Weaknesses in the manufacturing strategy: a case study

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Executive summary

Using their manufacturing strategy, Company A has been unable to turn the tide on increasingly poor financial and operational performance in the past 10 years. Problem is that it is unknown what the weaknesses of the current manufacturing strategy are and that there is uncertainty about how the manufacturing strategy can be improved to address the weaknesses and experienced issues. The goal of this research is to identify the weaknesses and give recommendations for the new manufacturing strategy, to improve operational performance. Based on this, the main research question is: how can the weaknesses in the current manufacturing strategy be addressed in the new manufacturing strategy?

To answer this question, several steps have been taken. First, the decision areas to be addressed by the manufacturing strategy and the characteristics of a strong manufacturing strategy have been identified through a literature review. Second, interviews with managers and experts of most departments have been held to identify the most critical decisions areas, and weaknesses and issues within these decision areas. Third, recommendations that address the weaknesses and issues have been given, based on applying literature to this case. The results of this research are summarized in Figure 14, 15 and 16 for respectively Planning and Control, Vertical Integration, and New Product Introduction.

For Planning and Control, recommendations have been made by creating a simplified model of the current method and comparing it with the reference model from theory (Q7). The first recommendation is to use historical data to improve the product configuration. The second is to reject orders or renegotiate lead-times to enable better control of the workload for critical resources. The third is to do MRP after the design phase, purchasing only a few long lead-time parts before the design phase, to improve the bill of materials. The fourth is to use Project Requirements Planning for more custom orders, taking into account lead-time variation of parts, to protect the assembly schedule from delays. The fifth is to enhance shop floor scheduling by tracking parts, to improve the supply of parts to assembly. It also helps to improve the accuracy of estimated production times, basing it on historical data. The final recommendation is to thoroughly evaluate the current planning method and implement the integrated solution from theory.

For the Vertical Integration, an overall vertical structure is recommended, which is to outsource production functions and focus on assembly and design. To make decisions of which production functions should be outsourced, a decision model has been proposed. If implemented, it should lead to a better vertical structure and better overall business performance.

For the New Product Introduction, the recommendations have been linked more to experienced issues. To address the issue of selling products during their development, it has been recommended to create a mission statement and a set of objectives through discussion. These should be clearly communicated, agreed upon by everyone and finally ways to keep each other accountable should be established. This prevents the setting of wrong priorities. To address the issue of DFMA execution, it has been recommended to find out where exactly execution fails, to then take appropriate measures, and to improve collaboration between designers and manufacturing experts. To address the issue of design for production efficiency, it has been recommended to add this to PROLaunch, to train R&D personnel on this aspect and to improve existing products on this area as well through doing a design review. Finally, implementation of a shifting strategy is recommended, to further improve the new production introduction strategy by creating a process where custom designs can be introduced as in the standard catalogue. If these recommendations are implemented, it should

lead to a higher quality, higher delivery reliability and more production efficiency of new products in the future.

To conclude, the main research question is answered by the given recommendations, as they address the weaknesses that have been identified, as discussed at the end of the decision area chapters. If the recommendations are implemented, the manufacturing strategy for three of the most problematic decision areas would be much stronger.

1 INTRODUCTION

1.1 RESEARCH MOTIVATION

Company A's sales went down from 146 million in 2007 to 99 million in 2015. In 2015, losses have been around 20 million, which is high considering 99 million in revenues, declining each year. These financial numbers have been putting pressure on managers to improve the results. One way they want to do this is through creating a new manufacturing strategy. Marne Schu, the operational excellence manager, is one of the people who are responsible for creating this new manufacturing strategy. He wanted someone who would look at it, to give recommendations from an outsider perspective; without the bias resulting from internal experience. The goal of this research is thus to give recommendations for the new manufacturing strategy.

1.2 PROBLEM IDENTIFICATION

The financial performance has been poor the past years, worsening every year. Operational performance is also underperforming on quality, delivery reliability and efficiency measures, compared to other Company A locations. Poor operational performance underlies the poor financial performance. Quality issues of new products during assembly have led to high rework costs and late deliveries. Low production efficiency has led to losses, as competitors set the market prices and Company A must choose either losing customers or making losses. Long and variable lead-times have led to low delivery reliability. These three examples show how poor operational performance has led to poor financial performance, and Company A's managers must find a way to turn the tide.

The manufacturing strategy is supposed to lead the company to strong operational results, but it has failed, seeing the poor operational results. That is why Company A's managers view the manufacturing strategy as one major way to turn the tide. However, there are two problems. First, they do not know the weaknesses of the current manufacturing strategy. Connected to this problem is that there is uncertainty of how the weaknesses should be addressed in the new manufacturing strategy. On some areas, there is a discussion of what idea is the best, such as the assembly layout. On other areas, there are no ideas at all, such as how to improve the planning method. The second problem is thus uncertainty of how the new manufacturing strategy should address the experienced issues and underlying weaknesses. This research addresses these three problems, helping to turn the tide by providing insight in the weaknesses of the current manufacturing strategy and giving recommendations for the new manufacturing strategy. Or put as the main research question:

How can the weaknesses in the current manufacturing strategy be addressed in the new manufacturing strategy?

1.3 RESEARCH AIM

The aim of this research is to answer the main research question. Thus, first to identify the issues and underlying weaknesses in the manufacturing strategy. Then, to give recommendations of how these weaknesses can be addressed in the new manufacturing strategy. The deliverable is this report, in which the issues and weaknesses are identified and recommendations are given. The practical relevance is twofold.

First, the identification of issues and underlying weaknesses give insight in issues. It can help to move from a firefighting culture to one where root causes are addressed, starting at the weaknesses in the manufacturing strategy. This top-down perspective should then be combined with a bottom-up perspective, as root causes are not only on a strategic level, but can be in the details as well. Second, the recommendations of how the weaknesses can be addressed can be used in the creation of the new manufacturing strategy. A stronger manufacturing strategy should not only be able to address a variety of current issues, but also prevent future issues.

1.4 ACADEMIC RELEVANCE

This research has a more practical focus, meaning that contributing to academic literature not a primary goal. However, this research does aim to contribute to academic literature. Because this research is a case study, the in-depth information gathered about the company can spark new research directions. The information gathered is twofold: identify manufacturing strategy weaknesses and identify issues that have resulted from these weaknesses.

Research has already been done on the implementation of manufacturing strategy and its impact on performance. (Thun, 2008; Rho et al., 2001) These focus on the importance of certain characteristics of manufacturing strategies and their impact on performance. For example, Rho et al. (2001) found that consistency plays a more important role than strategy or implementation in discriminating the superior from the inferior performance groups. However, I haven't been able to find research that focuses on the weaknesses and issues of existing manufacturing strategies and their implementation.

This research identifies some weaknesses and the issues that result from them. Future research can focus on finding patterns or common weaknesses and issues, for which this research provides a starting point. By finding these patterns and common weaknesses and issues, they could be addressed by either new research, consultancy firms or even government. Tackling the common weaknesses and issues could then lead to improved overall business performance.

1.5 THESIS OUTLINE

This thesis starts with the research design, with a description of research questions, the research approach and methods of gathering data. Then, the theoretical background answers two knowledge questions that are the basis for the rest of the research. The middle part of the research is divided in two: vertical integration and new product introduction, each with the same structure. These are the two parts of the manufacturing strategy that are analyzed. First, the weaknesses of the respective part of the manufacturing strategy are identified. Second, the issues that have resulted from the weaknesses in the manufacturing strategy are identified. Then, theory that addresses the identified issues is stated. Finally, recommendations that address the identified issues are stated, based on the theory on the issues. After these two main parts, the conclusion, limitations and future research are discussed.

2 RESEARCH DESIGN

2.1 RESEARCH QUESTIONS

The main research question is: how can the weaknesses in the current manufacturing strategy be addressed in the new manufacturing strategy? The weaknesses in the manufacturing strategy can only be identified when it is known what a manufacturing strategy is and consists of. Therefore, the first step is to identify the decision areas that together make up the manufacturing strategy, which can then be evaluated for weaknesses.

Q1. What decision areas should be addressed by the manufacturing strategy?

Because of the limited time-span of this research, not all decision areas can be assessed. For that reason, an analysis is made to identify the most critical decision areas, in terms of criticality of issues. The rest of the research will focus on three of the most critical decision areas.

Q2. On which decision area are the most critical issues experienced?

To be able to identify weaknesses, a comparison has to be made with a strong manufacturing strategy. The characteristics of a strong manufacturing strategy can be compared with the current manufacturing strategy, leading to the identification of weaknesses. Therefore, the second step is to define the characteristics of a strong manufacturing strategy.

Q3. What are characteristics of a strong manufacturing strategy?

Once three decision areas are chosen and characteristics of a strong manufacturing strategy are known, the decision areas can be assessed along these characteristics for each of the decision areas.

Q4. What are weaknesses in the decision areas of the manufacturing strategy?

Once the weaknesses are known, issues that result from these weaknesses can be identified.

Q5. What issues are experienced in the decision areas, as a result of weaknesses in the manufacturing strategy?

Before making recommendations, it is important to look at theory that addresses the identified issues. Peer-reviewed research is a reliable source on which the recommendations can be based.

Q6. What does theory suggest about the identified issues?

The final step is to apply the theory to Company A, resulting in a set of recommendations founded in theory.

Q7. How can Company A address the identified issues using their manufacturing strategy?

The main research question can now be answered to complete the cycle. The conclusion reflects on how the weaknesses can be addressed in the new manufacturing strategy by the recommendations that result from Q7.

2.2 RESEARCH APPROACH AND METHODS

The research questions are here translated in practical research steps. The methods to gather the data needed to answer the research questions are discussed for each research step.

Step 1: literature review. This step answers Q1 and Q3. To define which decision areas are part of a manufacturing strategy and what characteristics of a strong manufacturing strategy are, I do a literature review. These are knowledge questions, for which the knowledge is readily available in academic literature. For that reason, a literature review is the best way to answer them. The literature review starts with identifying major contributions to the scientific field and important books on the subject. Then a set of theories and a book will be chosen that are most applicable to this research and answer the research questions. The results are a set of decision areas that together form the manufacturing strategy (Q1) and a set of characteristics of a strong manufacturing strategy (Q2).

Step 2: identification of weaknesses and issues. This step answers Q2, Q4 and Q5. The identification of weaknesses in the manufacturing strategy, and the resulting issues, is done through interviews. Each of the decision areas is evaluated for issues. Based on the issues mentioned in interviews, a selection is made of the three most critical decision areas (Q2). Q4 to Q7 will be answered for each of these three decision areas. First, the characteristics of a strong manufacturing strategy are criteria which will be assessed for these decision areas (Q4). Then, issues resulting from the weaknesses will be identified, based on the same interviews (Q5). The results of this step are a selection of three most critical decision areas, a set of weaknesses and the resulting issues for these decision areas.

Knowledge on past decision making in Company A is not well documented, which is a weakness most managers are aware of. Most knowledge is in the heads of the managers and experts that have been involved in decision making. For that reason, interviews are the source of data needed to identify weaknesses and issues of the manufacturing strategy.

The interviews are semi-structured, which means that they follow a set of questions, but can diverge to other topics when considered relevant. To identify the weaknesses and issues on the various decision areas, SIPOC is applied. SIPOC stands for Supplier Input Process Output Customer and is a tool used in the Six Sigma methodology (Saxena, 2005). SIPOC is commonly used during the define phase of a process improvement project, because it aids in understanding the purpose and scope of a process. Exactly this understanding of the purpose and scope of a process is the reason why it is applied here. To identify weaknesses and issues, the process has to be understood. It helps to identify relations between the different issues and seeing the bigger picture. Additionally, it improves the reliability, by hearing stories from all different perspectives. The SIPOC analysis is performed for each part of the supply chain, covering the different decision areas that are part of the manufacturing strategy. In the questions, “your part” refers to the part the manager is responsible for. The questions are as follows:

1. Who are the suppliers to your part in the supply chain? (S)
2. What are the inputs to your part in the supply chain? (I)
3. Could you give a summary of what your department does as part of the supply chain? (P)
4. What are the outputs of your part in the supply chain? (O)
5. Who are the users of the output of your part in the supply chain? (C)
6. What issues do you currently experience? This can be on either of the five SIPOC parts.

The interview protocol is the same as the questions above, with an introduction included. The participants are selected based on the business process of Company A, where for each part of the overall business process, the manager is interviewed. Additionally, the director and operations manager, who are head of the organization, can give valuable insights over the entire spectrum. The managers are assumed to have the best ability to answer the questions, because they are responsible for decision making, management and collaboration of their areas of responsibility. Issues can also be better understood by managers, because their experience with the context of issues and their connection with other parts in the supply chain. In addition, some experts are interviewed to verify statements by managers and give more in-depth info where needed. These experts are also long-time employees, who have worked in different levels of the organization, which makes their perspective even more valuable. The people interviewed are stated in the table below (Table 1). The interviews took between 30 and 90 minutes.

