysis in the early phases of development holds little value to the R&D engineer, as identified issues quickly become obsolete. Reducing this early analysis to a more superficial one would make it faster to conduct and from an ME perspective reduce lead time on the critical path. The analysis could then be made more and more detailed as the project progresses.

5.3.3. Organisational Changes toward a More Agile Approach

As mentioned in section 4.2.1, the CEVT ME process is part of a complex vehicle development system that requires a holistic perspective to avoid suboptimisation. The system manager at BIW R&D argues that the development work is most efficient when the link between the interdependent R&D and ME engineers is strong. The manager states that cross-functional collaboration, including both formal meeting and spontaneous discussions, enables much more efficient communication which shortens the time between problem discovery and its resolution. The manager also mentions that the process's flexibility increases as a result of the proactive approach. When multiple people are involved and interested in the development process, more varied solution ideas can be sparked in the discussions and follow-up questions that take place at for instance meetings. Good cooperation and communication between upstream and downstream also help overcome the inherently different goals of the two organisations as described in subchapter 2.2. For collaboration to function well, both parties need to be engaged and committed. In the virtual analysis, as described in section 4.2.2, five different analyses are conducted concurrently by different functions from which R&D receives input. As mentioned by the system manager at BIW R&D, in general, none of the five analyses functions better than the others. The manager also describes that the results of all of these need to be taken into account by R&D during development as they may give conflicting recommendations. Since the five activities are conducted concurrently and under the same time constraints, improving just one will not improve the overall project lead time. It can, therefore, be argued that R&D should strive to have a close, collaborative environment with all functions involved in the virtual analyses. The limited scope of this study, however, makes it difficult to include the other functions in the analysis.

As described in subchapter 4.1, CEVT has recently moved towards a more project-based organisation, which has transferred responsibilities from the line organisation to the project ditto. This organisational change was conducted to improve cross-functional collaboration. As discussed in section 5.2.2, the ME organisation is highly dependent on good communication with R&D to be able to efficiently manage constant and continuous change. However, the identified barriers not only in terms of communication show that the work of ME can be enhanced further. The improvements to practices suggested in section 5.3.2 would be a step in the right direction. Nevertheless, as noted above, a more holistic perspective to change of the development process is required due to the inherent internal interdependencies of CEVT. Considering the generally complex product development processes of the automotive industry as described in subchapter 1.1, this need may be true for other companies as well.

A way to do this would be to continue on the path of organisational change and become even more project centred. As explained in section 2.4.1, for complex product development projects, organisational structures lying closer to the pure project organisation tend to have shorter development lead times than more functional structures. Additionally, as described in section 5.2.1 the ME engineers work independently and do not require colocation with other ME engineers, something that favours a more project-oriented structure. The ME function is not entirely downstream from R&D and they work more in parallel. Based on the findings in especially section 5.2.2, it becomes evident that the work of both R&D and ME would benefit from closer integration. The question arises as to why the two organisations exist as two separate entities at all since organising them separately limits this integration. By moving towards a more Scrum-like organisational structure as presented in section 2.7.2, the communication barrier to R&D would likely be overcome as ME engineers would conduct their work together with R&D. Consequently, they would not need to deal with design changes in the same way as today.

As stated in section 2.7.2, Scrum calls for vertically sliced, cross-functional teams that include all competencies required to perform the work independently of others outside the team. CEVT development projects are currently, as described in subchapter 4.1, organised according to PSS. This is an example of vertical slicing since every PSS represents a relatively independent section of the complete car. Since this structure already exists, it can be used as a relatively simple way to organise the proposed development teams of CEVT. These teams should further be self-organising to adjust and reshape the processes through the reflections after every sprint as described in section 2.7.2. Proactive engineers have managed to improve the process until now, and this development should be continued in self-organising teams. Self-organisation can however be hindered by demands originating in Geely since a condition to self-organisation, as described in section 2.7.2, is that nobody except the product owner should tell the engineers what to do.

