UNIVERSITY OF AGDER

# Analysing the implementation of a material requirements planning (MRP) system into an engineer-to-order (ETO) company: the case of National Oilwell Varco Norway (NOVN)

**Elisabeth Fidjeland & Tone Skovly Gabrielsen**

**Supervisors**
Tina Comes and Naima Saeed

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University of Agder, 2014

School of Business and Law

# PREFACE

This master thesis is written by Elisabeth Fidjeland and Tone Gabrielsen in 2014 and represents the concluding work of the finalisation of our Master's degree in Business Administration with a major in Performance Analysis and Project Management at the School of Business and Law, University of Agder.

The purpose of the thesis is to investigate if implementation of a material requirements planning (MRP) system supports the operations strategy of an engineer-to-order (ETO) company. The research was conducted by performing a case study of National Oilwell Varco Norway (NOVN).

The scope and the content of the thesis have been developed by the authors in cooperation with Lars Lohne at NOVN. The authors' supervisors, Tina Comes and Naima Saeed, at the University of Agder has also contributed with their advice.

The authors would like to thank NOVN for the opportunity to collaborate with them, as well as express their sincere gratitude to Lars Lohne, their contact person at NOVN, for his support and help in identifying the topic of the master thesis, as well as his advices, comments, information providing, and insights throughout the research.

The authors would also like to express their deepest appreciation to their supervisors, Tina Comes and Naima Saeed, for their good and valuable comments and guidance throughout the work on the thesis and before the thesis was handed in, respectively.

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# ABSTRACT

A material requirements planning (MRP) system is a computer-based planning and control system whose main objectives are to provide the right part at the right time, and to meet the schedules for completed products. The development of these systems revolutionised the manufacturing industry, and lead to it being adopted by many companies. The expectations of the systems were high, both from academia and industry in the subject area of production planning and control. However, the widespread use of the system has uncovered several failures, mainly because the systems are implemented under the assumption that "one-size-fits-all", and thus do not differentiate between various operations strategies. Prior research has already identified MRP systems as successful production planning and control systems in several operations strategies. Despite its importance, the previous research on MRP systems has not thoroughly addressed the systems strategic fit with an engineer-to-order (ETO) operations strategy. This thesis therefore focuses on the use of an MRP system in an ETO environment, and the overall objective is to investigate if implementation of an MRP system supports the operations strategy of an ETO company.

To help investigate the overall objective, a literature review and a case study has been conducted. The literature review was carried out to provide a theoretical base for the research and a foundation for the future work of the research. A case study was conducted to help get a better understanding of an MRP system's strategic fit in an ETO company to draw parallels between theory and practice. Numerical data has been collected to conduct statistical analysis. The case study company is a large ETO company that is about to implement an MRP system and that previously have used a similar system in some of its departments. Qualitative data from the case study have mainly been conducted through interviews and informal conversations with key informants employed in the case study company.

The result of this research shows that there is a clear misalignment between the decision support provided by an MRP system and the decision support required by an ETO company. The product-, market- and process characteristics of an ETO company are too much of a constraining factor for the MRP system, which may lead to reduced competitiveness. Furthermore, the research suggests that organisational factors, such as education level of employees, company size and culture have significant impacts on implementation of an MRP system.

The results gathered from the research have a foundation from relevant theory, which strengthens the quality of the thesis. The thesis has therefore contributed with increased knowledge and provides a better understanding of the use of an MRP system in an ETO company. In particular the definitions in the thesis, the identified variables, and the frameworks should be of interest for researchers, management, and consultant in the area of production planning and control (PPC). The research also has important implications for top management and policy makers in implementing an MRP system, as these stakeholders need to communicate effectively with their organisation about their MRP adoption intentions.

Case study findings suggest that MRP systems are not suitable for ETO products, and that MRP implementation is influenced by, but not necessarily bound by, existing national and organisational factors. The findings of this study aid the management of organisations that are implementing MRP systems to gain a better understanding of the likely challenges they may face and enables them to put in place appropriate measures to mitigate the risk of implementation failures.

# ABBREVIATIONS

| | |
|---|---|
| **ANOVA** | Analysis of Variance |
| **ATO** | Assemble-to-Order |
| **BOM** | Bill of Material |
| **BTO** | Buy-to-Order |
| **CODP** | Customer Order Decoupling Point |
| **EOQ** | Economic Order Quantity |
| **ER** | Engineer Responsible |
| **ERP** | Enterprise Resource Planning |
| **ETO** | Engineer-to-Order |
| **JIT** | Just-in-Time |
| **LFL** | Lot-for-lot |
| **MPS** | Master Production Schedule |
| **MRP** | Material Requirements Planning |
| **MRPII** | Manufacturing Resource Planning |
| **MTO** | Make-to-Order |
| **MTS** | Make-to-Stock |
| **NOV** | National Oilwell Varco |
| **NOVN** | National Oilwell Varco Norway |
| **OM** | Operations Management |
| **PLC** | Product life cycle |
| **PPB** | Part Period Balancing |
| **PPC** | Production Planning and Control |
| **SME** | Small and Medium sized Enterprises |
| **SPSS** | Statistical Package for the Social Sciences |
| **STS** | Ship-to-Stock |

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# 1 INTRODUCTION

The globalisation of the economy, increased availability of information and advancement in information technology has led to increasing competiveness in today's marketplace. In the past decades, the main focus of competition has shifted from price towards faster and more reliable delivery as well as the need for manufacturing firms to become more responsive to the increasing changes in customer- and market requirements (Hicks et al., 2001). One of the key factors of manufacturing responsiveness and success is a company's planning and control of material flow (Little et al., 2000).

The earliest contributions to the development and advancement of material planning and control systems are dated back to the early 20th century. However, the most significant contributions have been made the last five decades (Mabert, 2007). The development of the computer-based manufacturing management system MRP during the 1960s revolutionised the manufacturing industry (Islam et al., 2013). Academia and the manufacturing industry have since then put a great deal of effort into further developing the system. Today, MRP is the most popular manufacturing management system in the world (Sum & Ng, 2014).

Like other supply chain management systems, MRP systems have been rapidly implemented under a "one-size-fits-all" mind-set (Gosling et al., 2013). However, the widespread use of the system has unveiled that behind the large success of the MRP system, there are also many failures (J. C. Anderson et al., 1984). For instance, even though MRP systems perform well with many different operations strategies, they do not, at the present date, perform satisfactorily in companies with an ETO operations strategy (Bertrand & Muntslag, 1993; Little et al., 2000).

An ETO operations strategy is based on demand driven practices to fulfil specific customer orders (Jin & Thomson, 2003). The main characteristics of environments with this type of operations strategy are high levels of customisation for each product and that the products are typically managed in a project environment. Another important characteristic is that production flow is driven by actual customer orders (Gosling et al., 2013). In an ETO operations strategy the decoupling point, which is the point in the value chain where the product is linked to a specific customer order, is located at the design stage (J. Olhager, 2012).

However, as there is a lack of order specifications at the time of an order placement and continuous changes must be accommodated as a product gets finalised. The location of the decoupling point in an ETO environment makes manufacturing planning therefore complex (Islam et al., 2013).

For an operations strategy to work optimally in various business environments, problems need to be structurally the same. However, as the various operations strategies have distinct characteristics leading to structurally different problems, the "one-size-fits-all" mind-set regarding MRP is not correct. The fact that companies in various business environments apply MRP systems indicates that there is a gap between theory and practice (Little et al., 2000). And even though there exist extensive literature that has reviewed MRP systems in various operations strategies, the authors of this master thesis has had difficulties finding literature that touches upon the fit between an MRP system and an ETO operations strategy. It is therefore obvious that for a company to meet today's market requirements and stay competitive; there is a great need to understand the fit between the ETO operations strategy and the capabilities of an MRP system.

Based on this background, this master thesis reports on a qualitative and quantitative research to make a theoretical contribution to whether implementation of an MRP system supports the operations strategy of an ETO company. This has been done by working with a specific case, National Oilwell Varco Norway (NOVN), which is going to implement an MRP system in the near future. To narrow the gap between theory and practice, practical relevance and realism has guided the objectives, scope and limitations for this research, as well as the applied research methodology, which will be thoroughly elaborated in Chapter 4. Both ETO and MRP will be further elaborated in Chapter 3.

The structure of the thesis can be visually followed using the schematic in Figure 1.1. The figure shows that Chapters 2, 3, and 4 are theoretical chapters covering the main theory relevant for conducting the research. Chapters 5, 6, 7 and 8 present the quantitative and qualitative findings from the case study phase of the research using data collected from NOVN and data gathered from interviews. Chapter 8 also includes a section where the findings of the different research phases are integrated. Chapter 9 draws conclusions from all phases of the research.

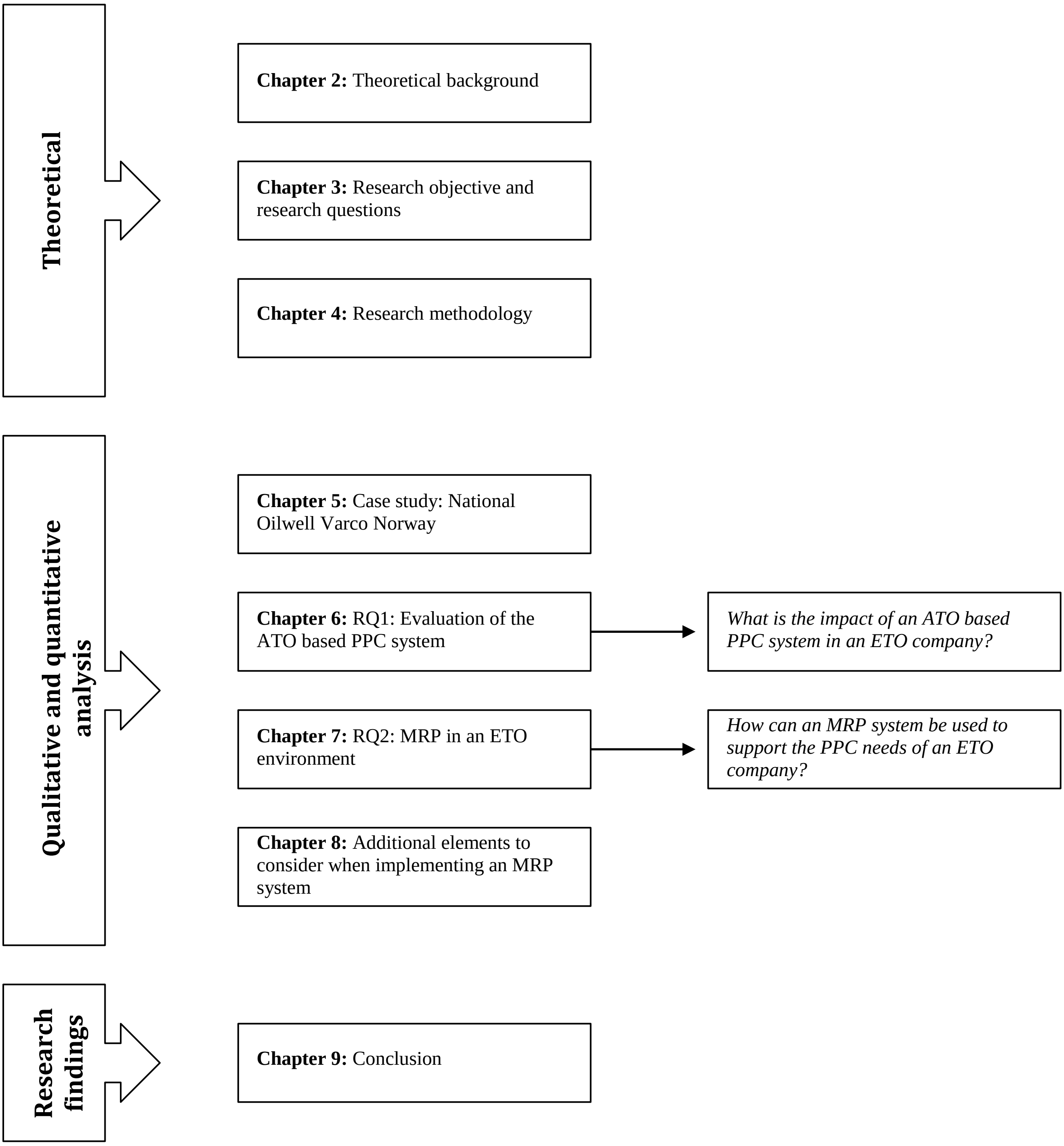



**Figure 1.1:** Thesis structure

# 2 THEORETICAL BACKGROUND

The aim of this chapter is to establish the theoretical foundation of the thesis to be able to investigate what the impact will be on the performance of an ETO company when implementing an MRP system. This will be done by establishing the role of the production planning and control (PPC) system within operations management, the PPC systems relation to operations strategy, what factors should guide the choice of PPC approaches and how PPC performance can be evaluated. This chapter therefore provides an overview of the literature related to the main research areas within operations management (OM) that are relevant for this research.

Section 2.1 gives a thorough review about OM and its key responsibilities and relations, which are the basis for further structuring the theory related to PPC. Sub-section 2.1.1 introduces planning and control and outlines PPC's importance for a company's performance. Sub-section 2.1.2 elaborates on operations strategy and its perspectives, which have an impact on PPC. Sub-section 2.1.3 introduces approaches for designing PPC and focuses on the ETO operations strategy and its determinants, as it is applicable in this research. Section 2.2 outlines the importance of a PPC system and a company's long-term success of linking corporate objectives, operations and operations strategy together. Section 2.3 identifies measures for evaluating PPC performance, which is tested empirically in Chapter 6. Section 2.4 concludes the chapter with a review of MRP, one of the major topics of this research.

## 2.1 Operations management

The topic of this thesis focus on MRP, ETO and PPC, and both Jonsson (2008, p. 46) and Slack et al. (2004, p. 6) view these areas as being a part of operations management (OM). There are several similar definitions of OM. Heizer and Render defines OM as "activities that relate to the creation of goods and services through the transformation of inputs into outputs" (Heizer & Render, 1988, p. 4). Whilst Slack et al. (2004, p. 6) defines OM as the "the term used for the activities, decisions and responsibilities of operations managers" (Slack et al., 2004, p. 6). However, due to this research's objectives and aims, and because this research uses a large company as its case study, Barnes (2008, p. 3) definition of OM has been found to be applicable. Barnes (2008) defines OM as "the management of the resources and processes required by an organisation to produce goods or services for customers" (Barnes, 2008, p. 3). Figure 2.1 displays OM’s key responsibilities and relations, which will be explained in the following.


**Figure 2.1:** A general model of operations management and operations strategy (Slack et al., 2004, p. 31).

### 2.1.1 Planning and control

Planning and control is important for all operations processes, both within and across companies, and is concerned with managing the operations processes and ensuring that they run effectively and efficiently (Klassen & Menor, 2006, p. 135; Slack et al., 2004, p. 322). While planning is a formalisation of what is intended to happen in the future, control is the process of monitoring and revising plans if changes occur to achieve the objectives of the original plan (Slack et al., 2004, pp. 324-325).

Planning and control involves multiple activities. However, four activities are considered to be most common (Slack et al., 2004, pp. 333-346):

- Loading - determining the amount of work allocated to a work centre.
- Sequencing - determining the order in which the work will be tackled.
- Scheduling – determining at what time various work should start and end.
- Monitoring and control – ensuring that planned activities are happening and rectify deviations through intervention.

These activities are required to reconcile supply and demand in adherence to customer requirements (Slack et al., 2004, p. 333).