Director	Operations manager
Marketing manager	Sales manager
R&D manager	Procurement manager

Industrialization expert and manager	Operational buying manager
Assembly manager	Operational excellence manager
Planning manager	Engineering expert and manager

Table 1. Interviewees within Company A.

Step 3: theory on issues. This step answers Q6. As explained before, it is important to look at what theory suggests about the identified issues. Academic literature can give valuable insights on how the issues can be addressed by the manufacturing strategy. It increases the quality of the recommendations. For that reason, a literature review is applied. This step is similar to step 1, except for different search terms. The applicability of articles to this research is an important criterion during the literature review.

Step 4: recommendations for the manufacturing strategy. This step answers Q7 and the main research question. A set of recommendations are made, based on theory, that address the weaknesses. These recommendations are not step-by-step action plans for resolving all issues, because it is unrealistic to attempt to solve these major issues in a 10-week project. The recommendations highlight points of attention that should be considered when formulating the new manufacturing strategy. The method is logical reasoning to formulate recommendations based on theory and conversation with relevant managers to validate these recommendations. The reason for these conversations is that they know better how theory applies to Company A, because they know more about Company A. Additionally, their expertise and opinion can bring valuable additions to the recommendations. The results of this step are recommendations and a conclusion for each decision area. This conclusion is a reflection on how the recommendations address the weaknesses in the respective decision area, answering the main research question.

2.3 Validity and reliability

People are subjective and therefore biased. For that reason, there is a risk of internal validity issues for the results that are based on interviews. Not much data is available within Company A to validate claims in interviews. For example, the planning manager could be biased that his own department has no issues, but supply chain is simply too unreliable in meeting due dates. His assessment could be false. Maybe he does not see that the planning method makes it impossible for supply chain to deliver on time. The risk is that the wrong conclusions are drawn, that the issues identified lie somewhere else. This is addressed by interviewing a manager from every department, from sales to assembly. By doing this, claims can be verified by managers with a different perspective, increasing internal validity. However, if a company-wide bias exists, this will result in internal validity issues, which is a risk.

The identification of weaknesses and issues has a low external validity, because these are only obtained from and for Company A. The issues might, and probably do, exist at other companies however. The recommendations are based on academic literature that does have external validity in general. Therefore, companies with similar issues might benefit from the recommendations in this research. However, this should be considered for each individual case. Thus, there is some external validity regarding the recommendations, when linked to the issues.

The interview results are somewhat dependent on the moment. If in the month that interviews were held, a certain problem caused many issues, then that would likely be mentioned more frequently than a problem that has been there longer on the background. However, the second problem might have more impact, but people have simply gotten used to it. In that sense, there is an issue of reliability. This issue is addressed by interviewing several people with over 20 years of experience within Company A. They are more able to discern temporary and long-term issues. They know how it was before certain issues emerged. Additionally, my own logic helps to discern between temporary and long-term issues.

3 Theoretical background

3.1 Introduction

The aim of this chapter is to help understand the concept of manufacturing strategy and answer two research questions, of which the overview can be seen in Figure 1. First, the definition and context of manufacturing strategy help to understand the concept and place it in the bigger picture. Then, the first research question is answered: what decision areas should be addressed by the manufacturing strategy? These decision areas give structure to the rest of the research, because research questions 4 to 7 will be answered for three of these decision areas. Finally, the third research question is answered: what are characteristics of a strong manufacturing strategy? Each decision area is evaluated along these criteria.

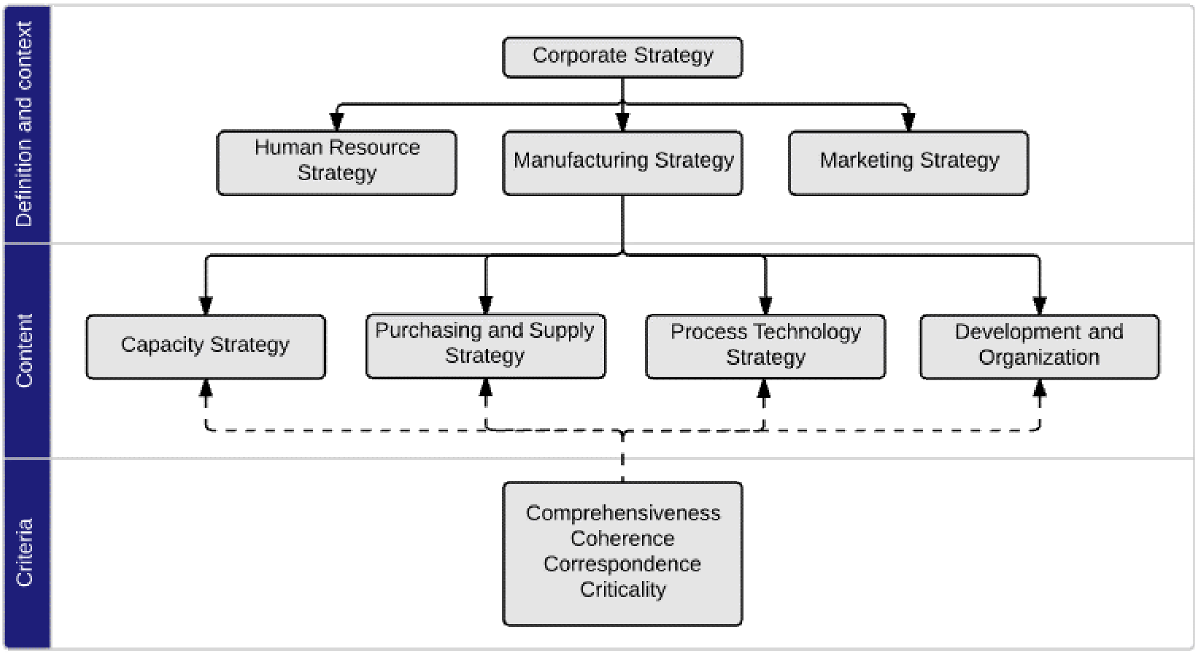

Figure 1. Theoretical background overview.

3.2 Definition and context

Skinner (1969) was the first to coin the term "manufacturing strategy" in his breakthrough article "manufacturing – the missing link in corporate strategy." He argued that manufacturing strategy is vital in business performance on the long term. He advocated the concept of a focused factory, which focuses on a limited set of tasks and excels at these. The concept of a focused factory has proven to remain valid. For example, Bozarth et al. (2009), found that all types supply chain complexity negatively impacts manufacturing plant performance. The scientific field has evolved from this initial concept. Currently, Nigel Slack is one of the major authors on the subject. Slack and Lewis (2011, p. 22) stated the following definition: "Operations strategy is the total pattern of decisions that shape the long-term capabilities of any type of operation and their contribution to overall strategy, through the reconciliation of market requirements with operations resources."

Operations strategy and manufacturing strategy are used interchangeably and are the same in scientific literature: Slack and Lewis (2011) use operations and Hayes and Wheelwright (1984) use manufacturing. In this research, manufacturing strategy is used, because it is used by Company A.

To further clarify what a manufacturing strategy is, it helps to view it in its context. Manufacturing strategy contributes to business competitiveness through its role as a functional strategy. This means that it provides a strategic orientation within its function, which is manufacturing in this case. As will be elaborated in the next paragraph, this function consists of several decision areas. This is shown in Figure 1.

3.3 MANUFACTURING STRATEGY CONTENT

Slack and Lewis (2011) developed a set of four decision areas to be addressed by a manufacturing strategy, or in other words: the content of the manufacturing strategy. The definitions for each area by Slack and Lewis (2011) are first stated, then some additional clarification is given.

(1) Capacity strategy: "how capacity and facilities in general should be configured." (p.269) The capacity strategy consists of strategic-, medium-term, and short-term capacity decisions. Strategic (or long-term) decisions are on a year to months scale, concerning facilities and process technology. Medium-term decisions are on a month to weeks scale, concerning aggregate number of people and degree of subcontracted resources. Short-term decisions are on a week to hours or even minutes scale, concerning the provision of individual staff within the operation and loading of individual facilities, which is the planning of a company.

(2) Purchasing and supply strategy: "how operations relate to its interconnected network of other operations, the entire supply chain." (p.269) It includes considering the position of the company in this network to understand how the dynamic forces in the network will affect them, and to decide what role they wish to play in the network. The first part is to decide what to make and what to buy, which is commonly called the vertical integration strategy. The second part is to decide how is bought, what kind of relations and contracts are established and how these suppliers are managed, including supply risk management. This is commonly called the procurement strategy.

(3) Process technology strategy: "the choice and development of the systems, machines and processes that act directly or indirectly on transformed resources to convert them into finished products and services. " (p.269) Slack (2013) distinguishes between three types of process technology: material-processing technology, information-processing technology and customer-processing technology. For each of these types, the available technologies must be identified and their strategic value has to be determined, considering the feasibility, acceptability, and vulnerability of the technology.

(4) Development and organization strategy: "the set of broad- and long-term decisions governing how the operations is run on a continuing basis." (p.269) Slack and Lewis divide this in two parts: strategic improvement and product and service development. Strategic improvement concerns the organization of both breakthrough and continuous improvement, deciding how the company will attempt to improve itself over time. Product and service development is both the improvement of existing products and the new product development process, deciding how new products will be developed.

3.4 MANUFACTURING STRATEGY CRITERIA

Slack and Lewis (2011) developed a set of four requirements for a good manufacturing strategy. These can be applied to assess the quality of an existing manufacturing strategy. It helps to identify weaknesses and their type. Knowing the type of weakness is useful, because measures to improve a manufacturing strategy need to be different for different types of weaknesses.

(1) Comprehensiveness: companies can fail by not noticing the potential impact of, for example, process technology. Alignment is only complete when all decision areas are considered. A decision area is a weakness of comprehensiveness when it has not been receiving adequate attention, in terms of analysis and thorough decision making. A decision area creates no weakness in comprehensiveness when it has been thoroughly analyzed and decisions have received adequate attention.

(2) Coherence: when the choices made in each decision area do not pull the operation in different directions. A weakness of coherence occurs when decisions made in different areas are working against each other. If such inconsistencies are identified, there is a weakness of coherence.

(3) Correspondence: strategies pursued in each decision area should reflect the true priority of each performance objective. Every decision is a trade-off and thereby each decision reflects a priority. If decisions are found that set different priorities, compared to the manufacturing mission, there is a weakness of correspondence.

(4) Criticality: identification of the most important decision areas regarding the performance objectives. Critical decision areas should receive appropriate attention. If a decision area is crucial to one of the performance objectives, and it has not received much attention (see comprehensiveness), there is a weakness of criticality. The difference with comprehensiveness is that for critical decision areas, more elaborate analysis and decision making is required. Thus, a decision area that is critical for quality, can be a weakness of criticality without being a weakness of comprehensiveness.

4 IDENTIFICATION OF CRITICAL DECISION AREAS OF THE MANUFACTURING STRATEGY

The choice on which decision areas will be addressed in this research is based on the interviews. To decide this, each decision area is assessed for these two criteria, which is summarized in Table 2. First and foremost, impact: how much impact the issues of a decision area have on the main competitive priorities. Impact is high when most managers consider the issues to significantly hold back the performance on one of the main competitive priorities. Impact is medium when some manager considers the issues to have some impact on overall performance, but not to be high priority. Impact is low when at most one manager considers the issues to have some impact on performance. To be able to assess impact, it needs to be determined what the competitive priorities for Company A are. According to the director and the operations manager, the two highest in the hierarchy at Company A, the competitive priorities are, in order of importance: quality, delivery reliability and cost. The second criterium is frequency: how frequently the issues were mentioned during interviews. Frequency is high when issues are mentioned in at least half of the interviews, medium if 2 to 5 interviewees mention it and low if it is mentioned by no one. If no issues are mentioned for a part of the strategy, it does not mean there are no issues. There might even be major issues, only these are then not identified by employees. However, for this research I will focus on the most critical issues that are being recognized. It is reasonable to assume that the most pressing and critical issues are being recognized by at least some managers.

Issue	Impact	Frequency
Capacity: long-term	Low	Low
Capacity: medium-term	Low	Low
Capacity: short-term	High	High
Purchasing: vertical integration	High	High
Purchasing: procurement	Low	Medium
Technology: material	Medium	Low
Technology: information	Medium	Medium
Technology: customer	Low	Low
Development: new product	High	High
Development: improvement	Medium	Medium

Table 2. Identification of critical decision areas.

As described by Slack and Lewis (2011), each decision consists of a few sub-areas. Each of the decision sub-areas will now be evaluated for these two criteria.

Capacity strategy. (1) The long-term capacity strategy concerns facilities and process technology. Current facilities are rather new and more than sufficient for current activities, nobody debated this. Process technology, regarding capacity, has not been mentioned in interviews. Thus, no critical issues and few mentions. (2) The mid-term capacity strategy concerns the number of people and their skills. An issue mentioned here was the lack of engineers, which has been addressed by opening new vacancies. There is consensus that the number of people and their skill is adequate. Thus, low impact and it had few mentions. (3) The short-term capacity strategy concerns planning and control. This has been frequently brought up by a variety of managers. Some issues mentioned were that planning is often not met, leading to delivery reliability and unfavorable sequencing for engineers. Additionally, design changes often happen in a later stage, which the current planning and control cannot cope with. Because delivery reliability is the second highest priority and planning is critical in this regard, this has a high impact. It has also been frequently mentioned.