Based on the argumentation presented above, with the need for a holistic perspective to be taken on the organisation of product development within CEVT, a different way of organising is presented below in Figure 5.4. The proposed organisational structure is project-oriented and partly based on the Spotify organisational structure. It includes agile ideas about the importance of individuals, their interactions and customer collaboration, aspects already deployed by the proactive engineers. The core feature of the presented organisational structure is to completely collocate the ME engineers with R&D. As described in section 5.2.1, an ME engineer can conduct her work largely independently from other ME engineers and becoming integrated R&D would, therefore, not affect her ability to execute the ME tasks. The new project-based division would be done according to the existing PSS as explained in chapter 4.1 since this is the structure used by both ME and R&D today. Other interdependent functions to R&D are included in the proposed structure as well. Their way of working, however, has not been sufficiently mapped and their need for integration is uncertain. The emphasis is on the interactions between ME and R&D, and the benefits to be gained through colocation.

Arranging the development teams according to the existing PSS would mean that, just as today, the coordination of these teams would need to be facilitated somehow. As mentioned in subchapter 4.1, function groups and parts are interdependent, even though the connections are not as numerous as within a PSS. As described 2.7.6, dependencies and the long planning horizons of large projects increase the need for aligning multiple teams with each other, which can be challenging. In the same section, different approaches to managing this coordination are presented. They differ among other things on the size of the organisation and the segmentation of backlog items, but they commonly function as Scrum on an aggregated level in the organisation. Bigger tasks are discussed, the planning horizon is longer, and dependencies between teams are mitigated. It is paramount that CEVT ME aim to establish well-functioning cross-team coordination to take full advantage of the possible improvements that the re-organisation provides. Given the complex nature of the automotive development process, the importance of coordinating across PPS should already be apparent. Therefore, it is likely more about adapting the existing effort to better suit agile methodology than to design an entirely new one.

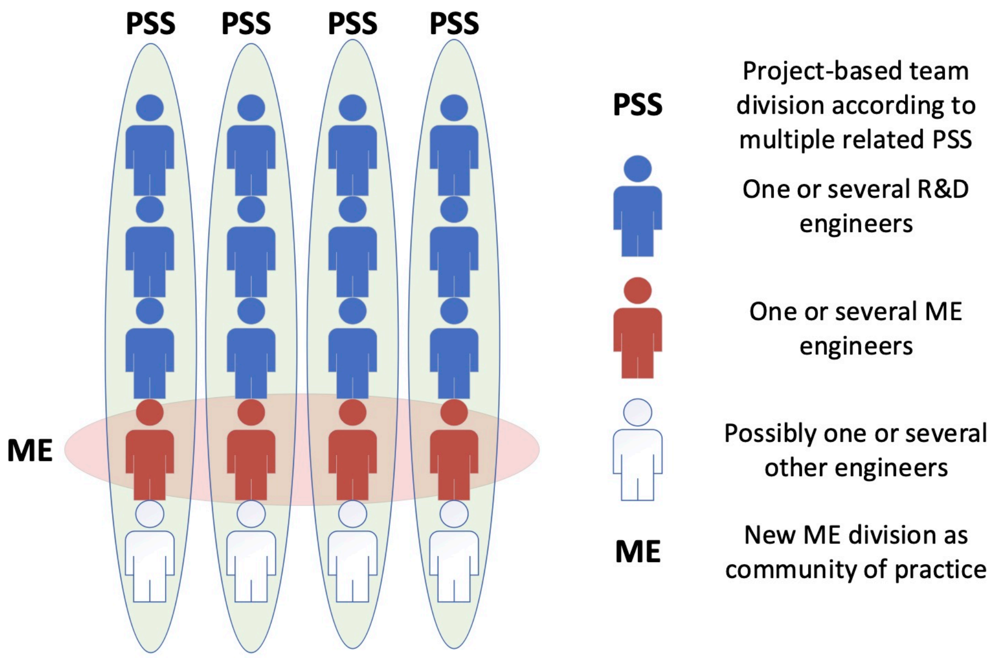

Figure 5.4. Proposed organisational structure integrating ME with R&D.