The balance between planning and control changes during the product life cycle. In the long-term (month or years), the emphasis is on planning and the main focus is on the financial objectives. The specific customer needs are still unknown, thus a company can only plan on an aggregated level. In the medium-term (week or months), plans get more detailed, and operational objectives complement the financial ones. On the short-term (hours and days), control is of paramount importance to address the customers' needs as they are articulated. At this stage it is difficult to make planning changes, as resources are already set. Changes will therefore be made based on a company's prioritisation of their performance measures (Slack et al., 2004, pp. 325-326).

#### 2.1.1.1 Production planning and control systems

To execute planning and control, companies apply PPC systems. Due to globalisation and increased competition together with rising customer expectations, more volatile planning horizons, and shifts in demand, planning and control has become more complicated in the past decades (Grant, 2003). Shifts in demand require shorter planning horizons, thus creating a higher need for control. Because of this, PPC systems have become increasingly important (Stevenson et al., 2005).

A PPC system should support decision makers by providing an overview of key planning and control activities and by defining data and information that managers need (Vollmann et al., 2005, p. 4). Typical functions of a PPC system are material requirements planning, demand management, capacity planning, scheduling, and sequencing. The purpose of these activities are to reduce Work in Progress (materials and partly finished products that are at various stages of the production process) reduce lead-times, lower stock holding costs and improve responsiveness (Stevenson et al., 2005). The amount and usage of PPC systems are widespread (J. C. Anderson et al., 1984; Schroeder et al., 1981; Stevenson et al., 2005). The most commonly used PPC systems today are material requirements planning (MRP), manufacturing resource planning (MRPII), just in time (JIT), Kanban and workload control (Zijm, 2000).

The choice of PPC is closely linked to operations strategy (Hayes, 1985; J. Olhager, 2003a; Porter, 1983, 1985; Stevenson et al., 2005). However, there are rival opinions regarding whether PPC systems should be defining the operations strategy of the company, or if the operations strategy should be guiding the choice of PPC systems. Skinner (2007) Porter (1983), Stevenson et al. (2005) and Slack et al. (2004, p. 65) explain that to drive competitiveness in companies, operations strategy should drive the choice of PPC system. Hayes (1985) on the other hand argues that technology is the foundation of operations strategy and that the PPC system should therefore guide the choice of operations strategy. In line with the wording of the overall research objective of this thesis, the authors adopt Porters (1983), Skinner (2007), Stevenson et al. (2005) and Slack et al. (2004, p. 65) view as the rival opinion above suggests that an operations strategy and a PPC systems will not achieve a company's full potential unless there exist a link between them. This further outlines that the choice of a PPC system is a strategic decision and critical to the success of any company (J. Olhager, 2003a; Stevenson et al., 2005).

There exist a wide range of PPC systems, and they all claim to be universally suitable, making it difficult to choose the most appropriate one (Stevenson et al., 2005). Stevenson et al. (2005) argues that the systems claim to be universally suitable because there exist no indications of what type of companies that can benefit from the systems. Thus, such systems will not be able to cater all specific PPC needs, as each production environment and company has its unique characteristics (Bertrand & Muntslag, 1993; Stevenson et al., 2005). Slack et al. (2004, p. 324) explains that a company's constraints and capabilities are defined within their PPC system, and the PPC system thus serves as the interface between a company's strategy and operations. The company's operations strategy and the design of the company's operations therefore have important implications for the appropriateness of a PPC system (cf. Figure 2.1). In the following sections the different factors that should guide the choice of PPC approaches will be introduced and explained. These factors will be used as a tool for structuring qualitative and quantitative data in Chapter 6.

### 2.1.2 Operations strategy

There are several definitions of operations strategies. Swamidass and Newell (1987) describe operations strategy as a tool for use of manufacturing strengths as a competitive weapon to attain business and corporate objectives. Platts et al. (1998, p. 517) have defined operations strategy as "a pattern of decisions, which determine the capability of a manufacturing system and specify how it will operate, in order to meet a set of manufacturing objectives which are consistent with the overall business objectives". Skinner (2007) says that operations strategy can be seen as a set of manufacturing policies designed to maximise performance of trade-offs among success criteria to meet the manufacturing task determined by a corporate strategy. However, this research argues that an operations strategy can be seen as a company's plan of action, which describes the company's pattern of strategic decision and actions as well as how the company will use their resources in operations and how these resources can be a source of competitive advantage (Barnes, 2008, p. 28; K. K. Boyer & McDermott, 1999; Hill & Hill, 2009, p. 31; Slack et al., 2004, p. 67). In the following sections, a number of perspectives that has continual influence on operations strategy, and hence encompasses the choice of PPC system, will be introduced and explained (Slack et al., 2004, pp. 67,70).

#### 2.1.2.1 Company objectives and performance measures

The objective of a company is concerned with what the company would like to achieve. It defines the overall strategic direction of the company as a whole as well as which market segments it intends to serve and grow in (Barnes, 2008, p. 24; Hill & Hill, 2009, p. 24; Slack et al., 2004, p. 68). The ultimate objective of implementing a PPC system is to contribute to the profits of the company. This is accomplished by keeping the customer satisfied by meeting delivery schedules. More specific, the objectives of a PPC system are to establish schedules and routines for work, which will ensure the optimum utilisation of materials, workers and machines, and to provide the means for ensuring the operation of the company in accordance with these plans (Nagare, 2007).

Performance measurements can be seen as measurement of outcomes and results, which are used to assess how well a company is achieving its desired objectives. Several authors have defined five performance measures for operations within a company. These are: quality, speed, dependability, flexibility and costs, which all have an impact on customer satisfaction (Ferdows & Meyer, 1990; Flynn & Flynn, 2004; Gunasekaran et al., 2004; Slack et al., 2004, p. 44; Vokurka et al., 2002; G. P. White, 1996). It is unlikely that a company can excel simultaneously on every aspect (Slack et al., 2004, p. 44). The importance of the measures should therefore reflect which measures are most valued by a company's customers, and the company should prioritise the measures accordingly. For example, if a particular market segments objective is to produce at low cost, a company will strive to achieve an operations strategy that facilitates producing at low cost and in high volumes, leading to speedy deliveries and low flexibility (Barnes, 2008, p. 25).

#### 2.1.2.2 The product life cycle

Products require different operations management in each stage of the product life cycle (PLC) (Slack et al., 2004, pp. 75-76). The PLC is divided into four stages; introduction, growth, maturity, and decline (cf. Figure 2.2), and can be described as the period of time where a product is developed, brought to the market and eventually removed from the market (C. R. Anderson & Zeithaml, 1984; Jonsson, 2008, p. 159; Rink, 1979; Slack et al., 2004, p. 76). Thus the PLC represents the time when it is financially defensible to sell a product in the market (Jonsson, 2008, p. 159). For example, a product in the introduction stage is often innovative and thus few competitors are offering the same product. Slow growth and uncertainty is predominant, as the customer's needs are not yet fully understood. For the company to stay competitive, its operations must be flexible enough to accommodate changes in customer needs. In contrast, when the product reaches its maturity stage, the focus is on reducing cost and achieving dependable supplies, as fewer but larger competitors dominate the market (C. R. Anderson & Zeithaml, 1984; Slack et al., 2004, p. 76).

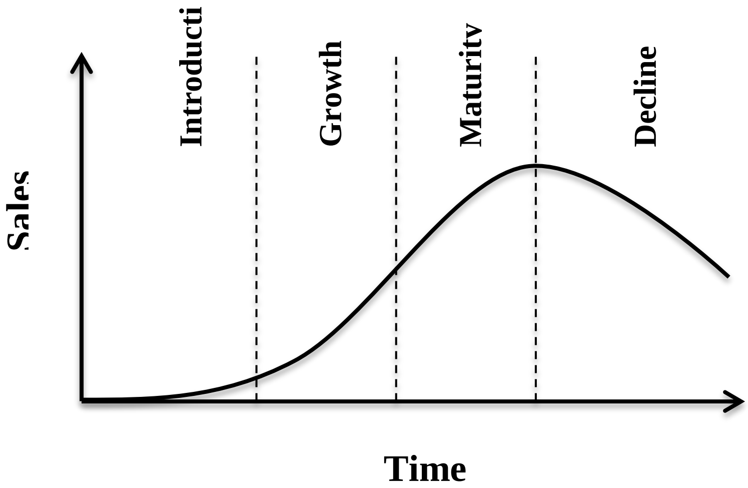



**Figure 2.2**: The product life cycle. The figure is adapted from Slack et al. (2004, p. 76).

### 2.1.3 Design

The design of a company's product and processes, as well as the market requirements, impose restrictions on operations strategy (cf. Figure 2.1) (W. L. Berry & Terry, 1992; Stevenson et al., 2005). The following sections investigate the role of the customer order decoupling point

(CODP) in several operations strategies and processes, in addition to establishing the fundamental difference of operations relative to the CODP (Bertrand & Muntslag, 1993).

#### 2.1.3.1 Operations strategies

Various literatures propose several operations strategies that can be employed by companies. Based on Naylor et al. (1999), Yang and Burns (2003), Olhager (2003b), and Wikner and Rudberg (2005) six different operations strategies are defined: engineer-to-order (ETO), buy-to-order (BTO), make-to-order (MTO), assemble-to-order (ATO), make-to-stock (MTS), and ship-to-stock (STS). However, Olhager (2003) simplified the classification of operations strategies to include MTS, MTO, ATO, and ETO.

- *Make-to-stock* (MTS) is an operations strategy that forecasts demand to determine how much should be produced of a certain item. The strategy converts components into finished end-items, and awaits customer orders. This strategy relies heavily on accuracy of the demand forecasts.
- *Make-to-order* (MTO) is an operations strategy that only manufactures the end product after the customer places an order. The strategy allows customers to purchase products that are customised to their preferences, and the products usually consist of both standard items and custom-made items. This strategy resolves the problem of excessive inventory, which is common within the MTS strategy.
- *Assemble-to-order* (ATO) is an operations strategy where the main components and subassemblies of a specific product are produced to stock based on a forecast of demand. The remaining components and subassemblies are not completed until the customer orders a product and includes its specific requirements, thus the ATO strategy can be seen as a hybrid of MTS and MTO. It is therefore a strategy that efficiently delivers a high level of product variety to customers, while maintaining reasonable response time and costs.
- *Engineer-to-order* (ETO) is an operations strategy that is based on demand driven practices where components are designed, engineered, and then built to fit specific customer specifications in response to customer orders. ETO will be further elaborated in Section 2.1.3.1.3.

(Bertrand & Muntslag, 1993; Hallgren & Olhager, 2006; J. Olhager, 2003b)

### *2.1.3.1.1 Customer order decoupling point*

The location of the customer order decoupling point (CODP) differentiates the operations strategies. It therefore has a key role in the design and managing of supply chains (Jodlbauer et al., 2012). Olhager (2003) defined the CODP as "the specific point in the manufacturing value chain for a product, where the product is linked to a specific customer order" (J. Olhager, 2003b, p. 320).

The four different operations strategies are related to the ability to accommodate customisation or the size of the product range, and their CODP's therefore have different positions. This can be seen in Figure 2.3, where the dotted lines represent the production activities that are forecast driven, and the solid lines represent the customer-order-driven activities.

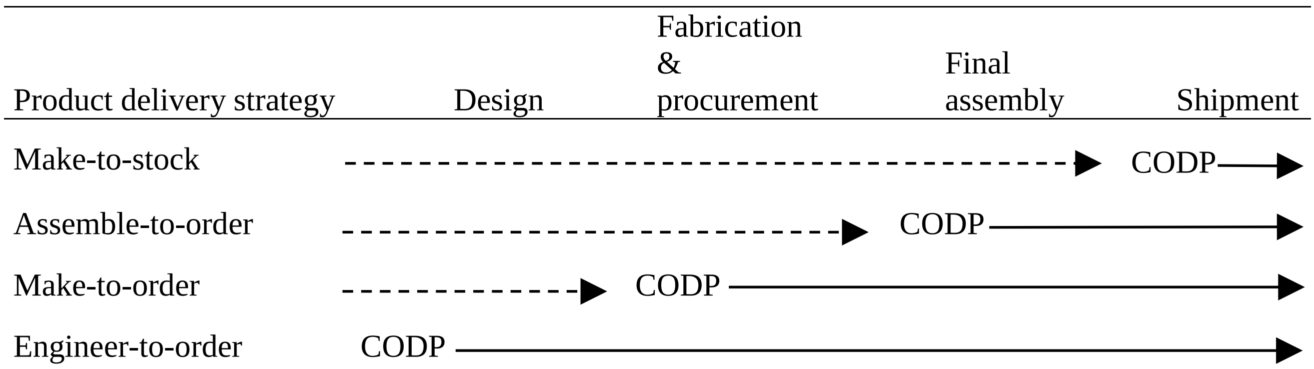



**Figure 2.3:** Different operations strategies related to different customer order decoupling points. The figure is adapted from Olhager (2003b).

As the CODP is the transition from customer-independent production to customer-dependent production, all activities before the CODP is based on the company's market research and planning, and all activities after the CODP is based on the actual customer's order.

### *2.1.3.1.2 Determinants of operations strategy*

The four identified operations strategies have different characteristics that enable a company to meet the customer's individual requirements. The location of the CODP should therefore be strategically motivated (J. Olhager, 2003b). Various literature propose several determinants of operations strategies, but there is a consensus that the placement of the CODP is mainly affected by a products demand and characteristics, as well as its belonging processes (Marshall, 1997; van Donk, 2003). Olhager (2003b) divides the most important characteristics into three categories related to market, product, and production. These will be further elaborated in association with ETO as an adequate understanding of the characteristics of an ETO supply chain is necessary for establishing the link between the PPC system and the PPC needs of an ETO company (W. L. Berry & Terry, 1992).

#### *2.1.3.1.3 Engineer-to-order*

ETO products tend to be complex, technical and highly specialised. Because of this, ETO companies usually specialise in one type of product or related types of products, and thus have their own core technical competency. Sectors that usually fall into the ETO environment are construction, shipbuilding, complex sub-assemblies, and capital goods, which include machinery and oil exploration rig (Rahim & Baksh, 2003). Because of this, the drilling supply sector falls under the ETO operations strategy.

Authors use different terms when describing the ETO environment, which show that there is a lack of clarity of what is the appropriate terminology to use. For instance, project (Elfving et al., 2005), one-of-a-kind (Hameri, 1997), design-to-order and engineer-to-order (Hicks et al., 2000) are frequently used in combination with supply chain, production, organisation and system when referring to ETO. Bozart and Chapman (1996), Rahim and Baksh (2003), and Wadhwa et al. (2006) argues that ETO companies offer existing designs modified to order, whilst several other authors such as Bertrand and Muntslag (1993), Wortmann (1995), Little et al. (2000), and Vrijhoef and Koskela (2000) argues that ETO companies offer completely new designs developed to order. This suggests that there is a lack of agreement as to what degree ETO companies offer customised products. In spite of this, most authors agree that all production dimensions in an ETO company is customised for each order, that the CODP is located at the design stage, and that the companies operate in project environments with project specific demand (Bertrand & Muntslag, 1993; Hicks et al., 2000; Hicks et al., 2001; Martínez-Olvera & Shunk, 2006; J. Olhager, 2003b; Samadhi & Hoang, 1995; Thompson et al., 1998; Vrijhoef & Koskela, 2000; Wikner & Rudberg, 2005; Wortmann, 1995). This essentially means that there is a consensus on that ETO companies are both dynamic and uncertain, and must therefore be flexible.