Purchasing and supply strategy. (1) Vertical integration has been mentioned frequently. The issues were mentioned to be doing too many activities, some of which put a high pressure on costs. The activities were mentioned to be too many to manage, leading to inefficiencies and the surfacing of many smaller issues. The impact on costs and resulting inefficiencies and issues make this a critical area, thus high impact. (2) Procurement has been mentioned twice, but only in positive light: a new procurement strategy is in the making. No critical issues were mentioned.

Process technology strategy. (1) Material processing technology was mentioned once by a manufacturing expert. He stated that most technology is old and no plan exists on what will happen once machinery breaks down, possibly shutting down important functions in case of failure. It is currently not producing any critical performance issues, but might in the future, depending on how it will be handled. Thus, medium impact. (2) Information processing technology has been mentioned by the operational excellence manager and planning manager. They state that there is a lack of monitoring of the production processes. Real production times are not available, which makes planning less reliable. Furthermore, improvement efforts and root cause analyses are hampered by the lack of data. The impact is less reliable planning and difficulties with addressing issues, which can be considered medium impact. (3) Customer processing technology is not important for Company A and wasn't mentioned in interviews.

Development and organization strategy. (1) New product introduction has been mentioned in more than half of the interviews. Issues mentioned were manufacturability issues and delivery issues in new products. If this trend continuous with other new products, it is thought to be a threat to the future of Company A. Because of the criticality for quality and delivery reliability, it has a high impact. (2) Strategic improvement has been mentioned a few times. Issues were mostly that the number of improvement programs and changes have been creating instability in the past years. This is a significant issue, but does not directly have a high impact on quality, delivery reliability or performance. Thus, medium impact and medium frequency.

The results are summarized in Table 2. The most impactful and frequent issues were found to be planning and control, vertical integration, and new product introduction. Therefore, these will be addressed in this research. The order in which they are discussed is the same order as the parts are described in theory by Slack and Lewis (2011), which is applied in the table as well.

5 PLANNING AND CONTROL

5.1 INTRODUCTION

Planning and control is part of the capacity strategy, which is one of the four decision areas stated by Slack and Lewis (2011). More specifically, the short-term capacity strategy is the planning and control. First, weaknesses of the current planning and control systems are identified. Based on these weaknesses, issues that result from a poor manufacturing strategy are identified. Next, theory is found that applies to the identified issues. Finally, the theory is applied and recommendations are made to improve the manufacturing strategy. The main result of this chapter are recommendations to improve the current planning and control systems, achieving a better fit with the current product portfolio.

5.2 WEAKNESSES OF PLANNING AND CONTROL

(1) Comprehensiveness. A decision has been made to use Baan 4.0, including the MRP II planning method. The planning method has not changed in over 10 years, while many other aspects of the business and markets have changed. Some minor improvements have been made, such as a central meeting to discuss interventions, in case of delays of projects. However, given the many issues experienced, as will be elaborated in the next paragraph, a more thorough analysis and improvement seems necessary. This thorough re-evaluation has not taken place. For that reason, I conclude that there is a weakness of comprehensiveness.

(2) Coherence. MRPII is a commonly used planning method for ATO, being suitable for that type of production. Company A has been taking more ETO orders over the past years, increasing the number of engineers whom design directly for customers. Meanwhile, the planning method stayed the same. A planning method that struggles with ETO, which is explained more in the next paragraph. It is not necessarily pulling the organization in different directions, but changes in the product portfolio have not been addressed in this decision area, holding the organization back. Therefore, there is a slight weakness of coherence.

(3) Correspondence. Quality has not been hindered by the current planning method. Delivery reliability has been poor, as projects often do not go as planned. The reasons for this are more complex and will be discussed in the next paragraph. By planning everything to be ready exactly at the due date, instead of creating a buffer, higher utilization is achieved, keeping costs lower at the expensive of delivery reliability. By over-stating lead-time towards customers, a higher delivery reliability can be achieved. This is a trade-off, but currently the balance seems to prioritize cost over delivery reliability. This is not in line with the overall manufacturing objectives, thus a weakness of correspondence.

(4) Criticality. As will be explained in the next paragraph, the planning and control systems have a high impact on delivery reliability. Given that delivery reliability is the second highest priority and a weakness of comprehensiveness has been identified, there is automatically a weakness of criticality.

5.3 ISSUES RESULTING FROM THE WEAKNESSES OF PLANNING AND CONTROL

Delivery reliability is crucial for the customers of Company A. Without switchgear, operations cannot perform, which could lead to entire factories not being able to start production. Additionally, it is not possible to simply buy other switchgear, due to the custom and complex nature of these systems and long lead-time. Planning and control are important for delivery reliability, as will become clear from the identification of issues below.

The first issue is **unreliable lead-time promises**. According to the marketing manager and the planning manager, demand is unpredictable and fluctuates strongly, which means the workload does as well. Meanwhile the quotations manager stated that they base their lead-time promises on fixed lead-times, as stated in a lead-time sheet. Therefore, lead-times promised by quotations are often impossible to meet. To be able to give more reliable lead-time estimates, a few things should be known: current workload, forecast of expected workload, and capacity availability. Because no data is gathered on the shop floor of the progress, current workload is harder to estimate accurately. Furthermore, Company A is currently unable to forecast expected workload. The only thing that is known is capacity availability. However, there are difficulties estimating how much capacity is really needed. That is why that lead-times are fixed, with a few exceptions for heavily customized projects, resulting in poor delivery performance even before the order enters the business.

The second issue contributes to the first issue, which is **inaccurate time estimates**. The building blocks planning works with, such as production, assembly and design times, are inaccurate, according to the planning manager. When new processes are introduced, an estimation is made of the time they take, by executing the process once. According to the operational excellence manager, these estimates are optimistic. Because of many smaller issues, such as having to search for the right tools, real production times are higher than the estimated times. The processes are not monitored in any way, so there is no data available to improve the accuracy of the time estimates. This contributes to a less accurate and reliable planning, leading to delivery issues.

The third issue is the **inability of the control system to deal with design changes**. According to the order management manager, customers often change requirements over the time of the manufacture of the product, which is a requisite for success in the ETO business. This is a source of extra revenue and is a requirement of customers. Design changes imply that the project goes back to the drawing table, new components might have to be bought or made, and planning must change accordingly. According to the order management manager, due dates are not changed, leading to delays. A weekly meeting with about 10 staff members is organized, which usually takes about 4 to 6 hours, to discuss how the planning should change when a project deviates from the plan. Additionally, according to the engineering manager, communication with the customer often takes 1 to 2 weeks to receive a reply, leading to further delays if customers are dissatisfied with the design. These are all examples of how the current control system is unable to deal with design changes and deviations from planning efficiently, which leads to delivery issues.

The final issue is **missing parts during assembly**. When only a minor component is missing, the entire project must be halted. Sequencing must change and the lost time cannot be caught up with, because for the next day, other projects are planned. Missing materials is a complex problem, originating from a variety of issues. The product configuration tool allows faulty configurations and frequently produces incomplete bills of materials. This is caused by errors in the underlying data, which is a top priority for Company A to solve. Another reason is that purchasing is done before the design is finished, while the bill of materials changes after design. In this process, errors are created in the bill of materials and wrong parts are ordered.

5.4 THEORY ON ISSUES

MRPII was found to not be a good fit for the ETO sector, based on 30 industrial case studies (Bertrand and Muntslag 1993, Little 1995). Some reasons mentioned are the design function as part of the process and the presence of custom products and components. For that reason, Little et al. (2000) created a new reference model (Figure 2) that does fit ETO. The purpose of this model is to assist companies in reviewing their planning method, to find what changes are necessary to improve the method, to address key business needs. The reference model follows the MRPII format and adds or changes some sub-processes, which are marked in grey. They view the effective execution of these sub-processes as critical to good performance in the ETO sector.

The purpose of such reference models is to assist company management in a review of their planning and scheduling processes. This will enable the examination of a firm's current approach to see how well this supports its key business needs, and what changes are necessary to improve planning and scheduling information systems alignment to meet these key needs.

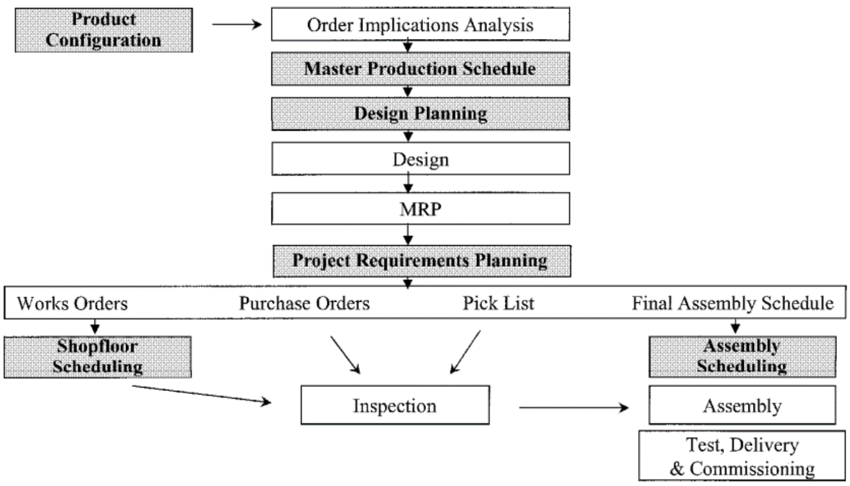

Figure 2. Outline ETO reference model. Little et al., 2000.

The added sub-processes are grey in Figure 3. Now, each of these will be discussed in more detail.

(1) Product configuration defines the parts that need planning for purchasing or manufacturing. Companies frequently struggle with creating a reliable product configuration. Omissions, inaccuracies or errors in the initial product specification lead to rework and late parts, thus delay. More severe errors in the product configuration can lead to products that are impossible to make and wrong cost estimations. It is important that historical data is used for the product configuration. Reuse of existing solutions and former bids should be applied wherever possible, to increase reliability. Often, modular design is used. Instead of customizing, modules can be configured to create many variations of the standard design. These modules have already been made and tested, omitting the need for custom design, decreasing cost and lead-time whilst improving the reliability of the product configuration.

(2) Order implication analysis is the assessment of potential load imposed upon critical resources. It must be made before order acceptance, so that the factory is not overloaded, which would lead to delay. The identification of the implications for the workload of new orders is vital to keep control of the workload and to maintain delivery dates. The order implication analysis done with the master production schedule, or in other words: a new function of the master production schedule in this proposed reference model.

(3) Design planning must be carefully controlled. It can take longer than the actual manufacture, having a large impact on the lead-time and delivery reliability. First, the design capacity must be measured and the workload must be monitored. Depending on the design functions, this should be broken down in sub-functions. The difficulty lies with the variables that impact design capacity: available labor hours, utilization, efficiency and skills. However, through monitoring, the design capacity can be determined using historical data. Most design tasks are a slight variation of existing techniques, components and systems. The novel element is comparatively small, thus it is possible to associate estimated times to those elements performed before. Many companies have moved away from detailed customized, but use modular design instead, which only requires minor modifications that can be done in under one week. According to the paper, one company that offered modular products with a high degree of customization overstated the quoted time by 33%, thereby ensuring on-time delivery.

(4) Project requirements planning is required instead of material requirements planning when lead-times for certain parts depend on existing work load. Especially when resources are scarce, which frequently is the case for customized parts, it is important for a new order to consider existing workload and a forecast of capacity availability. If this is not done, parts will often be late, leading to project delays. Every order is regarded as a project and scheduled on a forward scheduling basis. Thereby, a likely completion date is established. Then the customer is provided with the final due date.

(5) Shop floor scheduling must be coordinated to support final assembly schedule. It consists of a schedule for the manufacture of components, sub-assemblies and major assemblies. If only one minor component is late, the entire final assembly is delayed. Projects will be in different production stages, where delay can lead to conflicts. Because many parts are custom, estimated production times can differ or other issues can surface, frequently leading to these delays. Shop floor scheduling should react to these conflicts. By monitoring all different parts on the shop floor, conflicts can be noticed up front, so that scheduling can prevent issues further down the chain.

(6) The Final Assembly Schedule is a schedule of operations and parts required to complete a product for a customer in an assemble to order (ATO) environment. The assembly scheduling is vulnerable to missing parts. ETO companies have found to frequently struggle with missing only a minor part, causing delay of the entire project.

The paper ends with the proposal of an integrated effort, as shown in Figure 3. The purpose is to improve delivery reliability by proposing a process of integrated planning and execution. The key driver of this process is the Final Assembly Schedule. It starts at the order enquire stage, taking into account the current workload and capacity availability at design, production and assembly concurrently. The goal is to enable adherence to the assembly scheduling by back-scheduling through production and design.