In the proposed organisational setting, as presented in Figure 5.4, the individual ME engineer would belong to two different organisations. The primary belonging would be with the project team, corresponding to the PSS. This is with whom the engineer will work with daily and to whom the engineer will report. The secondary belonging would correspond to the current ME organisation but in the form of a less-connected community of practice. This would become the CEVT equivalent of the Spotify chapters presented in section 2.7.6. Such a community would enable the sharing of knowledge and best practices, achieving economies of scale in that part of the development process, as presented in section 2.7.6. This inversed matrix organisation would ensure enhanced integration with R&D without surrendering the need for specialisation. The specialisation-integration dilemma is described in section 2.4.1 as a key issue to the organisation of product development. Organising the ME engineers in this way would ensure that they still feel part of a team instead of being an external resource to R&D. This sense of belonging is paramount for social sustainability in an organisational change as described in subchapter 2.6.

Important to underline regarding the organisational structure proposed is that the exact configuration of the teams, their responsibilities and roles needs to be further evaluated. The presented structure should be considered a foundation onto which more detailed descriptions can be added. For example, as described in subchapter 4.1, ME engineers usually work on several different PSS which might not correspond to the current structure of R&D. However, the culture and practices introduced previously in this subchapter should function as a guide.

When conducting organisational change, it is important to take into account the impact on social sustainability and the people of the organisation, as explained in subchapter 2.6. Especially crucial in this case is the situation for the individual ME engineers, which would be changed radically with an entirely new belonging and way of working. If the proposed organisational structure is not implemented fully with only R&D and ME integrating, there is a risk that the ME engineers would become outsiders to the group. The system project leader argues that putting the ME engineers in a state of uncertainty where the ME organisation is weakened, while not becoming fully integrated into the new teams would not be acceptable. It would inevitably affect their wellbeing negatively, and consequently, reduce their motivation to accept and appropriate the change. Considering this, the organisational restructuring would need to be complete and involve all R&D work to assure the sense of belonging. If not, the ME line organisation would need to remain prominent.

Connected to the possible merger of the R&D and ME organisations is the relationship to Geely. Currently, CEVT ME acts as an intermediary between CEVT R&D and Geely ME. As described in section 5.2.2, they currently need to respond to changes and demands from both groups without being part of either. By integrating R&D and ME at CEVT, the coordination of those engineers would inevitably improve, as explained in section 2.4.1. R&D design changes would with the common organisation be directly integrated into ME work. The presented organisational change would not directly aid bridging the communication gap with Geely in China and the need to deal with sudden changes to requirements. Integrating further with Geely would be difficult due to both the physical and cultural distance. However, with the proposed organisational structure, the extra step in communication between CEVT R&D and Geely ME would be removed, and Geely would become the sole customer of ME activities in the teams. As mentioned in section 2.4.2, more direct communication enriches the information transfer. This in turn could enable closer customer collaboration and intensive communication as emphasises in agile methodology described in section 2.7.1.

6. Discussion and Conclusion

The purpose of this chapter is to discuss the findings of this report and provide concrete answers to the research questions of the study. This is based on the analysis in chapter 5 where theory and empirical findings were combined. Subsequently, a brief comment on possible future studies is given.

6.1. Discussion of Findings

It is difficult to determine whether the ME development process at CEVT is representative of development processes in other companies in the automotive industry and beyond. While companies certainly have similar processes in place and face similar challenges, the position of CEVT is unique. It is, as described in subchapters 1.1 and 4.1, a pure research and development company connected to Geely Auto but working with most companies in the larger Geely Group. It is of direct Chinese ownership while situated in Sweden, and a lot of communication needs to occur between the two countries. While most automotive companies have existed for a long time, CEVT was created very recently in comparison and is shaped by that. This indicates that CEVT might be an extreme case. Being an extreme case might, however, not limit the generalisability of the study. The world is becoming increasingly interconnected and China is taking a much more important role on the world stage. Automotive companies everywhere are faced with challenges requiring large changes. Consequently, an extreme case today might become the norm in the future. The findings of this study might, therefore, prove to be interesting to other situations as well and be generalisable.