##### 2.1.3.1.3.1 Market related characteristics in the ETO environment

*Delivery lead-time requirements*

Generally, high levels of customisation leads to increased costs, higher risks and long lead-times (Hicks et al., 2000). Konijnendijk (1994) pointed out that one of the biggest coordination problems in an ETO company is setting lead-times. To solve this problem, marketing and production must coordinate both the initial lead-time given to the customer, as well as any change in the product or planning that will influence this lead-time. However, in an ETO environment, it is likely that the customer will be prepared to wait longer in order to receive a fully customised product (Rahim & Baksh, 2003).

*Demand volatility*

Most products produced by ETO companies belong to low volume industries and is therefore exposed to demand volatility, which reduces the opportunities for advanced planning (Hallgren & Olhager, 2006; Rahim & Baksh, 2003). This is further complicated as the ETO environment, compared to other environments, is more prone to demand sensitivity in regard to macro-economic fluctuations (Bertrand & Muntslag, 1993; McGovern et al., 1999). Because an ETO company has a customer order driven production, dealing with this volatility by means of for example creating capacity stock, will run the risk of that stock becoming obsolete (Rahim & Baksh, 2003). Thus, unknown sales and product specifications for future customer orders makes it nearly impossible for an ETO company to conduct forecasts (Hicks & Braiden, 2001).

*Product range and customisation requirements*

Previous orders usually make up the product range of ETO companies. Because orders are more or less customer specific, every order is unique, and ETO companies therefore have a wide product range (Childerhouse & Towill, 2000; Hicks & Braiden, 2001; J. Olhager, 2003b). Product innovation is often led by the need to meet new customer requirements (Hicks et al., 2000). In terms of an ETO product there are often very strict regulatory requirements and design codes that must be fulfilled, especially regarding safety and reliability. But most important are the functional requirements of the product in question (Rahim & Baksh, 2003).

*Customer order size and frequency*

Each customer's order within ETO companies is considered to be large, as each unit of demand represents large portions of the design and production capacity (Hicks & Braiden, 2001). The customer order frequency in an ETO company tends to vary due to the fact that the company delivers products with unstable demand, which are customised to fit the customer's requirements (Gosling, 2011). Gosling et al. (2013) argues that one of the biggest challenges of an ETO company is uncertainty regarding the customer orders.

###### 2.1.3.1.3.2 Product related characteristics in the ETO environment

*Customisation opportunities offered*

For an ETO company the customers are its main objective, and the company is dependent on the ability to adapt to customers' requirements (Rahim & Baksh, 2003). The majority of products produced in an ETO company are highly customised and can be seen as completely new designs developed to order. However, modification of previous designs are also common (Gosling & Naim, 2009). The close involvement of the customer often results in frequent engineering changes, and indicates that unpredictability in the production characteristics are common in the ETO environment (Konijnendijk, 1994). Very often a customer will change its requirements along the process, for example a modification in shape or material, which will lead to changes in the product specification (Huang et al., 2001).

*Material profile and product structure complexity*

Driven by customer requirements, products produced in ETO companies are highly complex and they therefore have a multileveled product structure (Grabenstetter & Usher, 2013). A product's structure is reflected in its bill-of-material (BOM), which is a list that contains exact information on all parts or materials required to manufacture one unit of a specific end-product (Moustakis, 2000). Each different product, made by a specific manufacturer, will have its own separate BOM. For an ETO company the BOM is wide and multileveled, reflecting the diversity of components required and the extensive amount of assembly processes required, which implicates long lead times (J. Olhager, 2003b; Slack et al., 2004, p. 494).

###### 2.1.3.1.3.3 Production related characteristics in the ETO environment

*Production lead-time*

ETO products long lead times pose a major constraint on the CODP. In an effort to reduce lead-time to a lead-time accepted by the market, ETO companies will in the early stages of a project order components with long lead times. This poses a risk to the ETO company as the complete product structure tends to be uncertain in the early stages of a project and because customer requirements may change throughout the project (Bertrand & Muntslag, 1993; J. Olhager, 2003b).

*Number of planning points*

Processes such as sale, production and engineering, tend to be complex and time consuming for an ETO company (Rahim & Baksh, 2003). In an ETO company it is therefore necessary to coordinate the different processes, and balance the customer's requirements with the production capabilities for each customer order. Because of this, and because ETO companies produces low volumes of highly customised and unique products with long lead times, their production process tend to be structured as projects (Hickson et al., 1969; Silvestro et al., 1992; Slack et al., 2004, pp. 111-116). Such structures are considered to be a continuous process and a single production unit (Bertrand & Muntslag, 1993).

*Flexibility*

To keep up with the developments in the volatile markets, a company's ability to quickly adapt itself and its processes is crucial (Gosling et al., 2013; Hicks & Braiden, 2001; McGovern et al., 1999). This is especially important as the customer requirements within an ETO environment vary from customer to customer and because the different production characteristics will most likely vary from one product to another (Gosling & Naim, 2009). To overcome this challenge there is a strong need for flexibility, which according to Gosling et al. (2013), Little et al. (2000) and Rahim and Baksh (2003) is the answer to quick adaptability as well as an ETO company's key to success (Rahim & Baksh, 2003). McGovern et al. (1999) argued that because an ETO company would be able to understand and adapt customer's requirements, they hold a major competitive advantage.

*Bottleneck position*

Within an ETO company, every order starts in the engineering department, and tend to stay there for a large amount of time. This is due to the fact that designers are reluctant to release the BOM information too early in fear of receiving requests in engineering changes after it is released. The result of this is that the purchasing department often receives the necessary information for doing its job too late and therefore is not able to achieve good prices or to purchase the required items in time. The engineering function is therefore considered to be the main bottleneck within ETO companies (Cutler; Grabenstetter & Usher, 2013; J. Olhager, 2003b; Xu & Liang, 2011).

Olhager's (2003b) determinants of operations strategies also included other characteristics such as seasonality of demand, modular product design and sequence dependent set-up times. However, since these characteristics are not relevant for an ETO company, they are not elaborated in this thesis.

## 2.2 Strategic fit

As mentioned in Section 2.1.3.1.2, a company's operations strategy, and product-, market- and production characteristics determine the company's approach for managing its processes. Achieving a strategic fit between these elements is a key determinant of the company's ability to increase its performance and achieve long-term success (Barnes, 2008, p. 21; Ortega et al., 2012; Wagner et al., 2012).

Chopra and Meindl (2007) indicates that a company must achieve good understanding of three aspects: the customers needs, the degree of demand uncertainty within the environment the company operates in, and the limitations imposed by the characteristics of the company's products. As Chopra and Meindl's (2007) model on strategic fit (cf. Figure 2.4) indicates, when a company has achieved a good understanding of these aspects (horizontal axis), the company can determine how to appropriately respond to demand through its operations strategy in the form of an appropriate degree of responsiveness (vertical axis). By doing this the company can ensure that its operations strategy is within the zone of strategic fit (Chopra & Meindl, 2007, pp. 24-38). Based on product-, market-, and process characteristics products can be characterised as either certain or uncertain, while the operations strategy can be characterised as either efficient or responsive. Only when there exist a strategic consistency between a product's demand supply and demand characteristics, strategic fit is achieved (Wagner et al., 2012). Based on the characteristics of an ETO company identified in Section 2.1.3.1.3, this implies that a company with an ETO approach that offers a large variety of products to its customers, will increase the implied uncertainty because the demand per product becomes more disaggregate. Thus a company with an ETO operations strategy can achieve strategic fit for products with uncertain demand by improving its responsiveness.

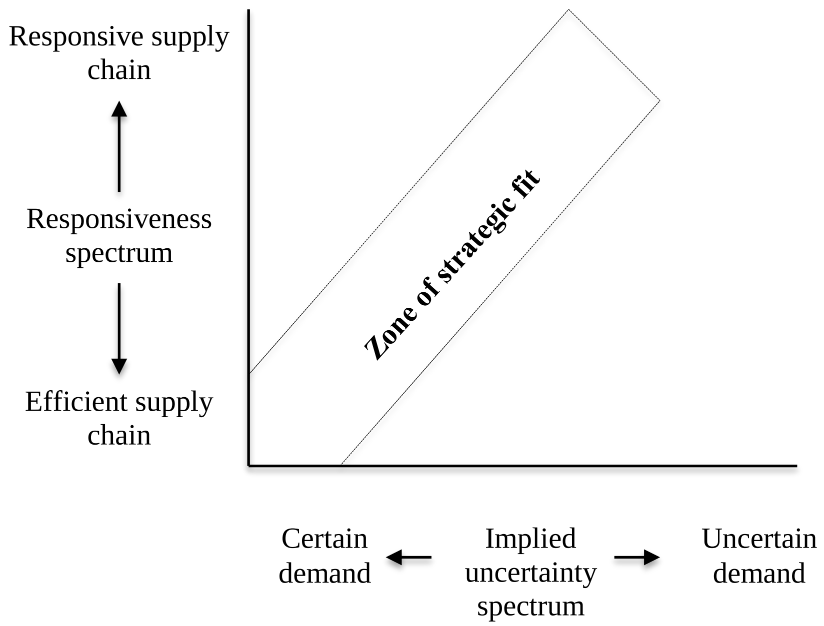



**Figure 2.4**: Finding the zone of strategic fit (Chopra & Meindl, 2007, p. 32).

The strong link between the market requirements and operations strategy concerns the choice of a PPC system. If the wrong PPC system is chosen, a misfit can occur between the market requirements and the operations strategy. This in turn can affect flexibility and cost as well as result in decreased performance and competitiveness, thus underlining the strategic importance of choosing the correct PPC system (W. Berry & Cooper, 1999; J. Olhager, 2003a; Slack et al., 2004, p. 120).

## 2.3 Impact of PPC systems

While market requirements defines a company's performance measures, a PPC system defines the company's ability to accommodate its market requirements (Cheng & Musaphir, 1996). It is therefore vital that there is a good fit between the PPC system and the company's performance measures. The impact of the PPC system on company performance can therefore be assessed considering the five performance measures identified in Section 2.1.2.1 (Gianesi, 1998).

Quality is closely linked to customer satisfaction, and refers to doing things right (Slack et al., 2004, p. 45). Higher quality can reduce the amount of mistakes and thus reduce costs and increase dependability as the stableness and efficiency of a company's processes are improved. The costs will therefore have an external impact on customer satisfaction, while dependability will have an internal impact (Gunasekaran et al., 2004; Slack et al., 2004, pp. 45-46).

Speed refers to doing things fast, and is concerned with how quickly a producer can respond to demand signals (Slack et al., 2004, p. 47). There are several appropriate ways to measure speed in regards to PPC systems. One of them is delivery lead-time, which is the time it takes from a customer places an order until the customer receives a complete delivery from the supplier. A speedy delivery has an internal impact as it can increase productivity, but also an external impact as customers are willing to pay more to have an order delivered quickly (Ferdows & Meyer, 1990; Gunasekaran et al., 2004; Slack et al., 2004, pp. 47-49).

Dependability refers to doing things on time, such as delivering a customer order when it is promised. It can be reflected by large variations in service levels, meaning that customers cannot always rely on receiving their complete orders on time. Dependability can have both internal and external impacts; such as saving time, cost reduction and providing stability (Ferdows & Meyer, 1990; Slack et al., 2004, pp. 49-50).

Flexibility refers to the ability of changing an operation in any possible way and is crucial for coping with demand uncertainty, responding to different types of variability and to be able to customise orders. For handling demand uncertainty, forecast accuracy is an appropriate measure, whilst safety stock is often used to mitigate stock outs and thus protect against demand variability. Flexibility has internal effects, in which it increases responsiveness, saves time, and maintains dependability (Gunasekaran et al., 2004; Slack et al., 2004, pp. 52-54; G. P. White, 1996).

Cost refers to profitability and the ability of producing at low cost. An improvement in cost can either increase profitability of existing volume of products, or reduce the contract price to sell higher volumes. There is high interdependency between cost and the other measures mentioned, as an improvement in the performance of one of them often lead to a cost improvement for the company as well (Barnes, 2008, p. 25; Gunasekaran et al., 2004; Slack et al., 2004, pp. 54-55). The five identified tangible measures and how to measure their performance in PPC systems are presented in Table 2.1.

In addition to the tangible measures, subjective measures should also be included when evaluating a PPC system to uncover the systems weaknesses and to get a better understanding of its performance results (Sum et al., 1995; E. M. White et al., 1982). Subjective measures are of interest as White et al. (1982) discovered several frequent problems encountered during PPC system implementation (cf. Table 2.1). Whilst lack of top management support was due to low support from finance, manufacturing, marketing and the head of the departments, the problems with PPC systems evolved around lack of clear goals and company expertise, as well as the lack of communication of these within the company (E. M. White et al., 1982).

| Performance measures | | |
|---|---|---|
| **Tangible measures** | Quality | Delivery promise<br>Amount of defect products<br>Number of customer complaints<br>Failure cost |
| | Speed | Frequency of delivery<br>Delivery lead-time<br>Production response time<br>Physical throughput time<br>Inventory turnover rate |
| | Dependability | Frequency of late or imperfect deliveries<br>Average lateness of orders |
| | Flexibility | Forecast accuracy<br>Level of safety stock<br>Excess capacity expressed by the amount of overtime |
| | Cost | Number of full-time workers<br>Cost of products<br>Value added |
| **Subjective measures** | Education of personnel | |
| | Lack of top management support | |
| | Implementation approach (Lack of time, personnel) | |
| | Problems with the PPC system (Lack of technical expertise) | |
| | Gaining acceptance | |
| | Inventory control and record | |
| | Accuracy | |
| | Forecasting demand | |

**Table 2.1:** The tangible and subjective performance measures. The table is adapted from Slack et al. (2004, p. 643).

This framework can be used to evaluate a PPC systems performance and provide a better understanding of its performance results. The framework will therefore be used as a tool for structuring and analysing the quantitative and qualitative data in Chapter 6.

## 2.4 Material requirements planning

This section provides a review of another major topic within this research, the PPC system material requirements planning (MRP), to help answer the research topic of the master thesis.

### 2.4.1 Material requirements planning

An important function of a PPC system is MRP. MRP is a computer-based planning and control system whose main objectives are to provide the right part at the right time, and to meet the schedules for completed products (Hill & Hill, 2009, p. 324; Vollmann et al., 2005, p. 222; E. M. White et al., 1982).

### 2.4.2 Evolution of MRP

By the 1960s, the main competitive focus within the manufacturing industry was price. Inventory management systems such as reorder point and economic order quantity (EOQ) was predominant within the manufacturing industry (Islam et al., 2013; Morabito et al., 2005). Although these systems addresses the amount of inventory that must be purchased or produced as well as determines the reorder point, they do not address the "when needed" aspect of the inventory (Mabert, 2007, p. 346). This led to the development of MRP.

Joseph Orlicky is considered to be the "father" of MRP (Mabert, 2007, p. 348). In 1964 Orlicky developed MRP after studying TOYOTA's manufacturing program. This revolutionised the manufacturing industry by enabling companies to plan for needed material based on an overall master schedule through a BOM. The same year as MRP was developed, Black & Decker became the first company to use the system, and since then MRP has become widespread throughout the manufacturing industries (Islam et al., 2013). The development of MRP has evolved into the more sophisticated and complex manufacturing resource planning (MRP II) and enterprise resource planning (ERP). However, MRP still remain the core of these systems (Ptak & Smith, 2008). Today, MRP is the most widely used PPC system in the world (Sum & Ng, 2014).

### 2.4.3 Basic concepts of MRP

The aim of MRP is to ensure fulfilment of customer orders by releasing a set of production orders for each item of the BOM, which allows synchronizing the internal and external logistics flow. For this purpose, the stock at hand, the planned receipts and the gross requirements determined from the master production schedule (MPS), which is the driving force of an MRP system, provides the basic calculations computed for each item of a future inventory level forecast (D'Avino et al., 2013). However, the most important function of the MRP system is considered to be its ability to reschedule when unplanned events occur. When updated, this rescheduling function attempts to maintain the alignment between the order due date and the order need date (C. J. Ho, 1989, 2002; C. J. Ho et al., 1995).