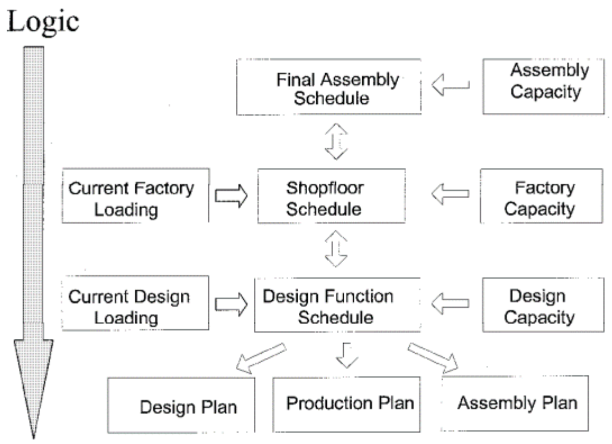

Figure 3. Integrated planning approach. Little et al., 2000.

5.5 Implications for the manufacturing strategy

Recommendations will be based on a comparison between the current situation and the reference model from theory. This is exactly what the reference model was made for. In Figure 4 the current planning method of Company A and the proposed planning model are shown. The current model is based on an explanation by someone from the planning department, whose responsibility is the planning itself for a set of products. It has been simplified in a similar fashion as the reference model from theory, using the same terminology for the same parts. That way, comparison is made easier.

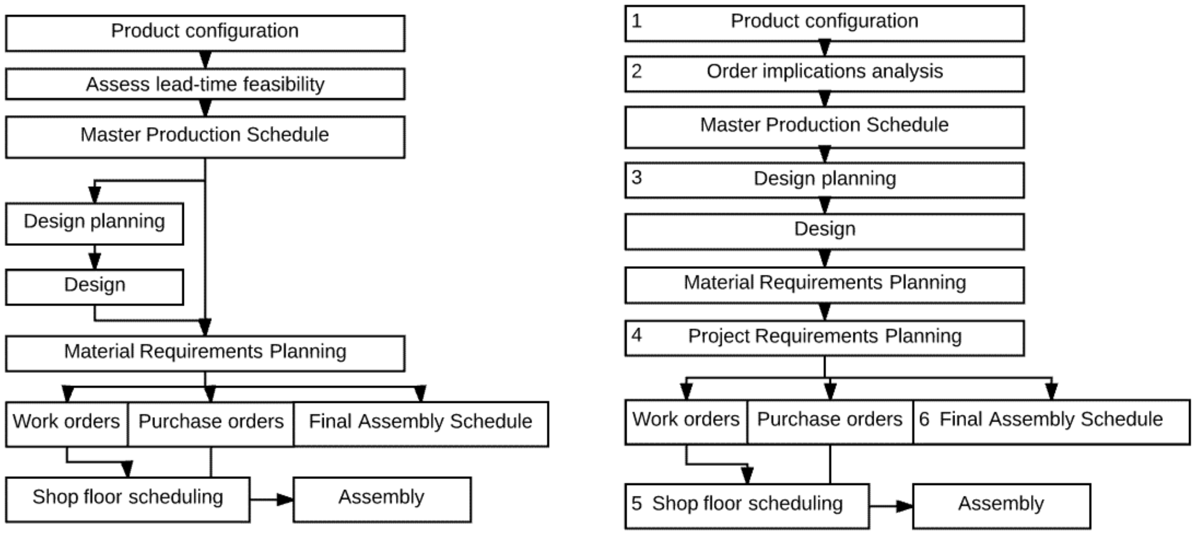

Figure 4. Current planning model and proposed planning model.

Based on a comparison with the reference model from theory, a new planning model is proposed. Each of the changes is marked with a number in Figure 4. Every proposed change will now be discussed, where the numbering corresponds to the numbering in Figure 4.

(1) Product configuration at Company A is done with BidManager. Sales uses that configuration tool to quickly make suggestions to customers, without needing to have detailed technical knowledge. In theory, it is described how errors in the initial configuration lead to larger issues later in the process. Exactly this is experienced at Company A, because BidManager is not perfect. It allows impossible designs. This is one of the main reasons for the fourth issue from paragraph 5.2, the missing materials. It is top priority to solve. Theory suggests using historical data, past projects, to improve the reliability of the product configuration. This is the first recommendation for Company A. To use past projects to improve the configuration tool. Bit by bit, faults in the tool can be fixed. Additionally, custom designs can be added in the tool as standards, to increase variety in the product offering. Because these designs have already been made and manufactured, these are more reliable, cost less time and are cheaper than custom design. This is discussed in the chapter of new product introduction, called the shifting strategy.

Once an order is accepted by the customer, the planning department assesses the feasibility of the lead-time of the order. In case the lead-time is not feasible, the planning tries to reschedule other projects to make space, depending on priority. This corresponds to the first issue from paragraph 5.2, the unreliable lead-times. Delays are communicated to customers via order management. This is similar to the **(2) order implications analysis**. Engineers frequently have a too high workload, leading to delays. Theory states that the order implications analysis should function as a regulating valve, accepting or rejecting orders. Company A currently does not reject orders at this stage, but accepts the delays. Therefore, projects are late even before the order enters the company, causing low delivery reliability. Furthermore, it also threats other projects planning, because workload becomes too high for critical resources. The recommendation is to keep better control of the workload, to reject orders or negotiate due dates at this stage, based on the order implications analysis. Planning and order management should be involved in this process. Order management communicates with customers, while planning performs the order implications analysis.

In the reference model, **(3) design planning** and design itself are done before the MRP. Within Company A, work orders and purchase orders are placed concurrently with the design phase. Because some parts have long lead-time, which can be purchased before the design phase, it is important to place these purchase orders as quickly as possible, to reduce the total lead-time. However, design changes have frequently led to incomplete or errors in the bill of materials. These errors were only encountered during assembly, leading to project delay. Another issue is that some designed parts sometimes have a longer lead-time than expected. Because of this, some parts are simply not there yet when assembly starts as scheduled. I recommend that certain parts are marked as long lead-time, which are the only parts purchased before design is complete. Then, the complete MRP is created once design is finished. The result should be a more complete and error-free bill of materials and a more complete MRP, causing less issues for the assembly schedule.

Company A only uses a MRP, while a **(4) Project Requirements Planning** fits some orders better. Theory states that standard lead-times are often a problem, especially for custom designed parts. As explained before, some parts are simply not at assembly when needed, causing delays in the assembly schedule. I recommend that a Project Requirements Planning is applied for orders that involve more customization. An exact distinction of when to use this should be determined by the planning department themselves.

(5) Shop floor scheduling is difficult for Company A. Because parts and processes are not tracked or monitored, it is difficult to keep track of them. Missing parts is often only discovered during assembly. I recommend creating an information system where the shop floor scheduling is monitored in real-time, using barcodes or RFID to track parts. Purchased parts should be tagged as soon as they are delivered, so that these are linked to the shop floor scheduling system as well. This can enable a better pick list and parts inspection, before the parts are fed to assembly. Better control can be exercised when a project deviates from plan when real-time data is available. Using the data, assembly can be rescheduled beforehand, in case parts are delayed. No more missing parts during assembly, leading to improved delivery reliability. The data can also be used to gather data on the real production times, which solves the issue of inaccurate time estimations, the second issue from paragraph 5.2.

The **(6) Final Assembly Schedule** is central in the integrated solution proposed in theory, where the goal is to enable adherence to the assembly scheduling by back-scheduling. The issues mentioned in theory, such as missing minor parts during assembly, causing major delays, has also been identified at Company A. Therefore, I recommend the current planning method is evaluated and this integrated solution from theory is implemented. How this will work in detail depends on the information systems used. This is too detailed and complex to discuss in detail here. I recommend that planning experts dive into this to reshape their planning method. The implementation of the integrated solution from theory requires the implementation of the recommendations from this paragraph, as they are all building blocks that play a role in the integrated solution.

5.6 DISCUSSION

The **weaknesses of comprehensiveness and criticality** was that the planning and control have received a lack of attention. The reference model from theory has been compared with the current planning model, based on which changes to the planning model have been proposed. If Company A chooses to implement the recommendations, and further details the new planning model, this can be considered a thorough analysis and re-evaluation. Then, planning receives the attention it ought to receive, solving the weaknesses of both comprehensiveness and criticality for the planning. The focus has been on planning, thus the issue of coping with design changes has not been addressed. To entirely solve the weaknesses, the control systems should also be re-evaluated thoroughly.

The **weakness of coherence** was a misalignment between the planning method and the product portfolio. It has been shown that the current planning method does not fit engineer-to-order products, and a new planning method has been proposed to solve this problem. If Company A chooses to implement the recommendations, the weakness of coherence is solved.

The **weakness of correspondence** was giving cost a higher priority than delivery reliability by aiming at high utilization, at the cost of delivery reliability. By adding the order implications analysis, the workload is monitored more closely, and projects can be rejected, resulting in a lower utilization but higher delivery reliability. By applying project requirements planning where necessary, the lead-time variation is being accounted for, improving delivery reliability. These two recommendations give a higher priority to delivery reliability relative to cost. Thus, if Company A chooses to implement these recommendations, the weakness of correspondence is solved.

6 VERTICAL INTEGRATION

6.1 INTRODUCTION

The vertical structure is part of the supply network strategy, which is one of the four decision areas stated by Slack and Lewis (2011). Only the first part of the supply network strategy is considered here, because procurement strategy is already being developed by the procurement department and considered out of scope according to my supervisor within Company A. The vertical integration strategy concerns make or buy decision making, which activities are to be done in-house and which are being outsourced. First, weaknesses of the current vertical integration strategy are identified. Based on these weaknesses, issues that result from a poor manufacturing strategy are identified. Next, theory is found that applies to the identified issues. Finally, the theory is applied and recommendations are made to improve the manufacturing strategy. The main result of this chapter is a recommendation for the overall vertical structure and a decision-making model for individual decisions.

6.2 WEAKNESSES OF THE VERTICAL INTEGRATION STRATEGY

The weaknesses are identified for the vertical integration decision area, based on the four criteria from the theoretical framework (Slack and Lewis, 2011).

(**1) Comprehensiveness**. Vertical integration decisions have been made bottom-up. Surprisingly, there are no documented analyses on these strategic decisions. Production managers have in the past determined what they ought necessary to do in-house, have discussed this with management, which then led to investment. The result is a highly integrated structure, which means many activities are done in-house. More specifically, Company A does almost everything, from product design to parts production to assembly. Some parts are purchased, such as sheet metal and a few more technical parts. No plan exists that states what the vertical structure should be in the future. From the interviews, I concluded that there is no consensus between managers on what should be the vertical structure, except that the current structure consists of too many activities. For example, one manager said that they should focus on assembly and custom order engineering because the market demands more custom products, while another said they should stop custom order engineering because it is not profitable, and focus on assembly only. A decision on what should be the future vertical structure has yet to be made, thus comprehensiveness is a weakness.

(2) Coherence. The current vertical structure has emerged over the years and business processes have emerged together with it, creating a fit. The highly integrated structure has recently been pulled in a different direction, by outsourcing R&D to an Company A location in Austria. Thereby, some of the advantages of the highly integrated structure have been lost, such as manufacturing knowledge at R&D, which yields advantages through design for manufacturing and assembly. When a decision is made on what the vertical structure should be, outsourcing R&D could suddenly be coherent with strategy. For example, when the new strategy would be to focus on assembly only. Therefore, weaknesses of coherence should be re-evaluated after making vertical integration decisions.

(3) Correspondence. By keeping production in-house, quality can be monitored and controlled closely. Delivery reliability can also be increased by keeping production in-house, by having full control over the scheduling and planning. Cost-wise it is often cheaper to outsource. Because the priorities in order of importance are quality, delivery reliability and cost, the decision to keep most activities in-house is in line with the priorities. However, this depends on the ability of in-house production to deliver higher quality and delivery reliability, which should be determined for each individual case. In general, there is no weakness of correspondence, but there might be for individual cases where outsourcing would increase quality and delivery reliability.

(4) Criticality. The operational excellence manager and a financial analyst stated that the costs of production capabilities, such as capital investments and overhead, are a large portion of the total costs of the company. More precise numbers could not be given due to confidentiality. The amount of attention received, as discussed in relation to comprehensiveness, has not been in line with the impact on total costs. Therefore, criticality is a weakness.

6.3 Issues resulting from the weaknesses of the vertical integration strategy

I concluded that there are weaknesses in both comprehensiveness and criticality in the vertical integration strategy. A lack of attention to the vertical structure decisions, especially when considering the high impact on costs, have led to a poor vertical structure.

The first issue is too expensive production processes. Capital intensive production processes require high capital investments. Economies of scale are important to minimize the cost. Maximizing utility is important, because the high investments in capital need to be earned back, which is a general rule for all capital-intensive processes (e.g. blast furnaces). Stable demand, or demand smoothing, is necessary to maximize utility. Company A have several production processes that fall in this category: casting, sheet metal modification, copper modification, and metal coating. Company A has relatively low volumes and thus low scale when compared with competition, but even more when compared with companies that specialize in one of these processes. Company A thus cannot achieve economies of scale. Furthermore, demand consists of few large orders, resulting in a highly variable demand. That is another reason why Company A cannot achieve high utilization. Specialized suppliers can do these processes cheaper, because they do have economies of scale and can reduce demand variability by pooling the demand for many different customers, leading to a higher utilization. That is why buying instead of making can significantly reduce costs.