At CEVT, as mentioned in subchapter 5.3, hardware development is to a great degree virtual. Considering the intrinsically complex product development processes of the automotive industry, it can be assumed that the same is true for other companies as well. As mentioned in subchapter 1.1, due to the increasing market volatility, all processes in automotive development are in constant need of reducing lead time and managing change. The virtual development process, mimicking software development, and the need to manage constant change sets the stage for more agile practices. The same arguments used for CEVT ME to support the move towards a more agile way of working should, therefore, be applicable to the industry as a whole. In this particular study, it was emphasised that the most important aspect of any change towards more a more agile product development process is organisational culture. At CEVT ME, it was seen that some engineers already work according to a more agile approach using the existing structures and tools as a foundation while adapting them to better suit the needs of the organisation. By starting with culture, it should be possible also in other companies to utilise the pre-existing structures as a foundation to become more agile.

Interestingly, but perhaps not surprisingly, the case of CEVT ME shows that the efficiency of the development process is highly dependent on the work practices of the individual engineers. Such engineers continuous and close communication with their R&D counterparts. Considering the importance for any manufacturing engineering function to balance the needs of R&D and manufacturing, the need for close collaboration with R&D should be true to other similar organisations as well. The same engineers at CEVT have parted from the formal structures to better adapt their work to the situation. Since the best practices are not reflected in the formal process descriptions, certain engineers continue to work in a more inefficient way. The best practice should be the rule and not the exception, which would be true to any organisation.

Exploring the barriers, a factor that in addition to the ones examined might influence process efficiency at CEVT ME, but where adequate data has not been collected, is cultural differences. As described in subchapter 2.5, the organisational cultures of Sweden and China score differently on the cultural dimensions as defined by Hofstede and are often almost opposites. CEVT is as described in subchapter 1.1 a company based in Sweden but with a Chinese parent company and it maintains close links to the Chinese organisation. These circumstances might have an influence on the work of the CEVT ME organisation as the cultural differences are intrinsic. Multicultural organisations come with advantages shown in subchapter 2.5., but they also present challenges. National culture cannot be changed, you must understand and respect it. The preferred ways of working are not the same in a Chinese and a Swedish company.

As discussed in section 5.2.3, many of the formalised and defined work practices created for CEVT ME are not being followed, with consequences of this also presented. As outlined in subchapter 2.5, Chinese and Swedish national cultures deal with formal processes and structures in different ways. Chinese organisations tend to emphasise formal processes in which every employee has a set place. Additionally, people generally favour maintaining order over acting as they please. Swedish organisations typically take the opposite approach, and managers are more laissez-faire. As mentioned in section 4.2.2, the product development system used at CEVT originates in Volvo, but it has been adapted and adjusted to suit the reality of the Geely Group. It has thus been influenced by Chinese culture and its focus on formal processes. The double work generated by the process descriptions presented in section 5.2.3 might be a result of the differences between Sweden and China in approaching formal processes. In a Swedish organisation, people typically want to be less restricted when working. At CEVT, people need to understand the product development system as a foundation to rather than a detailed description of how to conduct their work.

Although this not been explicitly stated in the interviews, the perceived difficulties in communicating with Geely mentioned in section 5.2.2 might also partly be connected to cultural differences. This holds both for the time and effort required to retrieve information from Geely as well as the impact of the more intrusive demands originating in Geely top management. As described in subchapter 2.5, communication in Chinese organisations tend to be indirect and selective while the opposite is true in Swedish equivalents. Consequently, retrieving information from colleagues at Geely might be more difficult since they communicate in a less direct way that the Swedish engineers are used to. Also mentioned in subchapter 2.5. is the Chinese emphasis on the need for close relationships to collaborate well with colleagues. For people to maintain good communication with Chinese colleagues, you first to have a good relationship with them. Forming such relationships might be difficult for CEVT ME engineers considering the physical and organisational distance to Geely.