A diagram of a basic MRP system can be seen in Figure 2.5. The figure shows that an MRP system has three major input components: the MPS and the BOM, as already mentioned, but also inventory data. Inventory data keeps an up-to-date record of each item in the inventory and contains information such as quantity at hand, safety stock level, and procurement lead-time. The inventory data is updated whenever an inventory transaction is made (Avraham & Karni, 2013; Roy, 2005, p. 141). Based on these MRP inputs the MRP system is able to determine what work orders and purchase orders that are needed and when these orders must be placed to ensure that all materials arrive when needed.

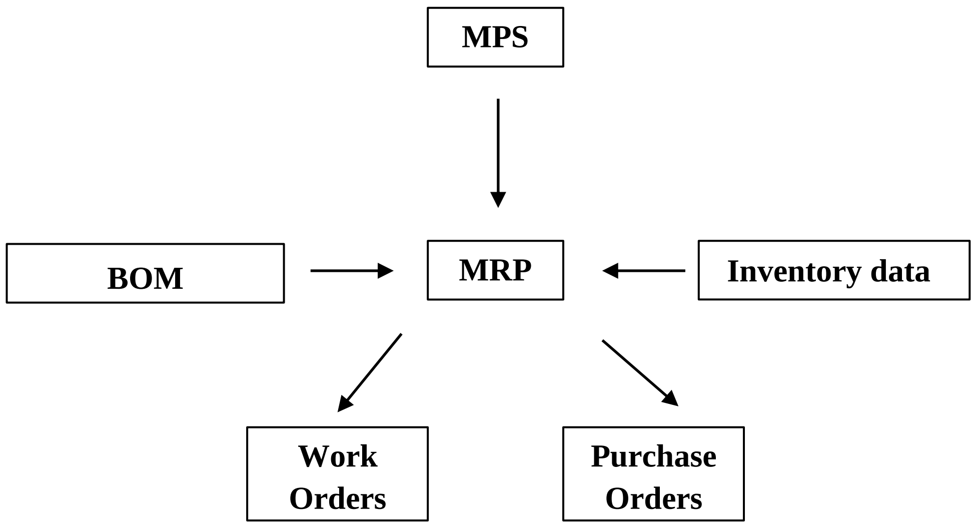



**Figure 2.5:** The basic MRP system. The figure is adapted from Avraham & Karni (2013).

### 2.4.4 Prerequisites and assumptions of MRP

According to Roy (2005) and Bertrand and Muntslag (1993) there are several prerequisites and assumptions that need to be fulfilled for an MRP system to function optimally.

- A MPS must exist and be stated in the BOM. Thus allowing companies to combine planned parts and forecast for any level of the BOM.
- The system requires that a BOM must exist at planning time, and also assumes that the BOM is both completed and accurate for when it is released into the system.
- Individual item lead-times are known and can be supplied to the system, at least as estimates. These estimates are used as a basis for the MRP system to provide the right part at the right time.
- All inventory items are required to have their unique part number, as the MRP system assumes that identical part numbers are interchangeable.
- For an assembly to be released for production, all components of that assembly must be available at the time of assembly order release.
- MRP assumes processes independence between items. This means that the manufacturing of any given inventory item can be started and completed on its own and is not dependent on other orders for completing the process.
- The system requires inventory records containing data on the status of every available item, and assumes that all items goes in and out of stock.
- All processes must be of physical nature.

The most important requirement of the MRP system however, is that file data inserted to the MRP system is accurate, complete and up to date as it facilitates full traceability back to the BOM of the project (Roy, 2005, p. 138).

### 2.4.5 MRP advantages

When an MRP system is successfully implemented there are several benefits that can occur. Because an MRP system provides accurate control over the many complex activities that a company perform, these activities are synchronised so as to ensure that parts are manufactured when they are needed in the next stage of production. By doing this, the system ensures no shortages of components in inventory and eliminates uneven utilisation of resources (Roy, 2005, p. 152).

Also, several studies that have been conducted on the usage of MRP systems have found the following tangible advantages to be the most common: increased inventory turnover, better delivery lead-time, increased percentage of time meeting delivery promises, reduced percentage of orders requiring “splits” because of unavailable materials, and reduced number of expeditors (Aghazadeh, 2003; J. C. Anderson et al., 1984; Petroni & Rizzi, 2001). Subjective advantages that often occur are improved competitive position, improved product quality, improved productivity, increased information on which to base decisions, better production scheduling, reduced safety stock, better cost estimation, and increased accuracy of BOM, MPS and inventory (Sum & Yang, 1993; Sum et al., 1995).

### 2.4.6 MRP drawbacks

Although MRP systems are widely used within manufacturing companies and has several benefits, they also exhibit significant drawbacks (D'Avino et al., 2013). The MRP system is largely constrained by the product structure, lot sizing and frequency of updates (Roy, 2005, p. 134).

One of the drawbacks is that the MRP system uses deterministic data to develop plans (Hicks & Braiden, 2001). It therefore ignores real life uncertainties that can occur and affect the production. These uncertainties can for example be shortages and variability in materials and labour, faulty components, and uncertainties in respect to lead-times of materials. When these uncertainties occur, it may affect cost and customer delivery performance (Koh et al., 2000).

However, one of the most significant drawbacks of the MRP system is “nervousness”. Nervousness relates to the rescheduling function of the MRP system (D'Avino et al., 2013). MRP system nervousness is described in several ways in the literature (Blackburn et al., 1986; Carlson et al., 1979; Minifie & Davis, 1990; Penlesky et al., 1989). What these descriptions all have in common is that MRP system nervousness can be seen as instability in or excessive rescheduling of planned and open orders (C. Y. Ho, 2007).

According to Blackburn et al. (1986), Lee and Adams (1986), Wemmerlöv (1989), and Ho and Ireland (1993), MRP system nervousness is caused by various variables. Environmental variables, such as demand variability, capacity utilisation and cost structure, are factors beyond the operating system, and thus decision makers have little or no control over them. Whilst operating variables, such as lot sizing techniques, length of lead-time and length of planning horizon are controllable and exist within the operation system. Any uncertainty in the production systems can cause planned- or open-orders to be rescheduled in the MRP system, so as to be able to maintain up-to-date priorities. However, too frequent rescheduling changes can result in excessive rescheduling and outweigh the benefit of maintaining the up-to-date priority (C. J. Ho, 1989). Large inefficiencies such as excessive inventory, risk of a decrease in customer service, risk of lost revenues, misguided capacity plans and risk of missed production schedules are among the consequences of MRP system nervousness (D'Avino et al., 2013).

There exist several methods for dampening system nervousness (C. J. Ho et al., 1995; C. Y. Ho, 2007; Minifie & Davis, 1990). In an MRP system, production uncertainty can generally be resolved by two approaches; the use of slack or buffer, and the use of rescheduling capability. Conventionally, safety stock, safety lead-time and safety capacity are the most common inventory oriented methods used as slack to buffer the production system, and thus dealing with quantity uncertainty. However, the general weakness of these dampening methods is that the buffer, which can take the form of unused capacity or extra inventory, can be costly to maintain. The alternative is to use the rescheduling capability of the MRP system, and thus realign the due date with the need date (Blackburn et al., 1986; Carlson et al., 1979). This can be done by implementing a lot sizing technique, which cope with rescheduling problems by determining timing and size of order quantities. Most of the techniques require extra inventories that can be used to accommodate schedule changes, and these built-in stocks can resolve small deviations in production schedules without changing the due dates of open orders, and thus reduce MRP system nervousness. However, the cost of carrying these extra inventories must be evaluated against the nervousness dampening effect (C. J. Ho, 2002; C. J. Ho & Ho, 1999; C. Y. Ho, 2007). The choice of a lot sizing technique is therefore a major factor affecting the MRP system nervousness, as the different lot sizing rules determines the amount of excess inventory (Y. Y. Lee et al., 1990). The simplest and most common is the lot-for-lot (LFL) technique. This technique minimizes the holding cost by ordering as little as possible each distinctive period (C. J. Ho & Ho, 1999). However, with no excess inventory, minor changes in plans will lead to MRP system nervousness (T. S. Lee & Adam Jr, 1986; Narasimhan & Melnyk, 1984; Wemmerlöw & Whybark, 1984). Other popular lot sizing techniques are part period balancing (PPB) and economic order quantity (EOQ). These techniques require built-in inventories and therefore facilities dampening of minor schedule changes (C. J. Ho, 2002; Narasimhan & Melnyk, 1984; Ram et al., 2006). Another lot sizing technique is the fixed order quantity technique (FOQ). This technique orders a predetermined quantity whenever an order is placed, and is one of the most common lot sizing techniques used in practice (C. J. Ho & Ho, 1999; Ram et al., 2006). Choosing the correct lot sizing technique is all about balancing the number of orders against the cost of carrying inventory.

For instance, LFL will keep average inventory levels low, but will result in more orders on average. While FOQ will have higher inventory levels, but will result in less orders on average. This means that as long as a company has the correct cost information, it is possible to derive the most effective and least costly lot sizing technique to use for any particular item (Narasimhan & Melnyk, 1984).

### 2.4.7 Factors affecting the successful implementation of MRP systems

Through a number of studies, several researchers have found that there are numerous factors that affect a successful implementation of MRP systems. In their studies, Burns et al. (1991), Kim and Lee (1993), and Samaranayake et al. (2002) all found that organisational factors, which among others include company size, company complexity and operations strategy, must be considered when implementing an MRP system. In addition to these factors, Sum et al. (1995) and Koh et al. (2000) also found that implementation is affected by the degree of uncertainty in the market place. It is also generally believed that MRP implementation is influenced by factors such as years of implementation, degree of data accuracy and extent of problems occurring during implementation (Aghazadeh, 2003; Ang et al., 1995; Sum & Yang, 1993; Sum et al., 1995; E. M. White et al., 1982; Wong & Kleiner, 2001). In addition to these factors some researchers believe that technological factors, such as degree of integration among MRP modules and MRP system features will affect the implementation (Keung et al., 2001; Sum & Yang, 1993). However, the majority of conducted studies points out that MRP implementation problems, more often than not, relates to people and the fact that they are not of technical nature (Burns et al., 1991; Callerman & Heyl, 1986; Ip, 1998; Sum et al., 1995; E. M. White et al., 1982). For example autonomous and highly educated people find it difficult to fit into the rigid MRP structure as they often have a need to unfold themselves in terms of innovation (Tang & Y.C., 2010).

### 2.4.8 Literature review on the use of an MRP system in an ETO environment

There is a lack of literature on the use of an MRP system in an ETO environment. However, this research has taken the same assumptions as Stevenson, Hendry, Kingsman, and Aslan did in their papers (2012; 2005). Although their papers were based on MTO companies, they defined MTO in a broad sense by using it as an umbrella term, thus referring to companies that produce customised products to fit the customer's specifications but that do not repeat the production of the product on a regular basis or in a predictable manner. This means that their definition of an MTO company included the basic characteristics of an MTO strategy, where the design is already available before an order is received and where the remaining work is manufacturing and assembly. In addition to this, their definition also includes product design, which is applicable for an ETO company. Thus, in their research the MTO term refers to products where production and design do not take place until after the customer order has been confirmed. This means that their MTO term includes ETO, but excludes MTS and ATO, and this assumption will thus be used as a foundation in this research.

As previously mentioned, MRP is the core within ERP. Because of this, this research assumes that some parts of the same literature's view on ERP systems can be used to describe MRP systems. Especially, since literature has found that ERP and MRP share similar implementation problems to achieve a successful implementation (Muscatello et al., 2003).

Several suppliers of MRP systems states that benefits of such a system can be accumulated by any organisation, independent of what type of product or service they may offer, as their systems are configurable to meet the needs of all types of operations strategies. However, literature suggests that a company that produce customised products, such as an ETO company, will possibly encounter challenges when implementing an MRP system (Bertrand & Muntslag, 1993; Deep et al., 2004; Stevenson et al., 2005). Thus, it remains unclear whether MRP can sufficiently accommodate an ETO company's needs. A summary of key studies that partially explore MRP adoption in an ETO context can be found in Table 2.2.

| Author | Topic | Operations strategy of the firm(s) | Research size | Findings |
|---|---|---|---|---|
| Bendoly and Jacobs (2006) | MRP | Various | N/A[1] | The authors conducted an investigation into the importance of a system being aligned with the company's specific process requirements and found that overall performance and satisfaction of a company becomes weaker if the company's operations strategy is misaligned with the adopted MRP strategy. |
| Bertrand and Muntslag (1993) | MRP | ETO | N/A | Based on the knowledge that many ETO companies have tried to implement MRP systems and ended up with little or no success, the authors conducted a conceptual study on the assessment of MRP suitability into the ETO environment. Their conclusion was that system functionality is the reason for the unsuccessful implementations of an MRP system. The authors also argued that the changeable environment and variation in design and production in ETO environments might severely affect the applicability of an MRP system in an ETO company. |
| Petroni (2002) | MRP | Various | 109 | The author conducted a survey and found that the main reasons for MRP implementation problems are data accuracy, level of functionality integration and level of management support. |
| Little et al. (2000) | MRP | ETO | 100 | The authors conducted a case study and found that the characteristics of the ETO operations strategy differ substantially from the basic assumptions of an |

[1] Not available (literature review only)

| | | | | |
|---|---|---|---|---|
| | | | | MRP system. |
| Stevenson et al. (2005) | PPC | MTO | N/A | The authors reviewed and assessed classical approaches to PPC and their applicability to MTO production. Their conclusion was that MRP does not provide sufficient support for managing customer enquiries in a MTO environment. |
| Muscatello et al. (2003) | ERP | Various | 4 | The authors conducted a thorough case study and concluded that MRP might be suitable for small or medium sized enterprises (SME) as MRP suppliers are turning their marketing sights towards these company sizes. |
| Mabert et al. (2003) | ERP | Various | 18 | The authors conducted a case study and survey of the impact of organisation size on ERP adoption in North American companies and found that large firms employ more of the functionalities offered by the system and customise the software more than smaller firms. |
| Laukkanen et al. (2007) | ERP | Various | 44 | The authors conducted a study of Finish companies and found that large companies expect more from the ERP system than small companies. |
| Buonanno et al. (2005) | ERP | Various | 366 | The authors conducted a survey of factors influencing ERP adoption in SMEs compared to large companies. In their research of business complexities, organisational changes and MRP adoption the authors found that company size was the only significant factor affecting ERP adoption. |
| Olsen and Sætre (2007) | ERP | ETO/MTO | N/A | The authors conducted case studies and found that an ETO company that was experiencing problems with determining realistic due dates, coping with increasing demand and accommodating the customisations requirements of |

| | | | | |
|---|---|---|---|---|
| | | | | each order was considering a number of ERP systems but was unable to find a system that was suitable for their problems. The company therefore developed its own in-house design and engineer solution to cope with product customisation and the design and engineer stage, as this was where the biggest problem lay. |
| Morabito et al. (2005) | ERP | Various | 150 | The authors conducted a survey of the impact of organisation size on ERP adoption in Italian companies and found that large firms employ more of the functionalities offered by the system and customise the software more than smaller firms. |
| Aslan et al. (2012) | ERP | MTO | N/A | The authors conducted a systematic literature review of the fit between ERP functionality and a MTO operations strategy and found that although ERP can provide benefits to MTO companies, it is obvious that there is a misalignment in important areas. The authors found several key areas that are in need of further research in order to improve this alignment, and especially focus on the link between the decision support provided by ERP systems and the decision support required by MTO companies at both the customer enquiry stage and the design and engineering stage. |
| Sriram et al. (2013) | Various | ETO | N/A | The authors conducted a conceptual discussion on the key challenges and opportunities that different PPC systems offer in an ETO environment, and found that MRP lack the capability to meet the requirements of an ETO company. |

**Table 2.2:** Summary of key MRP studies of relevance to an ETO context.

A common factor mentioned in the majority of the above reviewed studies is that there is a lack of literature on the MRP and ETO relationship, and the little literature that has touched upon this relationship has generally concluded that an MRP system will not function optimally in an ETO company. And as Bertrand and Muntslag (1993) pointed out in their study, the most common decision to use an MRP system is that there is a wide availability of MRP software, as well as the fact that it is rarely understood that the MRP software is not suitable for an ETO company. In fact, as the authors briefly explain, the MRP concept was developed for the MTS and ATO strategy. These strategies differ from ETO, as well as MTO, in that the customer plays a central role in the latter two strategies.