The second issue is that Company A tries to do too many activities. The concept of a focused factory, which focuses on a few tasks and excels at these, has been discussed in the theoretical background. It applies here: Company A performs so many activities, that the organization becomes too complex to manage efficiently. The firefighting culture, which has been discussed in the introduction, is partially caused by the complexity. According to the operational excellence manager, it is difficult to find root causes and structurally resolve issues due to the complexity. A complaint frequently mentioned is that many improvement activities and changes have been implemented in the past few years. However, these only further destabilized the company, instead of improving things. The number of activities, and resulting complexity, make it more difficult to improve or change something, because if somewhere in the organization a change is made, it often causes issues somewhere else.

6.4 Theory on issues

The issue identified is a poor vertical structure, which has been further elaborated in the previous section. The question then is: what would be a better structure? A recommendation should be made that addresses this question. Theory is the basis for the recommendations, as explained in the research design chapter. This theoretical section consists of two theories: “a typology of engineer-to-order companies” (Hicks et al., 2001) and “make or buy: three pillars of sound decision making.” (Schwarting and Weissbarth, 2011) The first theory describes different existing vertical structures of engineer-to-order companies, and their differences on several criteria. This theory helps recommending an overall direction regarding vertical structure in the next paragraph of this chapter. Because a vertical structure consists of many parts, each with their own characteristics, an overall direction is not enough to establish a better vertical structure. To make decisions for these individual parts of the vertical structure, make or buy decision making models are often used. The second theory describes which criteria should be considered for make or buy decision making. This theory will help to give recommendations on the make or buy decisions to be made on a more detailed level than an overall structure.

6.4.1 Typology of engineer-to-order companies

The order fulfillment strategy is vital for the vertical structure. An engineer-to-order company consists of other activities than a make-to-stock company. Hicks et al. (2001) created a typology of engineer-to-order companies in the UK, consisting of four types: (1) vertically integrated; (2) design and assembly; (3) design and contract; (4) project management. This theoretical section focuses on (1) vertically integrated and (2) design and assembly, because Company A is primarily a custom design, manufacturing and assembly location. The main difference is that vertically integrated companies do everything from design to delivery, where design and assembly companies buy the components and focus on design and assembly. Hicks et a. (2001) describe the types along a set of criteria. Table 3 is a summary of the paper.

(1) Vertically integrated	Criteria	(2) Design and assembly
Design; manufacturing; assembly	Core capabilities	Design; assembly
Stable volume	Demand	Unstable volume
Maximum potential added value	Added value	Value adding assembly; critical high value-added production in-house
Leverage through modularity and commonality	Supplier relations	Share product and process knowledge through supplier relationships; leverage depends on volume, value, alternative suppliers, switching costs, customer preferences
Design for manufacturing and assembly; design leads to technical specifications of components	Design	Potential loss of design for manufacturing; design leads to functional specifications of components
Capital intensive; high overheads; low utilization leads to low return on capital	Economic	Lower capital investments and overhead

Table 3. Summary of "a typology of engineer-to-order companies in the UK" (Hicks et al. 2001).

6.4.2 Make or buy: three pillars of sound decision making

This section is based on an article published by Strategy&, a subsidiary of PWC, called "Make or buy: three pillars of sound decision making." (Schwarting and Weissbarth, 2011) I chose this paper, because I found it to be more practically applicable and comprehensive than the peer-reviewed literature I found on this topic. Given their experience with assisting companies with make or buy decisions and worldwide reputation, their publication can be considered as somewhat reliable at least. The publication is summarized in Table 4, Table 5 and Table 6.

Make	Business Strategy	Buy
In-house process differentiates the product or service	Attractiveness of the process/business	Process/business is unattractive (e.g. hard to find workers, strict regulatory environment)
Capability has synergies across the business	Criticality for overall business success Proprietary processes Product differentiation	Materials or processes are not critical to end products or marketing efforts
Supply market is hostile or controlled by competitors	Industry dynamics and competitive positioning	Supply market is suitable for building close partnerships

Need to "pus the technology or capability envelope"	Dynamics of the technology or capability Rate of change Risk to core capabilities	Suppliers are willing and able to meet innovation needs

Table 4. Strategic factors for the make or buy decision making. Schwarting and Weissbarth, 2011.

Make	**Risks**	**Buy**
Few or no alternative sources of supply	Holdup risks	Holdup risk is low or sufficiently managed through contract of broader business relationship
High supply market risks	Availability of alternative sources and switching costs	Low switching costs and easily accessible alternative sources of supply
Imperative to couple supply and usage (real-time/short lead time) for quick response or quality	Transportation risks Lead times Supply disruptions	Uncoupling the supply chain as little impact
Sensitive intellectual property involved in process/product	Intellectual property protection	No sensitive intellectual property involved

Table 5. Risk factors for the make or buy decision making. Schwarting and Weissbarth, 2011.

Make	**Economic factors**	**Buy**
Internal cost advantage cost parity, high quality	Relative economic and operating performance advantage (Scale and utilization; Efficiency; Reliability; Factor costs; Quality)	Suppliers have lower costs or better quality
Significant recent investment in process technology that cannot be recovered	Capital requirements	Major new investments are required
Investments meet required return on invested capital	Financial returns	Suppliers have lower ROI targets
Company has strong, defensible skills base	Level of skills and expertise	Insufficient or weak in-house skills/capabilities; skills are difficult to acquire

Table 6. Economic factors for the make or buy decision making. Schwarting and Weissbarth, 2011.

6.5 Recommendations for the manufacturing strategy

The recommendations for the vertical integration strategy are divided in the same two parts as in the theory section: the overall vertical structure and detailed make-or-buy decision making. For the overall vertical structure recommendation, I apply the theory of Hicks et al. (2001) to the case of Company A, analyzing each criterion. Based on these criteria, a recommendation is made. The detailed make-or-buy decision making recommendation is a decision-making model, where the criteria from theory are changed to fit the case of Company A, in collaboration with the procurement manager.

6.5.1 Overall vertical structure

Each criterion from the paper by Hicks et al. (2001) is hereunder applied to the case of Company A. For each criterion, a conclusion is drawn on whether (1) vertically integrated or (2) design and assembly is more suitable. The current structure of Company A is more towards being vertically integrated, with some production processes being in-house. Still, some components are being bought, such as sheet metal.

Core capability – The core capability of Company A is nonexistent, according to a variety of people: from the marketing manager to the operational excellence manager. The technical knowledge of employees throughout the entire organization has been mentioned as a strength, but Company A does not distinguish themselves from competitors in the market in any way. Some old, yet stable, products yield some profits. All other products have yield losses. Core capabilities could be created by focusing on a few activities and excelling at these. If focusing on all activities simultaneously, it is nearly impossible to create core capabilities. You cannot excel at all activities simultaneously, especially if you are behind. Type (2) design and assembly is therefore recommended as the better option on this criterion.

Demand – The demand of Company A mainly consists of few, large projects. This means that volumes are unstable, consisting of high peaks for the various products. Because Company A is a small player in the market and competitors push the price down, Company A can only pick up the left-overs, as explained by the marketing manager. They cannot compete for more standard orders, thus pick up the mainly highly custom and large projects. Type (1) vertically integrated requires stable volume for the high capital investments in manufacturing to be economically viable, which was a part of the vertical integration issue identified in paragraph 5.3 and explained by Hicks et al. (2001). Type (2) design and assembly is therefore recommended as the better option on this criterion.

Added value – Higher added value is an advantage of type (1). Prerequisite is the ability to add value, which is something Company A is struggling with. In addition to type (2) design and assembly, type (1) includes production as well. No thorough financial analysis is available that states the added value of the production processes, however due to reasons mentioned before in the identification of issues (paragraph 5.3), it appears that Company A is not able to add value higher than the transformation costs with their production processes. Some exceptions might exist, that some processes do add value or are a core capability. This should be determined for each production process. The recommendation here is not either type (1) or type (2), but the recommendation is to determine the added value of each production process individually, keeping the ones that add value. In addition, it is recommended that production capabilities which are vital to success, which are a core capability, are kept in-house. That is a modified version of type (2), where some high value adding and core production processes are kept in-house.

Supplier relations – According to the procurement manager, few strategic supplier relations exist, outside other Company A locations. An example is Company B, which supplies high volumes of sheet metal and most of the standard technical components. Other contracts are established individually, based on cost, quality and other common criteria. In this respect, Company A is tuned towards type (1). According to Hicks et al. (20010, to move towards type (2), knowledge sharing is vital, because it enables a supplier to supply what is needed and improving their products. This would require substantial investments in supplier relations. Company A in its current state suits type (1) better, however can move towards type (2) by building more strategic supplier relations and engaging in knowledge sharing.

Design – Within the business unit, design consists of two separate aspects: new product design and customization of products (or engineering) for individual orders. New product design is the task of R&D, currently located in Austria and Dubai, which are other Company A locations. New product design is done on a global level, because Company A plans to produce the same products on different locations in the future, to access more markets. According to Hicks et al. (2001), an advantage of type (1) is to have better manufacturing knowledge at R&D. This advantage is non-existent for Company A, because R&D is not in Hengelo anymore. Therefore, neither type (1) nor type (2) is preferred in this regard. Customization of existing products for individual orders is done by the Custom Order Engineering department in Hengelo. For them, it is important to have manufacturing knowledge, which is currently very accessible. When outsourcing these production processes, a solution needs to be found of how this knowledge will be retained. Possibly through strategic supplier relations, where customized designs are discussed with suppliers and manufacturing knowledge is kept up-to-date through training. Type (1) is thus preferred in this regard and when moving to type (2), measures need to be taken.

Economic – high capital investments, unstable demand and a lack of economies of scale lead to relatively low utilization and low return on capital. The demand is unstable, because Company A has very small revenue compared to the total market. Orders are thus always large for Company A, and can value up to 2 million per order. Furthermore, Company A picks up "the breadcrumbs" as stated by the marketing manager. These breadcrumbs are out of the ordinary, often larger and more customized, not fitting within the standard portfolio of competitors. As explained in the problem identification section, specialized suppliers can achieve more economies of scale and higher utilization, achieving a higher return on capital, thus producing cheaper. Outsourcing production should therefore reduce costs, except when highly custom parts are required. In that case, flexible and small-scale production capabilities in-house could be cheaper. However, in general I recommend type (2) design and assembly.

I conclude that a modified version of the type (2) design and assembly is the better option for Company A. Challenges in retaining manufacturing knowledge and building strategic supplier relations do not seem to weigh up to the advantages. The most important advantage of type (2) is cost, due to purchasing instead of producing. Another advantage is a focus on fewer activities, leading to less complexity and probably increased quality and delivery reliability. The only modification to the type (2) is that production processes that are core capability, and thereby provide high added value, should be kept in-house. Next, a more thorough evaluation should be made for each of the production processes, to determine in more detail what the new vertical structure should be.

6.5.2 Detailed make-or-buy decision making

To make decisions for individual production processes, a decision-making model is established, which is based on the publication by Schwarting and Weissbarth (2011). The decision model has been discussed with the procurement manager and adjusted to suit Company A. It is in the form of Excel sheets, because it is widely used, easy to use and is practically viable for a decision-making model. The aim of the decision model is to perform a comprehensive analysis, before making a make or buy decision. It is then the basis for discussion, after which a final decision is made.

In addition to the two options stated by Schwarting and Weissbarth (2011), make or buy, a third option is relevant for Company A: buy +specials. This means purchasing standard components and modify these in-house to create specials when needed. This is important for Company A, because this enables them to be more flexible regarding customized design, while not having the full production capabilities in-house where volume is too low. Each make-or-buy decision is made for a so-called cluster: a set of machines that together can perform a set of transformations. For example, a variety of metal modification machines are a cluster. Keeping only one of these metal modification machines in-house doesn't make sense, because then the whole set of transformations are not possible anymore, since multiple machines are necessary for each of the transformations.

Now, the decision-making model will be discussed for each excel sheet. Figure 5 is the final sheet of the decision-making model, which automatically summarizes the results, based on what is filled in in the respective sheets. I show this first, because it gives a good overview, before discussing each individual aspect of the model. This sheet is useful to provide a solid ground for further discussion and the final decision. None of the important aspects can be ignored this way, while otherwise these decisions could for example be made with a focus on cost, while disregarding other important aspects, such as quality.

	Make	Buy	Buy +specials
Strategy			
Proprietary processes		x	x
Product differentiation		x	x
Core capabilities		x	x
Innovation needs	x		
Supply market		x	x
	Make	**Buy**	**Buy +specials**
Risks			
Transportation risk	Low	Moderate	Low
Holdup risk	Low	Low	Low
Supply risk	Minimum	Minimum	Minimum
IP risk	Minimum	Minimum	Minimum
Quality risk	Minimum	Minimum	Low
Innovation risk	Minimum	Minimum	Minimum
	Make	**Buy**	**Buy +specials**
Cost	0	0	0
	Make	**Buy**	**Buy +specials**
Comparison totals			
Quality	0	0	0
Flexibility	0	0	0
Delivery	0	0	0
Skill	0	0	0
Totals	0	0	0

Figure 5. Sheet 6: summary of the decision making model results.