Regarding the impact of changes and demands originating in Geely top management, it can be connected to cultural differences between Sweden and China in two ways. Firstly, as described in subchapter 2.5, Chinese organisations are more hierarchical, and the decision of a leader is not to be challenged. This contradicts the Swedish approach where people expect to be consulted on decisions. A major decision taken at Geely might, therefore, be seen as quite sudden and abrupt from a CEVT perspective since such decisions are normally the result of extensive discussions. Secondly, as China is a highly masculine society where hard work and achievement is valued, managers in China can expect subordinates to work overtime if a sudden change is made. In Sweden, this would not necessarily be the case. Consequently, the impact of drastic changes, especially of occurring late in a project, might be greater at CEVT than at Geely since people will not employ the same effort to compensate for it. Considering the need for consensus, this might be particularly true if the change is not well explained.

6.2. Conclusion

In the following three subsections, the research questions presented in subchapter 1.2 will be answered and concluded.

6.2.1. What is the critical path of the manufacturing engineering development process at CEVT?

The first research question investigates the critical path of the ME process, which is the sequence of activities that determine the overall process lead time. It is possible to approach this issue from two perspectives, by looking solely at the ME process, or by looking at the entire product development process. The activities that are drivers of lead time for the entire process are more important to improve since the activities only critical to ME do not directly impact the project lead time. In the case of CEVT ME, however, the same ME activity is identified as the most critical from both perspectives, namely, the virtual analysis. Additionally, internally at ME, the creation of assembly instructions is a bottleneck to some engineers which might influence their work in other activities.

The purpose of ME is to bridge the gap between R&D and manufacturing. The virtual analysis is the activity that requires the most coordination and communication with both R&D and manufacturing. This indicates that activities with inherent collaboration requirements, and dependencies to other groups, are critical to optimise in the pursuit of shorter development lead times.

6.2.2. What are the barriers to a more efficient manufacturing engineering process, with specific regard to the identified bottleneck activity?

The second research question examines the barriers existing within and without the ME organisation today to a more efficient manufacturing engineering process. The aspects of the process that already function well are not examined in detail. The primary focus is on the virtual analysis, which in the preceding research question has been identified as particularly critical to the overall process lead time. It is possible to identify at least two factors that hinder both a more efficient virtual analysis and a more efficient ME process in general. These factors can be seen as the fundamental difference between the more efficient, proactive engineer, and the less efficient, reactive engineer. The factors identified are (1) inadequate communication between ME and other interdependent groups, and (2) work practices described not reflecting best practices. The consequence of the factors mentioned is that they generate double work, or increase the time required to complete activities, for the ME engineers. It is important to underline that the barriers are not common to all engineers. The barriers are dependent on the approach of the individual engineer.

Regarding communication, ME engineers need to be able to successfully deal with design updates throughout the virtual analysis process. To do so, they must become aware of updates and changes that have occurred, and also anticipate when changes are about to be made. If not, engineers may need to conduct the same analysis multiple times on the same part. Richer, more frequent and better-timed communication with external parties would benefit this, and some engineers are already working in this way.

The work practice barrier relates to the difference between what has been specified in formal documents and what is the most efficient way for ME engineers to conduct their work. Engineers following the detailed process descriptions to the point tend not to be the most efficient ones and rather unnecessary work generated. This can be exemplified by a too detailed virtual analysis conducted at the beginning of a project, and by data releases never being entirely complete.

Additionally, as explored in the discussion of the findings, cultural differences might in part act as a precursor for the two mentioned barriers. There are fundamental differences between Swedish and Chinese cultures which influence how people approach formal structures, communicate and make decisions.

6.2.3. How can the identified bottleneck activity be improved to reduce lead times and make it more flexible without compromising quality?