# 3 RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

The literature review conducted in Section 2.4.8 clearly states that there is a need for research on the MRP and ETO compatibility as this will generate knowledge on the applicability of an MRP system in an ETO company. This chapter therefore presents the overall research objective of the thesis (cf. Section 3.1), as well as its corresponding research questions (cf. Section 3.2.).

## 3.1 Research objective

The objective of this research is to investigate if implementation of an MRP system supports the operations strategy of an ETO company. For this purpose, the authors of this thesis have worked with a specific case, NOVN, which is going to implement an MRP system in the near future. As requested by NOVN, part of this research will be conducted on the basis of one unit within the roughneck department delivering roughneck machines. This unit has in the past had an ATO operations strategy, as well as implemented an ATO based PPC system in connection with the commencement of series production. Although this system is not directly comparable to an MRP system, NOVN considers the performance of the ATO based PPC system highly relevant for evaluating whether an MRP system supports their ETO operations strategy. The ATO based PPC system was in use for three years before it was terminated.

The overall research objective of this thesis is to:
*Investigate if implementation of an MRP system supports the operations strategy of an ETO company.*

## 3.2 Research questions

Research questions help guide and centre the research of the overall research objective (Zikmund et al., 2013, p. 120) To address the research objective of this thesis, the overall research objective is broken down into two specific research questions:

Research question 1 (RQ1): *What is the impact of an ATO based PPC system in an ETO company?*

This research question is explicitly addressed in Chapter 6. To answer RQ1 research will be conducted on the basis of quantitative and qualitative research of the selected unit within the roughneck department. By analysing the performance of the roughneck unit during the time the ATO based PPC system was in use, it is possible to identify the strengths and weaknesses of the system and identify the impact it had on the unit.

In accordance with the literature reviewed in Chapter 2, a strategic fit between the product-, market- and production characteristics and the PPC system, is positively related to increased performance of a company. Based on this knowledge there is reason to expect that the roughneck units ATO operations strategy had a positive impact on the roughneck units performance, assuming that the ATO based PPC system was supporting the roughneck units ATO operations strategy. To answer this, a quantitative analysis of testing whether the ATO based PPC system has had a positive impact on the roughneck unit has been conducted. The ATO based PPC system serves as the independent variable, while the five tangible performance measures identified in Section 2.1.2.1 and elaborated on in Section 2.3: quality, speed, dependability, flexibility and cost serves as the dependent variables. Within NOVN, value added is considered to be an important performance measure. In this research, the value added is therefore treated as a separate measure constituting the sixth dependent variable. The list of measures applied in this analysis has been adapted in accordance with the available data retrievable from NOVN and computational resources. These dependent variables are discussed, the independent variables expected influence on NOVN explained, and related hypotheses are drawn.

*Quality*

As explained in Section 2.3, quality is closely linked to customer satisfaction and depends on how well the product fits patterns of customer preferences. For evaluating what impacts the ATO based PPC system has had on product quality, internal failure costs have been identified as an appropriate measure. Internal failure cost can be defined as the cost of poor quality caught before the product leaves the production facility and that can lead to rework, scrap and lost production hours. Reductions in internal failure cost can therefore enhance profitability (K. Boyer & Verma, 2010, p. 30). Within NOVN unforeseen extra working hours is a common measure of failure cost. The implementation of the ATO based PPC system was expected to enhance product quality, as the system would free up resources that could be redirected in order to enhance product quality. The ATO based PPC system should therefore have a significant impact on the product quality of the roughneck unit.

The following hypothesis is formulated:
*$H_1$: The ATO based PPC system led to a reduction in unforeseen extra working hours.*

*Speed*

The delivery lead-time, the time it takes from a customer places an order until the customer receives a complete delivery from the supplier, has been identified as an appropriate measure to investigate if the ATO based PPC system has had an impact on the ability of the roughneck unit to quickly respond to demand signals. As the roughneck units decoupling point was shifted forward from ETO to ATO, the time to market was expected to be reduced. The implementation of the ATO based PPC system was therefore expected to reduce delivery lead-time for roughnecks.

The following hypothesis is formulated:
*$H_2$: The ATO based PPC system led to a reduction in delivery lead-time.*

*Dependability*

While speed refers to the lead-time of a product, dependability refers to the ability to deliver the product in time of the contractual delivery date. Dependability can be reflected by large variations in service levels, meaning that customers cannot always rely on receiving their complete orders on time. Dependability can have both internal and external impacts; such as saving time, cost reduction, providing stability and developing fruitful customer relations. Frequency of late or imperfect deliveries is one of the identified measures that will reflect if the ATO based PPC system has had an impact on the roughneck unit's delivery reliability. NOVN regards late deliveries as imperfect deliveries, as they result in penalty costs. The dependability of the roughneck unit was expected to be enhanced by the ATO based PPC system as the new system enabled the unit to allocate components scheduled for a specific project to other projects depending on the project urgency.

The following hypothesis is formulated:
*$H_3$: The ATO based PPC system led to reductions in frequency of imperfect deliveries.*

*Flexibility*

Flexibility refers to the ability to respond to changes in the market. The ATO based PPC system was expected to increase the roughneck unit's flexibility and enable it to respond to changes in for instance a delay in delivery lead-time. Operational measures of flexibility are accuracy of forecast, level of safety stock and capacity utilisation. As the roughneck unit has an ETO operations strategy, no forecasts are conducted and raw material and components are not ordered before the order has been placed by the customer. Accuracy of forecast and level of safety stock will therefore not be a good measure in this setting. Additionally, the registered data on overtime hours on the roughneck projects are inadequate, making also this measure problematic to use. On the other hand, hours elapsed per roughneck project can provide an indication of the flexibility of operations within the roughneck unit, as a decrease in hours could indicate excess capacity.

The following hypothesis is formulated:

*$H_4$: The ATO based PPC system led to a decrease in working hours per roughneck.*

*Cost*

Cost refers to profitability and the ability of producing at low cost. A reduction in cost can either increase profitability of existing volume of products, or reduce the contract price to sell higher volumes. The ATO based PPC system was expected to improve the efficiency and optimize the use of available capacity and hence reduce cost per roughneck.

The following hypothesis is formulated:

*$H_5$: The ATO based PPC system led to a reduction in costs per roughneck.*

*Value added*

Value added refers to the ability to attribute a rather homogeneous product a greater sense of value perceived by the customer without necessarily increasing the cost of the product (Doyle, 2011). Such value added can lead to an increase in contract price. It is therefore a measure of profitability and is calculated as the profit margin. The ATO based PPC system was expected to reduce delivery lead-time for roughnecks, and thus add value for NOVN's customers. As NOVN considers delivery lead-time to be one of the main order qualifiers, potential customers of NOVN was anticipated to perceive shorter lead-times as value adding which would result in higher contract prices and thus higher profit margins.

The following hypothesis is formulated:

*$H_6$: The ATO based PPC system led to an increase in profit margin.*

This leads to the following research model (cf. Figure 3.1):

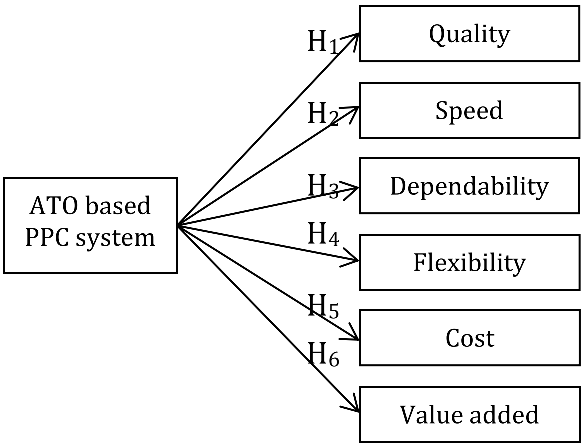



**Figure 3.1**: Research model.

As explained in Section 2.3, to get a better understanding of the ATO based PPC system's performance, subjective measures should be included when evaluating the PPC system. Qualitative research based on these subjective measures will be conducted on the basis of the roughneck unit's employees.

Research question 2 (RQ2): *How can an MRP system be used to support the PPC needs of an ETO company?*

This research question is explicitly addressed in Chapter 7. The roughneck unit's employees and other key informants within NOVN will be the subject of this research question. An analysis of the unit's employees experience with the system, as well as key informants that are thought to be knowledgeable and credible on the research at hand will unveil the main reasons for the system's performance and help identify potential challenges that can arise during implementation of the new MRP system. This will provide the foundation to explore how an MRP system can be used to support the needs of NOVN.

# 4 RESEARCH METHODOLOGY

This chapter presents and elaborates on the research methodology used in the thesis for answering the research questions developed in Chapter 3. The research questions are revisited and the nature of investigation for each of the research questions is reviewed.

Section 4.1 introduces the research design used in this thesis, as well as their relevance to the two research questions. Section 4.2 critically reviews and justifies the research methods used in the research. Section 4.3 gives a short description of the sampling unit of the research. Section 4.4 explains how the data was collected, as well as what data that was used to answer the research questions. Section 4.5 provides an assessment of how the research will achieve good scientific validity and reliability. Section 4.6 concludes the chapter with a table that link the research questions with research methodology.

## 4.1 Research design

The research design constitutes the master plan that specifies the methods and procedures for collecting and analysing the necessary information to achieve the objective of a study. (Zikmund et al., 2013, p. 64). There are three types of business research designs: exploratory, causal and descriptive. The three types have different approaches, and it is therefore important that the choice of research design matches the characteristics of the research problem, to obtain useful research results (Zikmund et al., 2013, p. 52). Based on what data was needed to answer the research questions of this thesis, the research conducted has been a combination of exploratory and descriptive research.

Exploratory research is often used to clarify vague situations or to discover ideas that may be potential business opportunities. It can also be used to help identify the research problem. This type of research does not have the purpose to provide conclusive evidence from which to determine a particular course of action, but provides more knowledge and better understanding of the research problem. It can also lay the foundation for further research (Zikmund et al., 2013, p. 52).

Descriptive research is used to describe characteristics of objects, people, groups, organisations or environments. In contrast to exploratory research, descriptive research is undertaken after the variables in question have been clarified and understood. A good descriptive research depends on stating clear hypotheses on how the variables in question interact with each other (Zikmund et al., 2013, p. 53).

The purpose of RQ1 is to explore what is the impact of an ATO based PPC system in an ETO company. The phenomenon of performance and how to measure performance of a PPC system is well explored in the literature (cf. Section 2.3). A descriptive approach has therefore been applied to address this research question. An assessment of relevant available literature on the phenomenon has been conducted. The consolidation of this literature makes up the base of the performance measures used to evaluate the ATO based PPC system's performance in the unit in question.

The purpose of RQ2 is to explore how an MRP system can be utilised to support the PPC needs of an ETO company. To get a comprehensive understanding of how PPC is managed in NOVN today and to identify challenges of the current PPC system, an exploratory approach has been applied. Furthermore, this knowledge is also the source of suggestions for additional elements that should be considered when implementing the MRP system in NOVN.

The overall focus of the thesis is to "investigate if implementation of an MRP system supports the operations strategy of an ETO company". The nature of this research topic suggests that the research is a combination of deductive and inductive reasoning, as is reflected by RQ1 and RQ2 (Saunders et al., 2009, p. 127). While deductive research is associated with deriving a conclusion about a specific instance based on a known general premise, inductive research is about establishing a general proposition on the basis of observations of particular facts (Zikmund et al., 2013, pp. 43-44). A variety of literature exists on benefits of a PPC system and how to measure it, which supports a deductive reasoning for addressing RQ1. However, because there is a lack of literature regarding the fit between an ETO company and an MRP system (cf. 2.4.8), RQ2 will be addressed by using inductive reasoning. Thus, given the descriptive and exploratory research designs and the nature of the research topic, this thesis is a mixed method research. The chosen research methods will be elaborated in the next section.

## 4.2 Research methods

Both quantitative and qualitative research methods have been chosen, as they are seen as the most appropriate way of conducting the research. Necessary data has been gathered by conducting a literature review and a case study to provide the foundation for answering the research questions.

### 4.2.1 Literature review

A literature review is a summary of previous research that is relevant to the topic at hand (Zikmund et al., 2013, p. 63). To get a better understanding of the phenomenon of this research, a comprehensive literature review has been conducted. It provides a historical background of the phenomenon as well as identifies knowledge gaps, degree of agreement on topic and the current status of research on the topic.

### 4.2.2 Case study

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clear (Yin, 2012, p. 7). It is often used to explore existing theory (Saunders et al., 2009, p. 147). A case study approach has therefore been applied to address the research objective of the thesis. The starting point for the case selection was an opportunity to collaborate with NOVN, who found the topic highly relevant and interesting. As NOVN is the only company studied, this research is classified as a single case study. The benefit of conducting a single case study is that it is possible to delve into the organisation. However, it may be problematic to generalise the findings of the research in this thesis, both statistically and analytically, as it only represent a single organisation and event (Bhattacharyya, 2006, p. 72; Yin, 2009, p. 38).

The case study has been conducted doing both quantitative and qualitative analysis. A quantitative quasi experiment has been applied to provide insight into the operational aspect of the research questions, while personal- and group interviews have been conducted to provide rich descriptions and insightful explanations of the research problem. In addition to the interviews, several informal conversations with company representatives have been carried out.

*Quasi experiment*

A quasi experiment aims to evaluate interventions and demonstrate causality of the interventions and their outcome (Cook & Campbell, 1979, p. 95). To describe the impact of the ATO based PPC system on the production of roughnecks, a quasi experiment with one group pre-test and post-test design, using a double post-test, has been conducted. Adding a second post-test facilitates ruling out maturity effects that may have explanatory power on the observed result (Cook & Campbell, 1979, p. 95). As the ATO based PPC system is no longer in use, it was not possible to make direct observations before or during its intervention. Therefore, archival records with performance data retrieved from NOVN's databases for the three periods constitute the data included in the experiment. This data has been further analysed through the statistical analysis tool, SPSS. An ANOVA have been used to test if there exist significant variances between the three measured periods (Zikmund et al., 2013, p. 542). Scheffe's test have been used to further test the significance of the means to establish between which periods of time there exist significant changes (Klugh, 1986, p. 287). A confidence interval of 95% is considered to be satisfactory to support or reject a hypothesis.

The main weakness of a quasi experiment is its lack of randomisation as it is difficult to control for variables that might have an impact on the results. Variables that may have an impact on the results of this experiment are productivity, demand, quality of employees, as well as the financial crisis. As quasi experiments tend not to be sufficient for permitting strong tests of causal hypotheses, the aim of this quasi experiment was to merely provide support for the causal inference (Cook & Campbell, 1979, p. 95).