Below (Figure 6)is the first sheet, which shows the legend and defines what the options are. Note that the light blue cells are to be filled in by Company A.

	= formula, do not edit
	= fill in
	= corresponding comment
Test	= heading

Decision options	
Make	= produce in-house
Buy	= purchase externally
Buy +specials	= purchase standards, modify in-house

All comparisons are on a yearly basis, e.g. costs per year

Figure 6. Sheet 1: legend and options.

The second sheet (Figure 7) evaluates the strategic importance of the cluster in question. The first difference with theory is the translation of criteria into simple yes/no questions, which is more intuitive. Some answers might be hard to answer with a simple yes or no, but happily enough space is created especially for these kind of remarks (not shown here due to limited space in report). The second difference with theory is that “criticality for overall business success” is divided in three questions: proprietary processes (1), product differentiation (2), core capabilities (3). The reason for this is that the procurement manager saw that some clusters are core capabilities, but do not have proprietary processes or technologies, for example.

Strategy	Answer	Favored
Are proprietary processes or technologies in the cluster?	No	Buy
Does the cluster significantly contribute to product differentiation?	No	Buy
Is the cluster part of the core capabilities?	No	Buy
Is the cluster unattractive? (e.g. hard to find workers, strict regulation)	No	Make
Are potential suppliers willing and able to meet innovation needs?	Yes	Buy
Is the supply market hostile and controlled by competitors?	No	Buy

Figure 7. Sheet 2: strategic factors.

The third sheet (Figure 8) evaluates the risks of the cluster in question. In addition to theory, a risk matrix (Figure 9) is applied to assess the risks. The risk matrix is a common tool, because of its ease of use and clarity, while still being relatively thorough. Disadvantage of the risk matrix is that it is largely subjective. However, since it is used as a basis for discussion, errors due to subjectivity can be partially filtered through discussion. Subjectivity is necessary, depending on the significance of the make-or-buy decision, because quantifying a risk in detail is very difficult in most cases. The probability and consequences categories and the accompanying classifications of low/moderate/higher risks have been set in collaboration with the procurement manager. He deemed these the most logical.

In addition to theory, risks are defined in more concrete terms, based on the criteria Company A uses. Quality risk is added because it is the top priority of Company A, and quality is a risk, which has led to issues in the past. Innovation risk is added, because Company A is in the process of radically changing their product portfolio, which makes innovation risk an important aspect in the make-or-buy decision making process. Risks are defined as:

1. Transportation risk: risk that component is delivered late or not at all.

2. Holdup risk: risk that suppliers will abuse Company A's dependency on them by raising prices or demanding better terms.
3. Supply risk: risk that supply is endangered because of financial health of supplier, political instability or exchange rate volatility or capacity.
4. Intellectual Property risk: risk that intellectual property is compromised.
5. Quality risk: risk that quality of the product is not conform technical specifications.
6. Innovation risk: risk that the current supplier, as well as potential other suppliers, cannot meet strategic innovation needs.

	Make			Buy			Buy +specials		
Risk	Probability	Consequences	Risk	Probability	Consequences	Risk	Probability	Consequences	Risk
Transportation risk	Rare	Moderate	Low	Moderate	Moderate	Moderate	Rare	Moderate	Low
Holdup risk	Moderate	Minor	Low	Unlikely	Minor	Low	Unlikely	Minor	Low
Supply risk	Rare	Negligible	Minimum	Rare	Negligible	Minimum	Rare	Negligible	Minimum
IP risk	Rare	Negligible	Minimum	Rare	Negligible	Minimum	Rare	Negligible	Minimum
Quality risk	Rare	Negligible	Minimum	Unlikely	Moderate	Minimum	Unlikely	Moderate	Low
Innovation risk	Unlikely	Negligible	Minimum	Rare	Negligible	Minimum	Rare	Negligible	Minimum

Figure 8. Sheet 3: risk factors.

Risk matrix	**Consequences**				
Probability	Negligible	Minor	Moderate	Significant	Severe
Rare (1-20%)	Minimum risk	Minimum risk	Low risk	Moderate risk	High risk
Unlikely (21-40%)	Minimum risk	Low risk	Low risk	Moderate risk	High risk
Moderate (41-60%)	Minimum risk	Low risk	Moderate risk	High risk	Extreme risk
Likely (61-80%)	Minimum risk	Low risk	Moderate risk	High risk	Extreme risk
Very likely (81-100%)	Low risk	Moderate risk	High risk	Extreme risk	Extreme risk

Figure 9. Sheet 3: risk matrix.

The fourth sheet (Figure 10) states the estimated costs of each option. Instead of the relative economic and operationg performance advantage criteria in theory (e.g. scale and efficiency) more concrete criteria are used here. Reason is that scale, efficiency, reliability and such are hard to define. According to the procurement manager, actual costs are easier to estimate, more reliable and easier to compare. The make costs estimate can be obtained by finance, and the buy costs can be obtained by asking for a quotation. The cost categories are comprehensive and commonly used within Company A, they have been established with a financial analyst and the procurement manager.

Cost categories	Make	Buy	Buy +specials
Raw materials			
Production costs			
Overhead			
Labor			
Adminsitrative			
Shipping and handling			
Inventory			
Price			
Total	0	0	0

Figure 10. Sheet 4: cost factors.

In addition to the theoretical three pillars, a variety of aspects still need to be considered. Part of the reason is that we, the procurement manager and I, found some aspects of the economic pillar unsuitable for the economic section. These are level of skills and expertise required and quality. We also found some two aspects missing: flexibility and delivery. These are in the fifth sheet (Figure 11).

(1) Quality is divided in three criteria that are used globally by Company A to assess quality: QSA score, DRM and DPPM. Defect parts per million is what it says. Defective material reports can give some depth to the DPPM number. For example, when a manufacturer produces only 100 products of a type per year, then only two errors can result in a bad DPPM number. Then, defective material reports can give insight in what went wrong, which could be a minor issue that occurred once.

(2) Flexibility also consists of three criteria. Cost of dealing with volume flexibility is important, because the demand consists mainly of few large orders. Ability to deal with specification changes is important, due to the frequent custom design requested by customers. Flexibility in change of leadtime is important, because delays are frequent due, for example, change orders.

(3) Delivery consists of two criteria. Costs of late delivery of component is important, especially when risk of late delivery is high. Impact on total project leadtime is important, because some components are critical and delay the entire project, which is very expensive.

(4) Skill is divided in knowledge and ability. Knowledge is important to understand production processes, to make technology decisions and design for manufacture. Ability is important, especially when it comes to operating specific equipment. Their scores are the availability of the required knowledge and ability in-house and the difficulty to acquire them.

Each of these criteria are weighted and scored on a scale of 1-5, where for each categories is defined what exactly each number means. For example, knowledge and ability matrices exist within Company A, which enables scoring each type of knowledge and ability required. Another example is the QSA score, which is a percentage that can be rescaled to the 1-5 scale. To reduce the subjectiveness, for each of these criteria it needs to be defined what exactly a score means. According to the procurement manager, it is important other managers are involved in further defining these scores. For that reason, the operationalization of the criteria and their categories have not been set.

Criteria	Make			Buy		Buy +specials	
	Weight	Score	Total	Score	Total	Score	Total
Quality							
Quality score (QSA score)							
DMR (defective material report) / CAPA							
DPPM (defect parts per million)							
Total	0		0		0		0
Flexibility							
Cost of dealing with volume flexibility							
Ability to deal with change of specifications							
Flexibility in change of leadtime							
Total	0		0		0		0
Delivery							
Costs of late delivery of component							
Impact on total project leadtime							
Total	0		0		0		0
Skill							
Knowledge							
Ability							
Total	0		0		0		0
Total	**0**		**0**		**0**		**0**

Figure 11. Sheet 5: other factors.

Now some final remarks. The model depends for a part on subjective judgement. Therefore, filling it in with multiple persons can be valuable. Further discussion of the scores and decision can improve objectivity. A conscious consideration has been made to balance reliability and ease of use. More important decisions should receive more thorough analysis of the criteria, resulting in more objective scoring, while less important decisions can be based on more subjective judgement to reduce the time needed to make the decision.

6.6 Discussion

The **weaknesses of comprehensiveness and criticality** came from a lack of attention, in terms of analysis, discussion and deliberate decision making. These weaknesses have been addressed by offering a thorough analysis of the vertical integration. First, the recommendation for an overall structure is based on several criteria from theory. Second, the make or buy decision for individual processes can be assessed thoroughly, using the decision-making model. If implemented, a new vertical structure strategy is created, which is based on a thorough analysis and discussion with relevant managers. Thereby, the weaknesses of comprehensiveness and criticality are solved.

7 New Product Introduction

7.1 Introduction

New product introduction is one of the two parts of the development and organization strategy of the categories stated by Slack and Lewis (2011). R&D, which designs new products, is not in Hengelo. However, Company A is still one of the main actors in the development of new products. Many experts within Company A contribute to the new product design through: technical product knowledge; manufacturing experts; marketing (identify customer needs); project managers. And, new product introduction has a high impact on the performance of Company A, which will be elaborated in this chapter. The main recommendations of this chapter are: create and communicate a clear mission and set of objectives; focus on improving execution of DFMA; add how product design can aid process improvement to the NPD process; implement a shifting strategy. First, weaknesses of the current new product introduction strategy are identified.

7.2 WEAKNESSES OF THE NEW PRODUCT INTRODUCTION STRATEGY

The weaknesses are identified for the vertical integration decision area based on the four criteria from the theoretical framework.

(1) Comprehensiveness. Company A uses PROLaunch, which is a comprehensive stage gate model. Each part of the new product introduction is thoroughly defined. PROLaunch is used globally by Company A. This decision area has been considered thoroughly. Therefore, comprehensive is not a weakness of the new product introduction strategy.

(2) Coherence. The Operational Excellence team has grown and received more attention, mainly to raise the productivity and decrease costs, since both have been far below industry standards. The operational excellence manager stated that the product design is severely holding back efforts to improve productivity and cost reduction. More specifically, the lack of standardization and modularity make it difficult to apply late point definition and other productivity-improving measures. Experts on the areas of manufacturing and operational excellence should provide their expertise on how product design can improve production efficiency, but that is currently not done at all. Thereby, the new product introduction strategy has been pulling the organization in different directions. This is a weakness regarding coherence.

(3) Correspondence. The latest new product introduction projects (products CX and CX-H) have been characterized by a focus on speed to market. According to the marketing manager, products that were still in development had already been sold. According to a manufacturing expert, who was involved in the new product introduction project for CX and CX-H, gate reviews were not done correctly. Once a product appeared to have issues during a gate review, it was moved to the next stage nevertheless. It was assumed these issues would be solved later in the process. These two examples show the focus on speed to market, however according to the operations manager, speed to market has much lower priority than quality and delivery reliability. Quality and delivery reliability have both suffered heavily under the focus on speed. By promising orders during development, many customers had to be disappointed because of difficulties during development. By ignoring some issues at a gate review, quality issues surfaced during assembly, while the entire manufacturing process was already operating. These are weaknesses regarding correspondence.

(4) Criticality. The new product introduction process is vital and decisions in this regard have received adequate attention on a global level. However, the execution of the designed process is just as important. Issues with the execution have frequently emerged, as explained in the correspondence part above, but not received adequate attention. These issues have been shown to be critical to delivery reliability and quality. There is a weakness regarding criticality when it comes to the execution of PROLaunch.

7.3 ISSUES RESULTING FROM THE WEAKNESSES OF THE NEW PRODUCT INTRODUCTION STRATEGY

According to the manufacturing manager, one issue was selling products (CX and CX-H) while they were still being developed. This put extra time pressure on the projects. Projects were moved to the next stage while the previous stage wasn’t properly finished, leading to quality issues during production. Delivery deadlines were missed, leading to low delivery reliability. As explained in the previous part, this was a weakness in correspondence. Higher management set the wrong priorities.

Moving projects to the next stage while the previous stage wasn't properly finished is an issue in itself. Various people, such as the manufacturing manager and several experts, stated that PROLaunch is good, but the execution was poor. This is the second issue identified. An example: drawers, which are a major component of switchgear, have been found to be breaking during assembly due to poor design. According to one manufacturing expert, he alarmed R&D of this problem in earlier stages of the new product development process, but his comments were ignored. More specifically, this does not concern the execution of PROLaunch in general, but design for manufacturing and assembly. If DFMA was correctly executed, this would have been prevented. A set of DFMA steps would have been executed, where manufacturability issues would be resolved before entering a gate review. And even then, strict criteria would have been used to evaluate the project at the end of a stage before moving to the next stage.