The third and final research question springs from the barriers identified in answering the previous question. It has become evident that the concepts of efficiency and flexibility are closely related when studying manufacturing engineering. Changes are intrinsic to the ME process and they must be managed efficiently for the entire process to be efficient. The answer to this research question therefore primarily examines how the process can be improved to anticipate and deal with changes in a better way. It is identified that a more agile approach would be beneficial in achieving this. The analysis is similar to the second research question divided into three areas. Firstly, the importance of having the right culture and mindset within the organisation is discussed since this is emphasised as the key aspect of more agile ways of working. Secondly, concrete suggestions on how work practises can be changed to make the process more efficient are presented. Thirdly, the advantages of a more structural change involving the entire R&D organisation is discussed. It is noted that suggested changes will not affect the quality of the process negatively, but that they, from an R&D perspective, might even improve it.

Assuring the right culture and mindset is the first step in any change towards a more agile approach. A more agile way of working is identified as possibly being better adapted to Swedish work culture than the current process of CEVT ME. Any cultural change is not exclusive to the virtual analysis and will affect the entire process. People must understand the benefits of frequent and direct communication with R&D, and of not following the current formal structures to the point. This mindset largely corresponds to that of proactive engineers.

Regarding changes in work practices, three main areas of improvement have been identified. Firstly, the ME function would benefit from a more continuous development process instead of having separate releases. Secondly, a simplified process and role description centred around output requirements and responsibility would allow for better self-organisation. Lastly, an evolutionary development process where the level of detail of the evaluations corresponds to the maturity of the design would allow for lead time reduction in the early phases of development.

Lastly, considering the interdependence of ME and R&D work, it might be advantageous to conduct a more thorough organisational change where R&D and ME are merged into one organisation. Based on agile development ideas, ME engineers should be completely integrated with R&D in project-oriented teams based on the functionality of the product. To assure sustained functional specialisation, the ME organisation is transformed into a community of practice. The result is a reversed matrix organisation where the individual ME engineer belongs to two different groups, a primary project-based team and a secondary function-based community.

6.3. Proposed Future Research

The suggested process and organisational improvements are, although based on theoretical and empirical data, not tested within the organisation. Some aspects are already used by proactive engineers, but to see the effects on lead times, they would need would be implemented and used by everyone. As with any change, resistance is likely to arise and the determination of the best way to implement the suggested changes remains to be conducted. Connected to this is also the need to study the work of other functions connected to R&D and how they would best benefit from a new organisational structure. To truly achieve shorter iterations and feedback cycles, the entire R&D process would be to be included. Lastly, it would be interesting to examine ways on how to better integrate the process with Geely since they constitute the major external partner in the process.

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Appendix

A. Interview Templates

Exploratory Interview Template

- Could you describe your role?
- What parts of a projects take the most time?
- What problems do you find in projects?
- How do you handle incomplete information?
- How do you handle the parts not being ready at the releases?
    - What are the consequences?
- In your opinion, what aspects can be improved in the projects?
- Is there any area in particular that you think we should focus on?

Detailed ME Interview Template

- Could you walk us through the DPA5 process, from concept release to FDJ?
    - What are the main activities?
    - Could you describe an analysis iteration?
        - How does the information reach the ME engineer?
    - What takes time?
        - How long does it take?
- How dependent are ME engineers of each other? Independent work?
    - Is there extensive collaboration between ME engineers?
- What happens when a virtual analysis cycle is complete? Is another one started immediately or are the other activities taking place in between?

R&D Perspective Interview Template

- In your opinion, how is the communication with ME in general?
    - Has the level of communication differed between projects?
- Can you mention any time that R&D has been bottlenecked ME during a project?
    - If so, what were the reasons?
- How do you find the analysis iterations to be working?
- How do you find the communication with ME to be working?
- What is your overall impression of the conduction of the releases?
- What are your work practices during the virtual analysis?
- When data from the virtual analyses are delivered by ME, how is it compiled?
- In your opinion, are there any apparent bottlenecks in the process, caused either by R&D or ME?
- Do you find the work and communication with ME to be individually dependent? By individually dependent we mean that the level of collaboration varies substantially between ME engineers.
- From the perspective of R&D, what separates an efficient ME engineer from a less efficient one?

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