*Interviews*

The interview is one of the most important sources of case study information (Yin, 2009, p. 106). A personal interview allows the informants to develop and give reasons for the choices that were made in a non-intimidating way (Saunders et al., 2009, p. 372). For the purpose of getting a thorough understanding of the case study issues and the key informants' perspectives on the subject, three personal interviews were conducted. This method was also selected to get an insight into the key informants opinions on the sensitive topic of the reason for why the ATO based PPC system was shut down.

As pointed out by Zikmund et al. (2013, p. 142), an interview with multiple key informants, as opposed to a personal interview, allows for higher degree of scrutiny and detailed descriptions of a given research. It may also produce thoughts around the subject that would not otherwise be produced. To get multiple perspectives on the subject of the research, and for identifying similar and rival opinions, the authors of this master thesis chose to follow the advice of Zikmund et al. (2013, p. 142) and conduct a group interview. Although it is preferable for such an interview to consist of 6-8 key informants, it was only possible to obtain two. The reason for this was that there were only a few employees remaining in NOVN that had central roles during series production in the given unit.

The main concern of conducting a group interview with only two key informants is that it may be difficult to discuss sensitive topics. On the other hand, a group interview can make key informants more willing to share their thoughts on sensitive topics as they become aware of other informants in the group with similar concerns and opinions as themselves (King & Horrocks, 2010, p. 63). Another concern is that the key informants answers may be coloured by the answers or the presence of other informants and therefore might not reflect their true answer (King & Horrocks, 2010, p. 62). To mitigate these concerns, anonymity was offered.

The conducted interviews of the five key informants, both the three personal interviews and the group interviews, have also shaped further questions that have been found relevant to the topic and appropriate to explore further.

## 4.3 Sampling

The sampling units consist of five key informants. Three of them were employed in the unit in question during the use of the ATO based PPC system, whilst the remaining two has extensive knowledge on series production and MRP. These are all informants that are thought to be knowledgeable and credible on the research at hand.

## 4.4 Data collection and analysis

### 4.4.1 Data collection

Multiple sources of evidence have formed the basis of this research. Articles published in reliable scientific journals and documents including annual reports, company presentations, and other internal reports provided by NOVN, were a rich source of evidence and thus constitute the theoretical data of this research. Qualitative and quantitative data has mainly been collected from NOVN’s information system, and through conducting interviews with the key informants. The quantitative data necessary for analysing the performance of the ATO based PPC system was extracted from NOVN’s information system. The interviews were recorded with the consent of the key informants to facilitate documentation. This allowed the researchers to fully focus on the answers the key informants provided. In addition, notes were taken during the interviews. This qualitative data was backed up by informal conversations and interactions with company representatives and other informants.

### 4.4.2 Data analysis

Data analysis consists of making sense of the data collected by converting quantitative and qualitative data into a format that can be further analysed to draw conclusions (Yin, 2009, p. 126). The general analytical strategies for this research rely on theoretical propositions, using both qualitative and quantitative data and examining rival explanations.

*RQ1: Literature review and case study (quasi experiment, personal- and group interview)*

The first research question focus on to what is the impact of the ATO based PPC system in an ETO company. A literature review was conducted to identify operational measures and develop a theoretical framework for how to measure performance of a PPC system. In addition, the main reasons for success and failures of PPC implementation were identified to describe the performance results of the ATO based PPC system. By using keywords and backwards literature search, relevant articles on the topic from reliable scientific journals were identified.

Necessary quantitative data has been extracted from NOVN's information system and summarised statistically before they have been analysed through conducting two different F-tests: ANOVA and Scheffe's test. An F-test determines whether there is more variability in the scores of one sample, than in the scores of another sample. It assumes that the means of a given set of normally distributed observations, having the same standard deviation, are equal (Zikmund et al., 2013, p. 546).

ANOVA

ANOVA tests if there exist significant variances between populations with two or more treatments (Zikmund et al., 2013, p. 542). To test whether there are significant variances between the three periods of time used in this research, an ANOVA test has been conducted. The output from SPSS provides the test with its given F-value as well as calculates the critical value for each test, which is the value the F-test must exceed to reject the null hypothesis (Zikmund et al., 2013, p. 546). The significance of the result is reflected in the p-value. For this study a confidence interval of 95% is considered to be satisfactory to support or reject a hypothesis. The null hypothesis should therefore be rejected if the p-value of a test is below 0.05.

Scheffe's test

While the ANOVA test is used to examine if there exist a difference between more than two groups, Scheffe's test examines which groups are significantly different (Klugh, 1986, p. 287). Scheffe's test have therefore been used to further test the significance of the means in order to establish between which periods of time there exist significant changes. Similar to the ANOVA test, SPSS calculates the given F-value and calculates the critical value in which the F-value must exceed to reject the null hypothesis; however, this is not displayed in the output from SPSS. However, the p-value reflects the significance of the test. Furthermore, a confidence interval of 95% is considered to be satisfactory to support or reject a hypothesis. The null hypothesis is therefore to be rejected if the p-value of a test is below 0.05.

The personal- and group interviews provide insights into more subjective measures of the PPC implementation. A content analysis of this data was conducted to identify corroborations and rival explanations, and to draw correct conclusions.

*RQ2: Literature review and case study (personal- and group interviews)*

The second research question focus on how the MRP system can be used to fit the PPC needs of an ETO company. Insights from the case study, in the form of personal- and group interviews, were used to map the characteristics of NOVN's need for PPC. Based on these characteristics, a literature review has been conducted to identify how an MRP system can accommodate these needs, as well as the potential challenges with implementing this system. These findings are then thoroughly discussed before conducting logical reasoning and recommendations.

## 4.5 Quality of the research design

The quality of this research design is assessed on the following criterions: external validity, internal validity, construct validity, and reliability (Yin, 2009, p. 40).

### 4.5.1 External validity

Generalizability is one of the main concerns when conducting a case study. In some cases, it is possible to generalise statistically to a population based on multiple case studies (Yin, 2009,

p. 44). As this research is a single case study it is not considered to be a representative sample regarding statistical generalization. The purpose of this research is therefore not to produce a theory that can be generalised to all populations, but merely describe what is happening in this particular research setting. (Saunders et al., 2009, p. 158). However, parts of this research may be of an analytical generalizable character if the findings of the research are supported by two or more case studies. In such situations replication may be claimed and hence be analytically generalizable (Yin, 2009, p. 38). Furthermore, the fact that a traditional MRP system is used as a basis for this research, instead of a vendor specific system, facilitates generalizability.

### 4.5.2 Internal validity

The main concern regarding internal validity when conducting a case study is the problem of making inferences whenever an event cannot be directly observed. This could be a concern if the researchers are biased (Yin, 2009, p. 43). To reduce making incorrect inferences based on either personal experience, data collected from interviews or internal reports, plausible explanations have been carefully considered and consulted with key informants of NOVN before making an inference.

### 4.5.3 Construct validity

The authors of this master thesis have chosen to follow the recommendations made by Yin (2009, p. 41), and has thus taken several measures to establish construct validity. Multiple sources of evidence have been used as a basis for this research. This is reflected in the amount of reliable scientific journals that have been used to identify operational measures for the concepts being studied. The questions asked in the interviews are grounded in theory. The number of informants that have been selected for interviews also allows the case study findings to be more convincing and accurate as they are based on multiple sources of information. To achieve well-structured interviews, an informant of NOVN carefully reviewed the interview guide before the interviews were conducted. Terms were rephrased to suit the office language of the key informants to make it easier for them to understand the questions. After the interviews were carried out, the informants were again contacted in situations where there was a need to clarify and expand on received information. Corrections were conducted when necessary. The case analysis were also interpreted and discussed in collaboration with key informants. Letting informants within the given unit of NOVN review the draft of the case study report has further increased construct validity (Yin, 2009, p. 41).

### 4.5.4 Reliability

Reliability is important if the research is to be replicated in the future. A case study protocol and database have therefore been developed in order to increase the reliability of the research conducted in this thesis. The former includes the main steps taken to conduct this research, while the latter contains the documentation of the data collected (Yin, 2009, p. 45).

## 4.6 Summary

To answer the two research questions the research of this thesis was designed as a mixed method research using descriptive and exploratory research. By performing an assessment of relevant available literature on the phenomenon in question and by conducting interviews with several key informants, this research was carried out using both the quantitative and qualitative research methods literature review and case study. A summary of key aspect of the research methodology used for answering the two research questions can be found in Table 4.1.

| Research question | RQ1:<br>What is the impact of an ATO based PPC system on an ETO company? | RQ2:<br>How can an MRP system be used to support the PPC needs of an ETO company? |
|---|---|---|
| Purpose | Identify strength and weakness of the ATO based PPC system and its impact on an ETO company | Increase understanding for how aspects of a used MRP system fit the PPC needs of NOVN |
| Research design | Descriptive and exploratory | Exploratory |
| Research methods | Literature review and case study | Literature review and case study |
| Data collection | Theoretical framework collected from literature based on keywords and backwards literature search, insights from case study such as quantitative data and interviews | Empirical insights such as qualitative data in form of personal- and group interviews and informal conversations, and proposed solutions collected from literature based on keywords and backwards literature search |
| Data analysis | ANOVA test, Scheffe's test and content analysis | Content analysis |

**Table 4.1:** An overview of the research methodology used in the thesis

# 5 CASE STUDY: NATIONAL OILWELL VARCO NORWAY

This chapter introduces the case study company that has been used to be able to answer the research objective of the thesis.

Section 5.1 gives a brief introduction to NOV and NOVN and how this company can be considered as a representative for ETO companies. Section 5.2 gives a profound review of the unit where the research has been conducted. This section also describes what operations strategy was used and how planning and control was performed in the given unit during series production.

## 5.1 National Oilwell Varco Inc.

National Oilwell Varco Inc. (NOV) is a worldwide leader in the design, manufacture and sale of equipment and components used in oil and gas drilling and production, the provision of oilfield inspection and other services, and in supply chain integration services. This makes NOV a single source provider to the upstream oil and gas industry (NOV, 2013, 2014a).

The company operates in three financial segments: Rig Systems, Wellbore Technologies, and Completion and Production Solutions (NOV, 2014c). Their vision is to be the world's leading and most innovative provider of both drilling and handling equipment as well as related services to the energy industry (NOVN, 2011).

NOV's headquarter is located in Houston, Texas. They have over 63,000 employees working in 60 countries, and had a revenue of US$22.77 billion in 2013 (NOV, 2014b; NOVN, 2013). Their history dates back to 1841, with the establishment of the company Brissonneau Brothers. Through several mergers and acquisitions NOV has become the worldwide leading company it is today ("NOV Milestones [video clip]," 2014).

### 5.1.1 National Oilwell Varco Norway

In 2003 NOV purchased the Norwegian company Hydralift, which became the start of National Oilwell Varco Norway (NOVN) (Reinertsen, 2013). NOVN is therefore a wholly owned subsidiary of NOV. NOVN is a part of Rig Systems, and their head office is in Kristiansand. The company is also located in other Norwegian cities, such as Stavanger, Molde, Oslo, Tønsberg, Arendal and Trondheim (NOVN, 2012).

NOVN has approximately 4,700 employees, and is Southern Norway's largest private employer (NOVN, 2012, 2013). They were ranked as Norway's 3rd largest exporter in 2012 and had a revenue of 31 billion NOK in 2013 (Fjose et al., 2013; Reinertsen, 2014). 75% of all new projects within the industry are carried out by NOVN, and at the end of 2013 NOVN's backlog was approximately 55 billion NOK, which amount to 56% of NOV's entire backlog.

NOVN's expertise is in quoting, engineering, project management, manufacturing, commissioning and field service (NOVN, 2008). A large part of their production is based on intermediate products that are produced in other NOV locations, mainly in USA, but also from countries such as South Korea, China and Poland (Fjose et al., 2013).

#### 5.1.1.1 Company objective and performance measures

NOVN's overall company objective is to be the world's leading and most innovative provider of drilling and handling equipment and related services to the energy industry. NOVN operates on the basis of four guiding principles: quality, safety, innovation and growth. While growth refers to the ability to expand in the market NOVN operates in, the safety of a product is considered to be depending on the quality of the product. The two former principles are therefore both related to quality, whilst the level of innovation depends on the flexibility of the company. This therefore suggests that the most important performance measure of NOVN is quality and flexibility.

#### 5.1.1.2 Characteristics of NOVN

As NOVN's decoupling point is located at the design stage where the order is linked to the customer, the company is considered to have an ETO operations strategy. For the generalizability of this research it is of paramount importance that the case study is a representative case for ETO companies. NOVN will therefore be described based on the characteristics identified in Section 2.1.3.1.3.

##### *5.1.1.2.1 Market related characteristics*

As NOVN operates within the oil and gas industry, its customers include drilling contractors, shipyards and other rig fabricators, as well as well servicing companies, national oil companies, major and independent oil and gas companies, and pipe-running service providers.

Although the size of these customers varies, each customer is characterised as large. For example, in 2009 one customer accounted for about 16.6% of NOV's total revenue. Customers of this magnitude constitute a major risk as loosing such customers will lead to a large reduction in revenue. This can be the result if the oil and gas prices fall below a range that is acceptable to the customer, thus resulting in a significant reduction in demand for NOVN's products (NOV Inc., 2010, p. 22). The reason for why the oil and gas prices could have such a large impact on revenues is because drilling activities are closely linked to the fluctuations of oil and gas prices that are determined in the market place. This means that the expectations for future oil and gas prices causes several shifts in the strategies and expenditure levels of oil and gas companies as well as drilling contractors, such as NOVN (NOV Inc., 2006, p. 15). Because of this, the market NOVN operates in can be characterised as highly volatile.

One of the main characteristics of NOVN is its ability to customise products according to customer requirements. As mentioned earlier, this poses a constraint on the company's delivery lead-time. Because of this, NOVN is dependent on early customer involvement already at the design stage. Although some of these customer requirements can be satisfied with previous designs, most orders need to be modified or designed from scratch. This wide range of differences in market requirements is reflected in the extensive product range offered by NOVN. The company's degree of product innovation is therefore mainly driven by new customer requirements.

##### *5.1.1.2.2 Product related characteristics*

NOVN's product portfolio consists of a wide range of products, all with distinct characteristics. However, as most of NOVN's products demand early involvement of the customer in the production process, they can be characterised as innovations or as products experiencing growth in sales and profit. The overall product portfolio of NOVN can therefore be located in the introduction, or in the growth stage of the PLC (cf. Section 2.1.2.2).

Most products produced by NOVN require a large diversity of components as well as an extensive amount of assembly processes to finalise the product. The general BOM is therefore A-shaped, which means that higher levels consumes the lower levels of raw material or components (Avraham & Karni, 2013). Thus, the products NOVN produce have a deep multileveled product structure.

#### *5.1.1.2.3 Production related characteristics*

Within NOVN, the enquiry-, design- and engineering stages are considered to add the most value to the company's products. However, because of the frequent engineering changes that occur due to the close involvement of NOVN's customers, these stages are also considered to be the company's main bottlenecks. NOVN's production characteristics therefore underline the unpredictability of these stages.

The above identified market- product- and process characteristics of NOVN are consistent with the characteristics of an ETO company elaborated on in Section 2.1.3.1.3. NOVN is therefore considered to be a representative case of ETO companies.

## 5.2 Roughneck unit

The roughneck unit is project based and has an ETO operations strategy in line with the overall operations strategy of NOVN. The roughneck unit designs several products. One of them is the pipe handling machine roughneck, often referred to as hydratong within NOVN. This machine is used to connect and disconnect pipes on the drill floor and eliminates the manual handling involved with suspended individual tools. It comes in nine different models all with distinctive features. These models consist mainly of components that are commonly used on most of the models, but they can also be adapted to customer requirements. In line with the ETO operations strategy the CODP of the roughneck unit is located at the design stage of the supply chain.