The third issue is again on the area of DFMA: lack of design for production efficiency. Operational Excellence experts have frequently voiced complaints over the lack of attention to production efficiency during product design. As explained in the previous section, the lack of standardization and modularity have hold back efforts to improve efficiency and productivity, according to the operational excellence manager. Even after requests for collaboration with R&D were made by the operational excellence team, no real collaboration emerged.

This section is ended with a description of two contributing factors for poor DFMA execution. A leading member of the R&D team stated that they considered manufacturing and assembly as the executers of their design. He stated they don't view manufacturing as an important party to collaborate with. Even though no big conclusions can be taken from one statement, it indicates an attitude that can be part of the reason for the poor execution of DFMA. Manufacturing experts experience this attitude in being ignored. According to a manufacturing expert, this attitude is partially thought to be the result of poor knowledge on the impact of product design on efficiency, costs and quality. Another contributing factor for the poor execution of DFMA is that R&D has been moved to Austria and Dubai, while production and assembly are still in Hengelo. However, DFMA issues already existed before R&D was moved and simply got worse.

7.4 THEORY ON ISSUES

This chapter consists of three theories. The main issue lies with the execution of DFMA. Therefore, the first theory is a short summary of a book by Boothroyd and Dewhurst (2010), called "Product Design for Manufacture and Assembly." It is generally considered to be the major book about DFMA. Second, theory on design from an operations management perspective is discussed, which is taken from the widely used operations management textbook by Slack (2013). It elaborates on the second theory by stating a few methods of how the first, and major, step of DFMA can be realized: design simplification. Third, a publication by Amrani (2010) about shifting strategy is discussed. It is a concept I came across during my literature research which I found to be highly relevant to Company A. It doesn't directly address one of the issues mentioned, but is an example of how product design can impact performance, and therefore falls within the new product introduction strategy. In the recommendations section, it will be elaborated why this theory is an important recommendation for improving the manufacturing strategy.

7.4.1 Product Design for Manufacture and Assembly

Boothroyd and Dewhurst (2010) define DFMA as follows:

- Design for Assembly means the design of the product for the ease of assembly
- Design for Manufacturing means the design for the ease of manufacture of the collection of parts that form the product after assembly

Subsequently, they propose a generic DFMA process, which can be seen in Figure 12. Design for assembly is an analysis that leads to a simplification of the product structure. Selection of materials and processes and early DFM cost estimates is done for both the design before and after DFA. That way trade-off decisions can be made. During this step, the best materials and processes to be used for the various parts are considered. From this, a best design concept follows. The final design for manufacture consists of a more thorough analysis for the detailed design of parts.

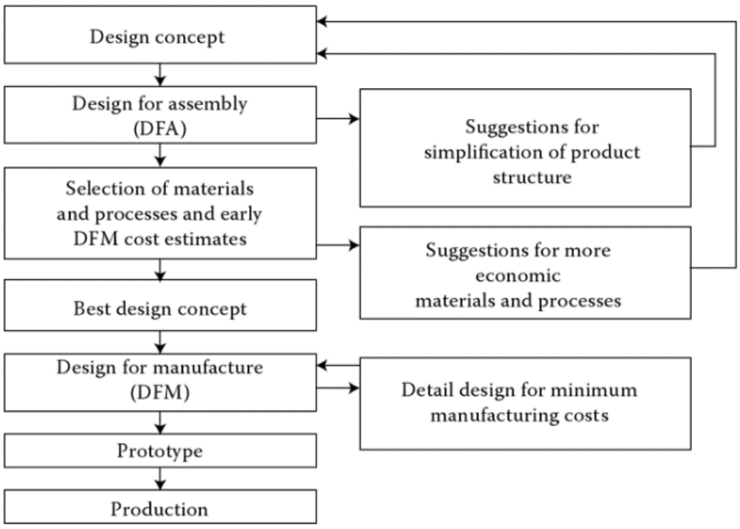

Figure 12. Steps in the DFMA process. (Boothroyd and Dewhurst, 2011)

7.4.2 Reducing design complexity

In his widely used operations management textbook, Slack (2013), states: “A key design objective should be the simplification of the design through standardization, commonality, modularization and mass customization.” (p.136) These are more specific methods for accomplishing the first step of the DFMA process: the simplification of the design.

High variety is costly. To overcome this, products and processes can be standardized by reducing variety to that what has real value for the end customer. Many companies have improved profitability through carefully reducing variety.

Commonality means using common elements within a range of products. It can also be applied in other cases, such as standardizing the format of information inputs to a process through design forms. Some advantages are that it reduces the complexity to produce products, requiring less process variety and less stock of spare parts. Standardizing information inputs can lead to less errors and less missing information. Less knowledge is needed to work on a wide range of products when they have more in common, which can yield advantages in maintenance and employability across different products.

Modularization involves designing standardized sub-components of a product, which can be put together in different ways. High variety can be offered to the customer through the fully interchangeable assembly of various combinations of a smaller number of standard sub-assemblies. These sub-assemblies can be produced in higher volume, thereby reducing their cost.

7.4.3 Shifting strategy

Specifically, for engineer-to-order products, several papers propose a "shifting strategy." The main idea of shifting strategy is stated by Amrani (2010): "At the end of ETO projects, new components once developed could be included in database and considered as either make-to-order, assemble-to-order or make-to-stock, allowing fastening order fulfilment by reuse the existing data."

The reuse of components that have been developed before can be enabled through a feedback loop. Once custom order engineering has customized a design for a customer, the customization is evaluated whether it is worth adding it to the standard configuration tool. Then the design is evaluated and improved where necessary. The last step is to integrate it in the configuration tool, which enables sales to sell a wider range of ATO products, which have shorter lead time and lower costs compared to customized products. This is thought to create a major competitive advantage for to ETO companies (Figure 13)ta.

When the design is a specific part, it needs to be decided if it is made to order, assembled to order, or made to stock. Furthermore, it needs to be decided whether it will be made or bought. The matrix by Amrani (2010) in fig16 shows three criteria by which can be judged what suits best.

From **ETO parts**	Repetitivity of demand	Storage costs	Bargaining power of customer
To **MTO**	●	●●●	●
To **ATO**	●●	●●	●●
To **MTS**	●●●	●	●●●

● Low ●● Medium ●●● High

Figure 13. From ETO parts to MTO, ATO or MTS. (Amrani, 2010)

7.5 IMPLICATIONS FOR THE MANUFACTURING STRATEGY

For each of the issues identified, recommendations are made in this section. Since most issues were about DFMA, both the theory and this section are focused on that. First, the existing DFMA procedure is analyzed and compared with the one from theory (Boothroyd and Dewhurst, 2010). Based on this analysis, recommendations are made. The second part follows from the first part: how product design can aid process improvement, which is based on theory from Slack (2013). Lastly, some recommendations are made based on theory on shifting strategy (Amrani, 2010). It must be mentioned that recommendations are not in-depth, but only provide some direction in which more detailed solutions can be found. It is not in the scope of this research to give tailored, in-depth recommendations.

7.5.1 DFMA process and execution

To make recommendations for the manufacturing strategy, it is important to start with looking at what is already in place. In the PROLaunch method, the following are part of the DFMA procedure:

1. Design, concept, function, and sensitivity to manufacturing variation
2. Manufacturing and/or assembly process
3. Dimensional tolerances
4. Performance requirements
5. Number of components
6. Process adjustments

7. Material Handling

In addition to this, Company A uses a Production Part Approval Process (PPAP), which is widely used in all kinds of industries. This is a standard used to formally reduce risks prior to product release, in a team oriented manner using well established tools and techniques. The purpose of PPAP is to demonstrate that the manufacturing process has the potential to produce a product that consistently meets all requirements during an actual production run at the quoted production rate. It is applied for new parts, design changes, supplier changes or part processing changes, as long as the change is significant enough to justify doing a PPAP.

It has been shown that processes are in place to ensure manufacturability and ease of assembly. However, this did not happen in the past two major new product introduction processes. If the procedure itself is not the problem, then the execution of the procedure is the problem. This has been mentioned by manufacturing experts, who stated that their warnings have been ignored in the process. The manufacturing strategy must address the poor execution of DFMA processes. A few ideas are:

1. Find out where the execution exactly when wrong in detail. Findings then must be addressed by appropriate measures. A measure could be training management, NPD project managers and new product developers on the subject of the execution of DFMA processes, in order to improve execution.
2. Re-establishing collaboration with manufacturing experts during the NPD process. By moving R&D to Austria and Dubai, collaboration has worsened. Ignoring warnings by manufacturing experts should not happen again, thus efforts should be made to improve the collaboration between Austria and Hengelo regarding DFMA, but possibly also in a wider sense. Opening discussion on what went wrong and establish new communication channels between the two departments can help to improve collaboration.

7.5.2 Product design for production efficiency

When comparing PROLaunch with theory, it shows that one aspect from theory is not covered by PROLaunch: how product design can aid in process improvement. This goes beyond the ability to manufacture a product the way it is designed. The operational excellence manager voiced frustration over the fact that R&D did not listen to his comments to standardize, increase commonality and increase modular design. Especially the ability to implement delayed differentiation is hampered by the product design. A few ideas to address this in the manufacturing strategy:

1. Add or change the DFMA process in PROLaunch to address process improvement as well. By making a formal process of designing for process improvement, it will be included in future NPD processes. In this process, collaboration with operational excellence experts is key, to ask them how they think the product design should be changed to make manufacturing and assembly more efficient.
2. Changing the process is not enough, it is also a matter of knowledge and skill. Manufacturing experts stated that R&D personnel often lacks manufacturing knowledge. Through training, R&D personnel can acquire the knowledge and skills that help them design products that are more efficient to produce. This training can be combined with the training in the execution of DFMA processes. Because training of staff can be too expensive, another option is to involve manufacturing experts and give them authority to give a go or no-go. Then, if DFMA is not correctly executed, the project will not continue to the next step, until manufacturability is approved by manufacturing experts.

3. Instead of only focusing on new products, the existing product portfolio can also be improved. Product changes are implemented on a regular basis, and improving commonality and modularity can be implemented through such product changes. Like previous suggestions, training R&D personnel and collaboration with manufacturing experts can be ways to achieve this.

7.5.3 Shifting strategy

A final consideration can be made for standardization through the shifting strategy. Company A is producing more engineer-to-order products every year, because the market is shifting towards more customization. Customers have been demanding more customization for a similar price. Competitors have been meeting these demands by creating modular designs and other ways to increase variety, without giving in too much on efficiency. Therefore, the price has not gone up much, while the demanded variety has. Company A has been slow in this aspect, and offer much less variety in their standard portfolio than competitors. This can partly be attributed to the higher volumes competitors have, allowing them to produce a higher variety more efficiently. This forces Company A to take on projects that go beyond the variation competitors offer, which are engineer-to-order products. Manufacturing experts have complained that these highly custom projects are done too cheaply, but the marketing manager stated that customers demand this price, and will otherwise still go to competition.

Reducing cost through the shifting strategy can be vital to compete with the high variety competitors offer. A recommendation for the manufacturing strategy would be to implement the shifting strategy as described in theory. When implementing a shifting strategy, clear boundaries must be set. This is because there is one major risk: further increasing the error sensitivity of the product configuration tool. As explained in the planning and control chapter, the product configuration tool is used by sales to configure products for customers. It is currently not entirely reliable, so when evaluating whether a design can be integrated in the tool, it must be carefully evaluated whether it poses a threat to the reliability of the tool or not. Based on the theory (Amrani, 2010), the steps of a shifting strategy for Company A would be these:

1. Evaluate whether a design should be added to the product configuration tool, depending on the risk of implementing and probability of future usage.
2. Evaluate the design itself and improve where needed, to ensure standardized designs are error-free.
3. Integrate the design in the information systems used by Company A.

Software can be used to automatically store designs as templates. Developing shifting strategy into more detail is out of scope.

7.6 Discussion

The **weakness of coherence** is the lack of attention to production efficiency in the product design, while in other decision areas, increasing production efficiency has been top of the list. This weakness has been addressed by recommending the addition of a procedure for designing for production efficiency to the PROLaunch procedure. Also, more collaboration with manufacturing experts and training of R&D personnel are recommended to address the weakness. Because products are often produced for a long period (10+ years), updating the design of current products, if worthwhile, has also been recommended. These three recommendations, if implemented, would align the improvement efforts of Company A with the new product introduction strategy, thereby solving the issue of coherence.

The **weakness of correspondence** is the prioritizing of speed to market, at the cost of quality and delivery reliability. This weakness has been addressed by recommending an analysis of the issues of the execution of DFMA and re-establishing the involvement of manufacturing experts during the product design. When manufacturing experts are involved to the extent that they can give a no-go during product development, because of manufacturability issues, the speed to market would be given the right priority again: below quality. These recommendations, if implemented, would restore the priorities as intended by the managers of Company A on the area of new product introduction, solving the weakness of correspondence.

The **weakness of criticality** is the poor execution of PROLaunch, which has had a high, negative impact on product quality. These issues should have been given a higher priority. The recommendations that address this weakness are the same as for correspondence: to analyze the issues of the execution of DFMA, to then address these issues, and to re-establish the involvement of manufacturing experts in product design. If the recommendations are implemented, quality issues on the area of new product introduction are given the right priority, solving the weakness of criticality.