The decision to undergo series production of roughnecks was a result of market shifts. In 2004, the time prior to implementation of the ATO based PPC system, the roughneck unit experienced a significant increase in customer orders. They especially experienced an increased demand for their most sold roughneck model, the MPT-200. As the roughneck unit at the time was delivering roughnecks at full capacity, accepting these orders would result in long delivery lead-times, which the customers would not accept. The roughneck unit acknowledged that the link between the market and production of roughnecks had drifted out of alignment creating a misfit, and that their current ETO strategy was not efficient enough to cater the new characteristics of the market. To cope with the increased demand the roughneck unit started to search for new ways to improve their production, planning and control processes in terms of speed and product quality. This resulted in a new operations strategy for production of the MPT-200 machine: ATO, also referred to as series production within

NOVN. To support the PPC needs of the roughneck units new operations strategy, a customised ATO based PPC system was developed. This system was not a software, but mainly consisted of working manually in Microsoft Excel, and can thus not be found in any literature. The system was fully implemented within the unit early in 2006 and was fully operable until late 2009. At this point it was decided to shut down the ATO based PPC system and return to their original ETO operations strategy. This decision to shut down series production of roughneck in 2009 was taken at the corporate level of NOVN in the wake of a failed attempt of series production of another product within another unit in NOVN. However, no formal evaluation of the ATO based PPC system and its performance has been conducted.

### 5.2.1 Assemble-to-order operations strategy

In line with the ATO operations strategy, the product structure of the roughneck needed to be decomposed into modules to reduce lead-time and increase operations efficiency. The roughneck's many features got broken down into modules that were considered to satisfy most of the current customer requirements. Instead of developing an equipment package for every project, only one equipment package was made for each module and used for several projects. Furthermore, documentation of the components was now issued per module, instead of per projects, as was the case prior to the ATO based PPC system. A module number for every module was created and had its own BOM.

As production lead-time poses a major constraint on delivery lead-time, establishing additional production capacity was crucial to facilitate an ATO operations strategy. Contracting with a Norwegian workshop, as a supplement to the original workshops located in Poland, became necessary in order to increase production capacity and hence be able to respond more quickly to the market. The excess workshop was assigned the most urgent jobs.

To avoid inventory cost and the risk of being left with obsolete items in inventory, purchasing orders were only issued when a contract with a customer was signed. Thus no components were purchased on speculation. In line with the ATO operations strategy identified in Section 2.1.3.1, the ordering of the modules can be seen as forecast driven activities as these are not linked to any project, while the linking of modules to project and final assembly can be seen as customer-order-drive activities. The ATO operations strategy therefore resulted in a forward displacement of the decoupling point, now located at the final assembly stage.

### 5.2.2 The ATO based PPC system

The ATO based PPC system was designed to provide an overview of the production of the modules as well as the pending projects waiting to be linked to its respective modules. When the roughneck unit received orders of MPT-200, they were placed into the ATO based PPC system. Based on the customer requirements, the appropriate modules for the project was identified and calculation of the material requirements was done by exploding these modules BOM's. If the customer requirements consisted of specifications beyond the modules, these requirements were handled separately and ordered directly on the specific project number. Instead of ordering components on specific project numbers on an on-going basis as the unit used to do prior to the ATO based PPC system, the modularity of the MPT-200, and the fact that documentation was attached to every component, allowed for ordering batches of components. Furthermore, the modularity of the MPT-200 allowed purchase orders to be issued more quickly than before, as there already existed an equipment package for the module. The components were therefore interchangeable before they were tied to a specific order at the CODP. The production progress of each module was reported in the ATO based PPC system so that it was easy to keep an overview. When the modules were completed, they were linked to the project that was most urgent to complete. The specific module used to build a specific roughneck was added to the general assembly drawing of the given project, which facilitated full traceability of each component, as well as its documentation, in every module, and hence the project. The cost of the projects was transferred to the project number and neutralised at the module number when the project was completed and delivered to the customer.

At the time of series production, and thus using the ATO based PPC system, the roughneck unit consisted of five employees. Two employees were dedicated workers on series production: a production manager and a technical assistant. As a roughneck consists of necessary components supplied by the electrical and hydraulic department, a contact person from each of these departments was appointed to be dedicated to series production of roughnecks and in charge of defining necessary hydraulic and electrical components. Additionally, a person within the purchasing department was also appointed to handle the purchase orders that were placed in regard to series production.

The production manager had the overall responsibility of managing the system and served as a single point of contact in relation to the workshops, the electrical and hydraulic department, as well as the purchasing- and cost and controlling department. The production manager thus was responsible for registering orders, purchase orders, notifying the different departments of new orders and follow up production as well as being responsible for keeping the ATO based PPC system updated at all times. The technical assistant assisted in this work. The remaining three employees were equipment responsible (ER) and were in charge of the total project delivery. Their main focus was on the technical aspects of the project and additional specifications that customers required and that was not produced by performing series production. The ER's had full insight into the system[2].

[2] Source of information is collected from the conducted interviews.

# 6 RQ1: EVALUATION OF THE ATO BASED PPC SYSTEM

In this chapter the findings related to the quantitative and qualitative evaluation of the ATO based PPC system are presented and discussed, thus answering RQ1.

Section 6.1 briefly presents what forms the basis of the quantitative and qualitative analysis. Section 6.2 analyse and evaluates the quantitative performance measures of the ATO based PPC system. Section 6.3 analyse and evaluates a number of subjective measures and provides a brief summary of the overall findings of RQ1.

## 6.1 Quantitative and qualitative evaluation

The performance of a PPC system is affected by how it is designed as well as numerous external conditions and circumstances that is beyond the company's control. To evaluate the ATO based PPC system implemented in the roughneck unit, a quantitative and qualitative analysis has been conducted. The analysis is based on the operational measures of the performance measures and the subjective measures identified in Section 2.1.2.1 and elaborated on in Section 2.3. In some cases performance data could be extracted directly from NOVN's information systems, however most of the analysis required collecting, structuring and cleansing large amounts of data. The statistics on the operational performance measures of the roughneck unit form the basis of the quantitative analysis; the quasi experiment. The findings from two interviews conducted with three key informants that were employed in the roughneck unit during the use of the ATO based PPC system provides the basis of the qualitative analysis. Parts of the findings of this chapter are therefore based on the authors' interpretations of evidence from these two interviews.

## 6.2 Quantitative measures

As explained in Chapter 3, six hypotheses have been formulated based on the tangible measures; quality, speed, dependability, flexibility, cost and value added:

*$H_1$: The ATO based PPC system led to a reduction in unforeseen extra working hours.*
*$H_2$: The ATO based PPC system led to a reduction in delivery lead-time.*
*$H_3$: The ATO based PPC system led to reductions in frequency of imperfect deliveries.*
*$H_4$: The ATO based PPC system led to a decrease in working hours per roughneck.*

*$H_5$: The ATO based PPC system led to a reduction in costs per roughneck.*

*$H_6$: The ATO based PPC system led to an increase in profit margin.*

The relationships hypothesised are depicted in Figure 6.1.

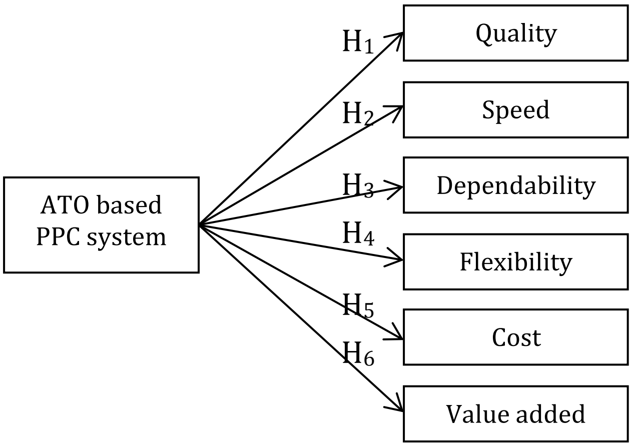



**Figure 6.1:** Research model.

These hypotheses will be tested by conducting a quasi-experiment of the ATO based PPC system's impact on performance measures. The quasi experiment is designed as followed:

(01 X 02) 03

01 = Pre-period

02 = Series production

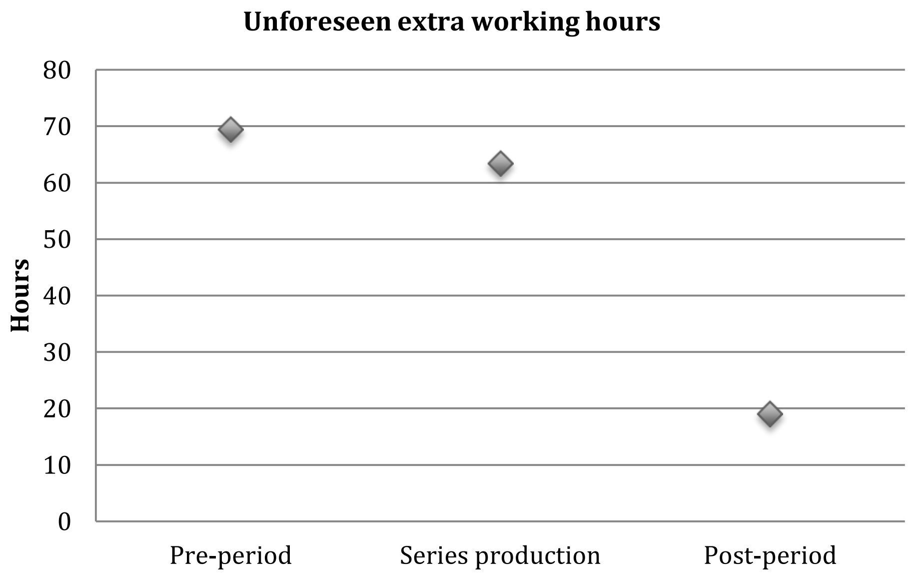
03 = Post-period

X = ATO based PPC system

The analysis is based on data on MPT-200 deliveries during the period of series production (02), lasting from 2006 until 2009. Equivalent data on the period prior to series production, 2004–2006, makes up the pre-period (01). Similarly, data on the period after series production, 2009–2012, constitutes the post-period (03). The post-period serves as a control period to establish that the observed effects are due to the independent variable; the ATO based PPC system (X). External effects and maturity effects that are considered to have an explanatory power of the observed results have been identified and taken into consideration when interpreting the results. The results of the ANOVA and Scheffe's test are presented in the forthcoming sections, followed by an interpretation of the result.

### 6.2.1 Quality

As explained in Section 3.2, failure costs have been identified as an appropriate measure for evaluating what impact the ATO based PPC system has had on product quality. Unforeseen extra working hours, which is a common measure of internal failure cost within NOVN, will reflect the systems impact on product quality. Such hours often occur because a deviation from the standard design quality has occurred. This deviation must then be corrected before the product is transferred to the customer. An example of such a deviation is defective products or materials that cannot be repaired, used or sold. The amount of unforeseen extra hours that have elapsed on the roughneck projects has therefore been measured in the three periods studied.




The overview of the average amount of unforeseen working hours of the three periods is depicted in the above diagram. Compared to the pre-period, the roughneck unit experienced a decrease from approximately 70 hours to 63 hours during series production. Unforeseen amount of working hours was further reduced to 20 in the post-period.

The null hypothesis in the ANOVA test:

*$H_0$: There exist no significant differences in variances in reduction of unforeseen extra working hours between the three periods measured.*

**ANOVA**

Unforeseen working hours

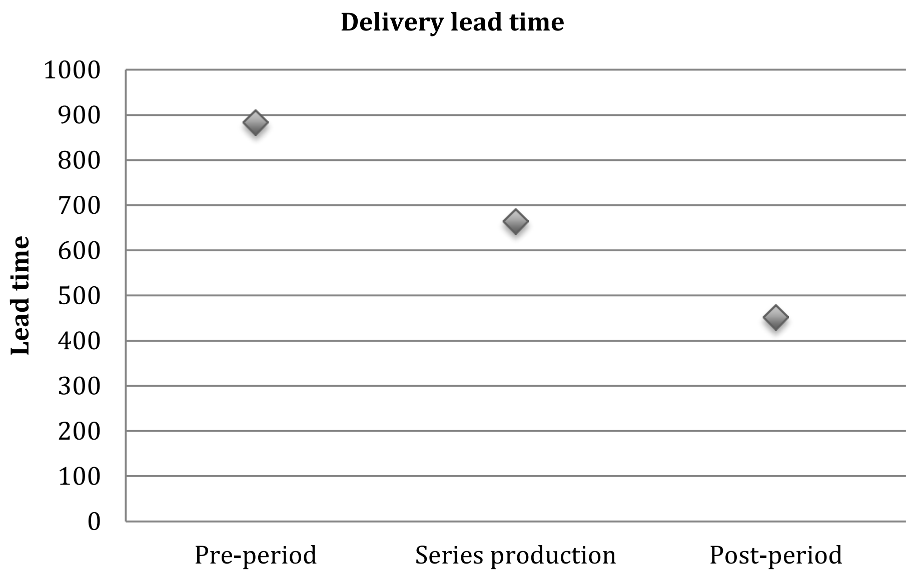
| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 72370.972 | 2 | 36185.486 | 1.844 | .161 |
| Within Groups | 3277431.434 | 167 | 19625.338 | | |
| Total | 3349802.406 | 169 | | | |

Critical value of F = 3.050

The analysis of variances of the three different periods is shown in the table above. The F-value of the test is 1.844 and the critical value of F is 3.050. As the F-value for this test does not exceed the critical value (1.844 < 3.050) the null hypothesis cannot be discarded. This result is reflected in a significance level well above 0.05 (0.161 > 0.005). It is therefore not possible to say with 95% certainty that there exist significant variances of unforeseen working hours for the different periods. The ANOVA test does therefore not provide any support for the hypothesis stated in $H_1$, but supports the $H_0$; the implementation of the ATO based PPC system did not lead to a reduction in unforeseen extra working hours.

### 6.2.2 Speed

In Section 2.3 delivery lead-time was identified as an appropriate measure to investigate if the ATO based PPC system has had an impact on the ability of the roughneck unit to quickly respond to demand signals. The delivery lead-time on roughneck projects has therefore been calculated for the time elapsed from the contract sign date to the contract delivery date.




As can be seen from the overview of the average delivery lead-time of the three periods depicted in the diagram above, the delivery lead-time has had a steady decline over the three periods.

The null hypothesis in the ANOVA test:
*$H_0$: There exist no significant differences in variances in delivery lead-time between the three periods measured.*

**ANOVA**

Delivery lead-time

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1157921.176 | 2 | 578960.588 | 22.195 | .000 |
| Within Groups | 1852075.316 | 71 | 26085.568 | | |
| Total | 3009996.491 | 73 | | | |

Critical value of F = 3.125

As can be seen from the table, the F-value of the test exceeds the critical value of F (22.195 > 3.125) and the significance level is well below 0.05 (0.00 < 0.05). The variance analysis therefore gives a strong indication that there are significant variances between the three periods that have been measured.

A Scheffe's test must be conducted to establish what periods contribute to these variances.