8 CONCLUSION

The first question was: what decision areas should be addressed by the manufacturing strategy? The decision areas have been identified by Slack and Lewis (2011): capacity strategy; purchasing and supply strategy; process technology strategy; development and organization strategy. In this research, the following areas have been addressed: a part of the capacity strategy (planning and control), a part of the purchasing and supply strategy (vertical integration) and a part of the development and organization strategy (new product introduction). These were chosen, because they were found to have the most pressing issues. This is the answer to the second question: on which decision area are the most critical issues experienced? The third question was: what are characteristics of a strong manufacturing strategy? These characteristics have been identified by Slack and Lewis (2011): comprehensiveness; coherence; correspondence; criticality.

Research questions 4 to 7 have been answered per decision area, and thus will also be concluded in that manner here. A quick recap of the questions:

- Q4. What are weaknesses in the decision areas of the manufacturing strategy?
- Q5. What issues are experienced in the decision areas, as a result of weaknesses in the manufacturing strategy?
- Q6. What does theory suggest about the identified issues?
- Q7. How can Company A address the identified issues using their manufacturing strategy?

From the capacity strategy, the planning and control has been discussed, which is summarized in Figure 14. All four weaknesses have been identified in this part of the strategy (Q4). Comprehensiveness because the planning method has not been subject to thorough revision in the past 10 years. Coherence because the shift in the product portfolio has not been addressed in the planning method, leading to inconsistencies. Correspondence because cost has received a higher priority than delivery reliability, by aiming at the highest utilization possible, not using any buffer, at the expense of delivery reliability. Criticality because of the weakness in comprehensiveness and the impact of planning and control on delivery reliability. The following major issues have been identified: unreliability of lead-time communicated to customers; inaccuracy of estimated production times; inability to cope with design changes; missing parts during assembly (Q5). Theory by Little et al. (2000) has been found that applies to these issues (Q6). The theory proposes a reference model for planning and control, with which companies can compare their own processes to identify potential improvements.

Recommendations have been made by creating a simplified model of the current method and comparing it with the reference model from theory (Q7). The first recommendation was to use historical data to improve the product configuration. The second was to reject orders or renegotiate lead-times to enable better control of the workload for critical resources. The third was to do MRP after the design phase, purchasing only a few long lead-time parts before the design phase, to improve the bill of materials. The fourth was to use Project Requirements Planning for more custom orders, considering lead-time variation of parts, to protect the assembly schedule from delays. The fifth was to enhance shop floor scheduling by tracking parts, to improve the supply of parts to assembly. It also helps to improve the accuracy of estimated production times, basing it on historical data. The final recommendation is to thoroughly evaluate the current planning method and implement the integrated solution from theory.

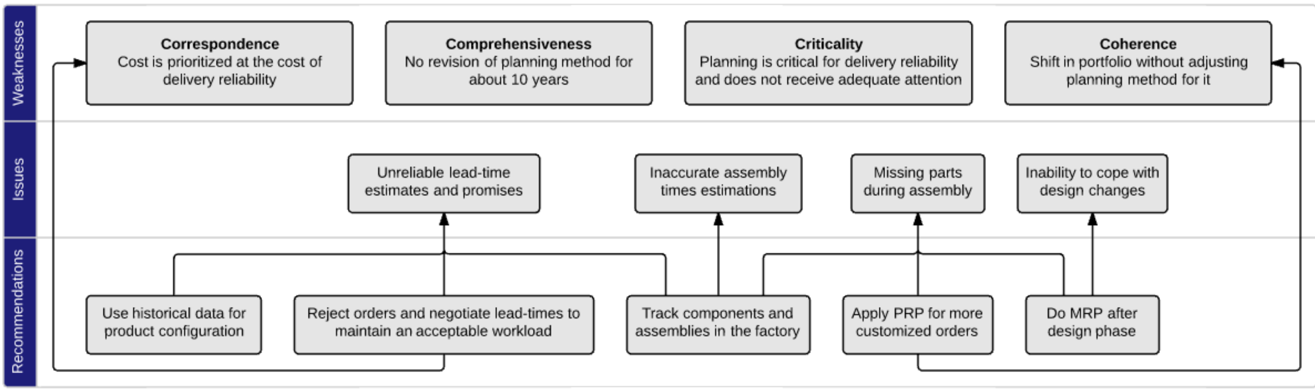

Figure 14. Summary of the planning and control chapter.

From the purchasing and supply strategy, the vertical integration aspect has been discussed, which is summarized in Figure 15. The weaknesses identified of the vertical integration strategy have been found to be comprehensiveness and criticality (Q4). Comprehensiveness because the vertical integration has received a lack of attention. A vertical structure has emerged over time instead of followed from careful planning and decision making. Criticality because vertical integration strategy has a high impact on costs, but has not received adequate attention. The main issue that has resulted from these weaknesses has been found to be a poor vertical structure (Q5). More specifically, too high costs of production capabilities and too many activities to manage are the two main issues that make it a poor structure. To come to recommendations, theory has been found (Q6) and applied to Company A (Q7). The issues have been addressed by recommending an overall vertical structure, which is to outsource production functions and focus on assembly and design. To make decisions of which production functions should exactly be outsourced, a decision model has been proposed. If implemented, it should lead to a better vertical structure and better overall business performance.

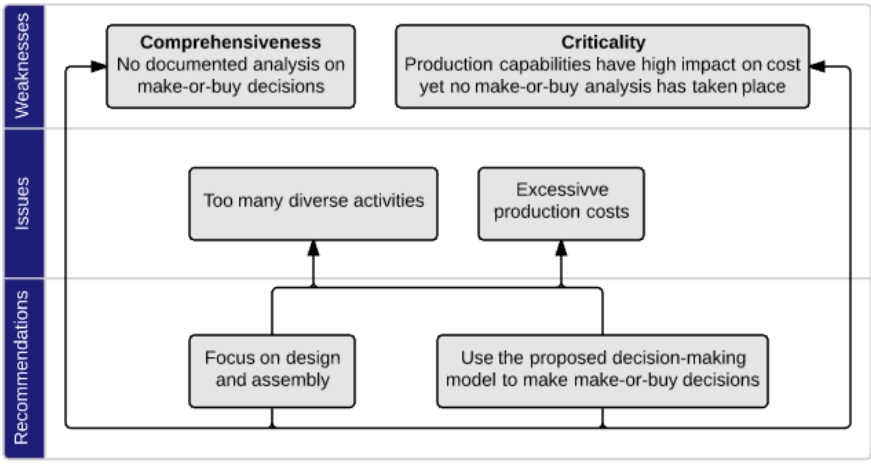

Figure 15. Summary of the vertical integration chapter.

From the development and organization strategy, the new product introduction aspect has been discussed, which is summarized in Figure 16. The weaknesses identified of the new product introduction strategy have been found to be coherence and correspondence (Q4). Coherence because a focus has been on increasing production efficiency through programs ran by operational excellence, while product design has been holding back their efforts by not designing for production efficiency. Correspondence because the focus has been on speed to market, which has led to quality issues and low delivery reliability, while the true competitive priorities are quality and delivery reliability and speed to market is much less important. The main issue that has resulted from these weaknesses are a quality issues, low delivery reliability and low production efficiency (Q5). More specifically, selling products during their development, a poor execution of DFMA and no procedure to design for efficiency have been identified as issues that together led to the main issue. To come to recommendations, theory has been found (Q6) and applied to Company A (Q7).

To address the issue of selling products during their development, it has been recommended to create a mission statement and a set of objectives through discussion. These should be clearly communicated, agreed upon by everyone and finally ways to keep each other accountable should be established. This prevents the setting of wrong priorities. To address the issue of DFMA execution, it has been recommended to find out where exactly execution fails, to then take appropriate measures, and to improve collaboration between designers and manufacturing experts. To address the issue of design for production efficiency, it has been recommended to add this to PROLaunch, to train R&D personnel on this aspect and to improve existing products on this area as well through doing a design review. Finally, implementation of a shifting strategy is recommended, to further improve the new production introduction strategy by creating a process where custom designs can be introduced as in the standard catalogue. If these recommendations are implemented, it should lead to a higher quality, higher delivery reliability and more production efficiency of new products in the future.

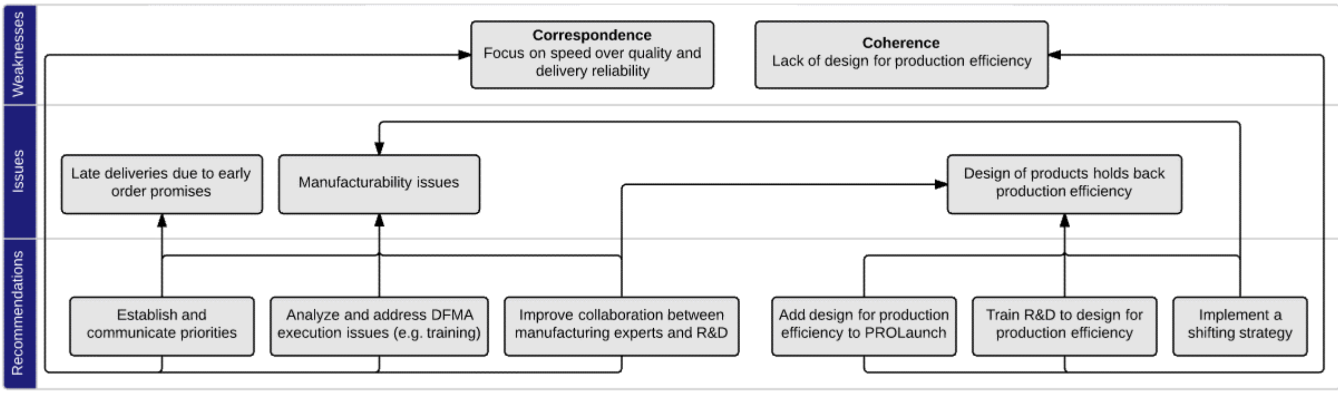

Figure 16. Summary for the new product introduction chapter.

To conclude the conclusion, the main research question was: how can the weaknesses in the current manufacturing strategy be addressed in the new manufacturing strategy? At the end of the chapters of each decision area, this question has been answered for that area. It has been shown how the recommendations address the weaknesses. Altogether, if the recommendations are implemented, the manufacturing strategy for three of the most problematic decision areas would be a strong one.

9 Limitations and Future Research

9.1 Limitations of Research

Due to the limited time span of this research, namely 10 weeks, two limitations exist. First, the recommendations are not directly implementable. Except for the decision-making model, the recommendations are points that require further attention and detailing. For example, analyzing where the execution of DFMA failed and taking appropriate measures is not a solution, but a next step Company A can take to address the issue. The risk is that recommendations are not followed-through upon, because they are not concrete and detailed yet. This is the responsibility of the managers of Company A, as I cannot do this for them. The second limitation is that only vertical integration and new product introduction are discussed. Most decision areas are not discussed here, because there were found to be less, critical issues. Future research should be done by Company A to analyze the entire manufacturing strategy. Especially to assess comprehensiveness, it is necessary to analyze all decision areas, because every decision area that has not received adequate attention is a weakness of comprehensiveness.

9.2 Recommendations for Future Research

After identification of the critical areas of the manufacturing strategy, I searched theory to apply to this case. Based on this research, I can say something about the availability and applicability of theory. I will do this for each of the three decision areas that has been addressed.

On the area of **planning and control**, theory was available on the planning and control method for engineer-to-order companies (Little et al., 2000; Bertrand and Muntslag, 1993), which was exactly what I needed. It has been shown to be applicable, like the researchers stated, by comparing the reference model with the used method. I was able to draw concrete recommendations, based on this comparison. Therefore, I regard theory on the area of planning and control for engineer-to-order companies to be both available and applicable.

On the area of **vertical integration**, I was able to find theory on the factors that should be considered when making a make-or-buy decision in general (Schwarting and Weissbarth, 2011), as well as which are successful vertical structures in the engineer-to-order industry (Hicks et al., 2001). However, I was not able to find empirical research on the make-or-buy decision. More specifically, which factors are important to choose either making or buying, based on past successes and failures. In terms of applicability, the research I found was not very specific on the criteria that could be used. Some criteria were mentioned, but still left room for interpretation. Therefore, for future research I recommend empirical research on the factors that are important for the make-or-buy decision and research that aims to specify these factors.

On the area of **new product introduction**, a broad array of literature was available. A detailed book on DFMA (Boothroyd and Dewhurst, 2010), some additional ways product design addresses production efficiency by Slack (2013), and a shifting strategy (Amrani, 2010). More detail might be available for design for production efficiency, however it was out of scope to search more in-depth here. Applicability is more difficult to analyze, as DFMA, design for production efficiency and shifting strategy are subjects that require more detailed attention, which I did not give them. The recommendations I drew from theory were in more general terms, therefore I cannot say much reliable about applicability. Thus, availability was good en applicability seemed good, given the detail available, especially on the area of DFMA.

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