The hypothesis to be tested in the following Scheffe's test:
*$H_2$: The ATO based PPC system led to reductions in delivery lead-time.*

**Multiple Comparisons**

Delivery lead-time

Scheffe

| (I) Period | (J) Period | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|
| Pre-period | Series production | 219.171 | 88.850 | .054 |
| | Post-period | 432.123* | 83.862 | .000 |
| Series production | Pre-period | -219.171 | 88.850 | .054 |
| | Post-period | 212.951* | 43.410 | .000 |
| Post-period | Pre-period | -432.123* | 83.862 | .000 |
| | Series production | -212.951* | 43.410 | .000 |

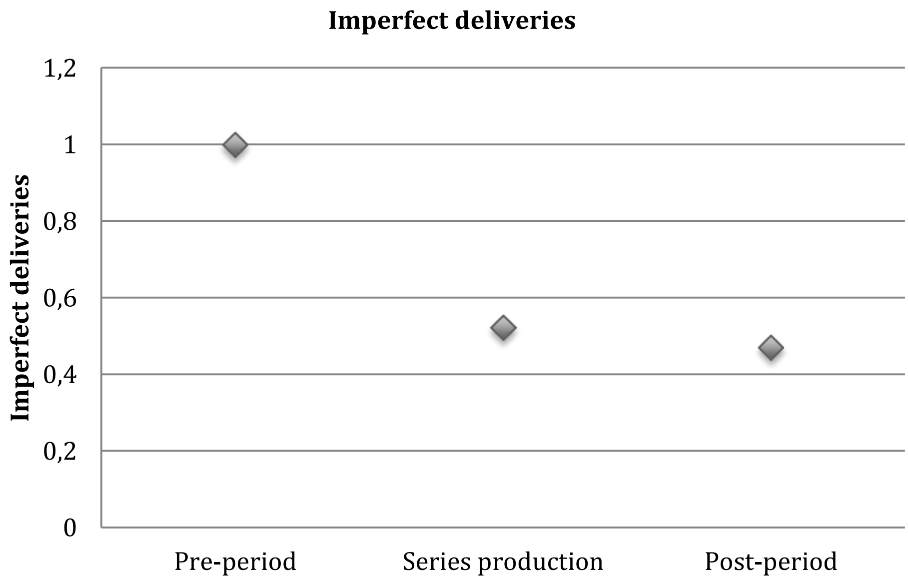
*. The mean difference is significant at the 0.025 level.

As can be seen from the table above, the pre-period had significantly longer lead-times than the period of series production. The Scheffe's test provides strong evidence, with a significance level of 0.05, which support the hypothesis stated above; the implementation of ATO based PPC system led to reductions in lead-time.

However, Scheffe's test also shows that the roughneck unit experienced similar reduction in delivery lead-times when comparing the pre- and post-period. It therefore indicates a maturation effect, which can have an impact on the observed result, thus reducing the likelihood that the ATO based PPC system has had a positive impact on delivery lead-times of roughnecks.

### 6.2.3 Dependability

The frequency of late or imperfect deliveries is the identified measure that can reflect if the ATO based PPC system has had an impact on delivery reliability of the roughneck unit, as explained in Section 2.3. The frequency of imperfect deliveries has therefore been measured across the three periods of time.




An overview of the average delayed projects is depicted in the diagram above. While all projects in the pre-period were delayed, approximately half of the project was delayed during the series production and post-period.

The null hypothesis in the ANOVA test:

*$H_0$: There exist no significant differences in variances in frequency of imperfect deliveries between the three periods measured.*

**ANOVA**

Projects delayed

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2.390 | 2 | 1.195 | 5.001 | .008 |
| Within Groups | 39.899 | 167 | .239 | | |
| Total | 42.288 | 169 | | | |

Critical value of F = 3.050

The result of the ANOVA test shows a F-value larger than the critical value, and a significance level well below 0.05. This provides strong evidence for that there exist significant differences in variances between the average of delayed projects across the three periods. The null hypothesis can therefore be discarded.

To establish what periods contribute to these variances, it is necessary to conduct a Scheffe's-test.

The hypothesis to be tested in the following Scheffe's test:
*$H_3$: The ATO based PPC system lead to reductions in frequency of imperfect deliveries.*

**Multiple Comparisons**

Projects delayed

Scheffe

| (I) Period | (J) Period | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|
| Pre-period | Series production | .477* | .162 | .014 |
| | Post-period | .529* | .169 | .009 |
| Series production | Pre-period | -.477* | .162 | .014 |
| | Post-period | .052 | .083 | .820 |
| Post-period | Pre-period | -.529* | .169 | .009 |
| | Series production | -.052 | .083 | .820 |

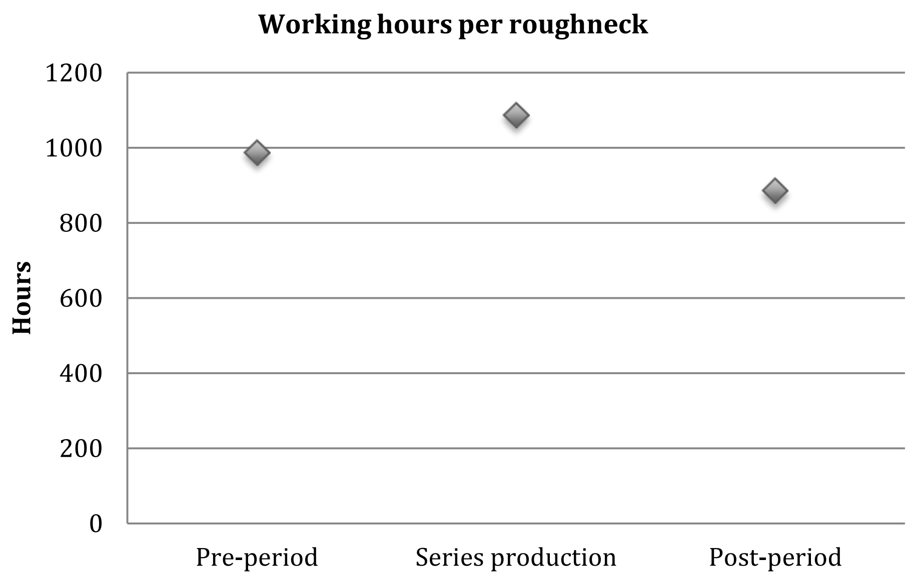
*. The mean difference is significant at the 0.025 level.

The Scheffe-test unveils that there are significantly fewer delayed projects during series production, compared to the pre-period. This analysis strongly suggests that the ATO based PPC system had a significant positive impact on the amounts of delayed projects, supporting the hypothesis stated above.

The test also shows that a small, but significant improvement in projects delays was achieved when comparing the pre- and post-period. This indicates maturation effect, which again reduces the likelihood of the results observed above.

### 6.2.4 Flexibility

As explained in Section 5.2.2, the components were interchangeable before they were tied to a specific order at the CODP. The ATO based PPC system should therefore enable the roughneck unit to respond to changes in for instance a delay in delivery lead-time for a component as identical components scheduled for other projects could be allocated to the more urgent projects. In Section 2.3, working hours per roughneck have been identified as an appropriate measure which can give an indication of the flexibility of operations within the roughneck unit, as a decrease in hours could indicate excess capacity and hence flexibility. To measure if the ATO based PPC system led to a decrease in working hours per roughneck, the amount of hours elapsed per roughneck have been measured across the three periods of time.




As can be seen from the overview of the average amount of hours elapsed per roughneck provided above, the roughneck unit experienced an increase of one hundred hours during series production, compared to the pre-period. During the post-period the amount of hours decreased by two hundred, compared to when series production was used.

The null hypothesis in the following ANOVA test:
*$H_0$: There exists no significant variance in frequency of imperfect deliveries between the three periods measured.*

**ANOVA**

Working hours

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1417888.662 | 2 | 708944.331 | 1.847 | .161 |
| Within Groups | 6.409E7 | 167 | 383756.863 | | |
| Total | 6.551E7 | 169 | | | |

Critical value of F = 3.050

The variance of analysis has an F-value below the critical value of F and therefore shows a weak result of significant differences between the periods in terms of amount of hours elapsed per roughneck, with a significance level well above 0.05. The null hypothesis can therefore not be discarded as the test does not provide an indication of that there exist significant differences between the three measured periods. Hence, the test does not provide any support to $H_4$ stating that the ATO based PPC system has led to increased flexibility.

Findings of the interviews however indicate that the roughneck unit had considerable higher flexibility during series production, compared to the pre- and post-period. The three informants employed in the roughneck unit at the time of series production all state that they experienced less workload during series production, compared to the other two periods. As one key informant explained:

> *Even though most work tasks had not changed, we were able to accumulate the tasks and execute them for several projects at once.*

This suggests that part of the reduction in workload was facilitated by the ATO based PPC system, which made it easier for employees within the roughneck unit to execute their tasks more efficiently. Furthermore, as one key informant explained:

> *During series production it was possible to have a single point of contact responsible for communication with workshops. This single point of contact could take over many of the task that the ER was previously responsible for.*

This suggests that the use of a single point of contact alleviated the amount of work the ER conducted in relation to purchasing of activities and communication with the workshops. During series production the ER's could therefore have a more technical focus on the completion of the projects.

Another evidence of the flexibility during series productions compared to the other periods is stated by one of the key informants:

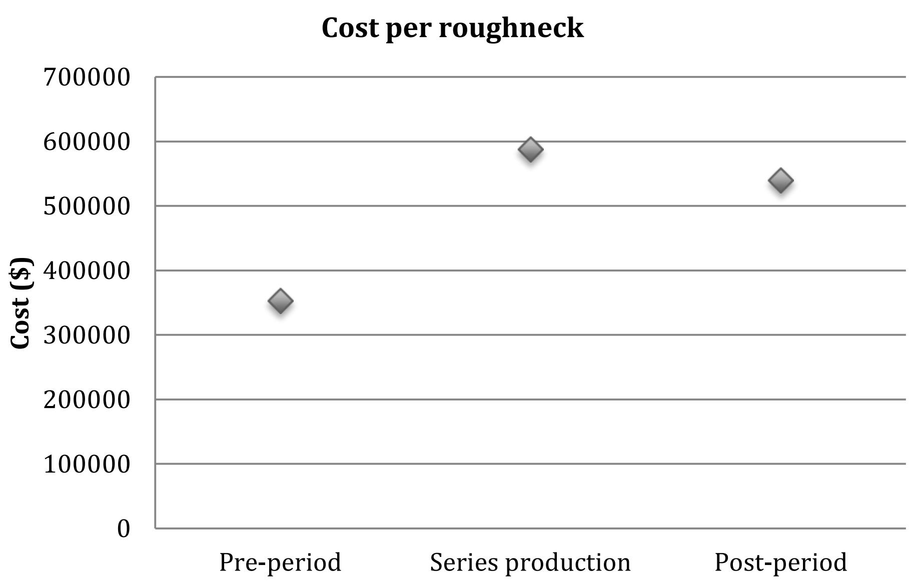
> *During series production we managed with less ER's than we do today, as every ER handled more projects simultaneously.*

While the roughneck unit managed with only three ER's during series production, it consists of six ER's in the post-period. This suggests that the roughneck unit increased their excess capacity making them more flexible in response to changes in demand during series production. However, the key informants state that part of this reduction in flexibility could be attributed to the increase in specific customer requirements per order and the increase in product variety. This made it more difficult for the ER's to keep an overview of what was ordered on each project.

The key informants state that the greatest flexibility was achieved by ordering components on module numbers, instead of project numbers, and the fact that the appropriate documentation was attached to every component. This allowed the roughneck unit to swap the modules between the projects, making the unit highly flexible when customers changed their requirements during the project, when the unit accepted an urgent order, or in case of a breakdown. The modules were then swapped to the project which required the specific module or that was most urgent to complete.

### 6.2.5 Cost

To measure if the ATO based PPC system has had a positive impact on cost in roughneck production, cost per roughneck have been measured.



The above diagram provides an overview of the average cost per roughneck during the three different periods. As can be seen, a two times increase in cost per roughneck occurred during series production, compared to the pre-period, and remained stable throughout the post-period.

The null hypothesis in the following ANOVA test:
*$H_0$: There exist no significant differences in variances of cost per roughneck between the three periods measured.*

**ANOVA**

Cost

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 5.322E11 | 2 | 2.661E11 | 4.274 | .015 |
| Within Groups | 1.040E13 | 167 | 6.226E10 | | |
| Total | 1.093E13 | 169 | | | |

Critical value of F = 3.050

The analysis of the periods measured show a strong result of that there exist significant differences in variances between the different periods in terms of cost per roughneck.

To establish what periods contribute to these variances, it is necessary to conduct a Scheffe's-test.

The hypothesis to be tested in the following Scheffe's test:
*$H_5$: The ATO based PPC system led to a reduction in costs per roughneck.*

**Multiple Comparisons**

Cost

Scheffe

| (I) Period | (J) Period | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|
| Pre-period | Series production | -234530.301* | 82446.488 | .019 |
| | Post-period | -186612.475 | 86296.217 | .100 |
| Series production | Pre-period | 234530.301* | 82446.488 | .019 |
| | Post-period | 47917.826 | 42332.468 | .528 |
| Post-period | Pre-period | 186612.475 | 86296.217 | .100 |
| | Series production | -47917.826 | 42332.468 | .528 |

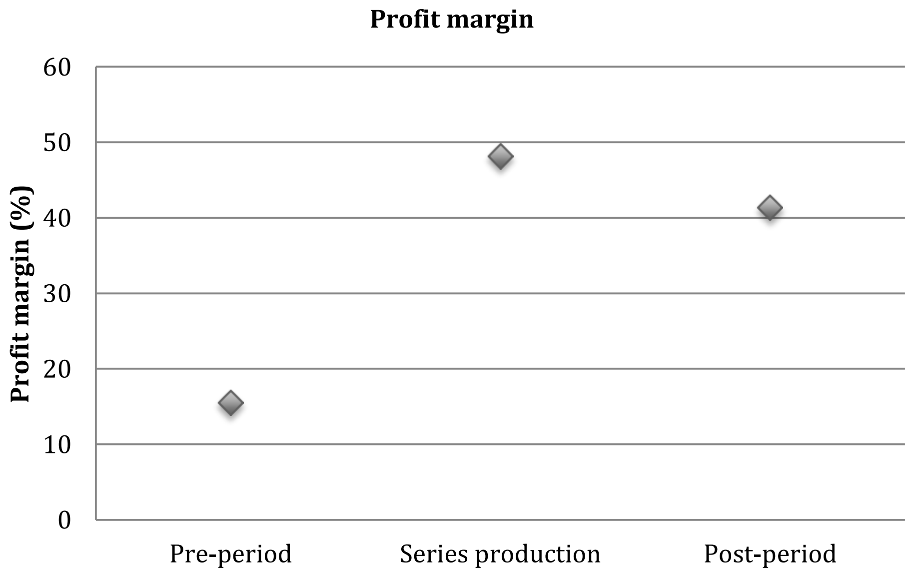
*. The mean difference is significant at the 0.025 level.

The result of the Scheffe's test reflects a considerable increase in cost between the pre-period and the period of series production. A significance level of 0.01 is a strong indication of that the ATO based PPC system has led to increased costs per roughneck.

Furthermore, the Scheffe's test shows that there are no significant changes between the period of series production and the post-period. This indicates that no maturity effects exist, which reduce the likelihood of the result derived above.

### 6.2.6 Value added

Value added is a measure of profitability that can be reflected through the profit margin. To analyse the roughneck unit's ability to achieve a greater sense of value of their MPT-200, as perceived by their customers, the average profit margin has been measured for the three periods of time.




An overview of the profit margin across the different periods is provided in the diagram above. While the profit margin was roughly fifteen percent during the pre-period, it was over three times as large during series production. In the post-period, the profit margin decreased by seven percent.

The null hypothesis in the following ANOVA test:

*$H_0$: There exist no significant differences in variances of profit margin cost between the three periods measured.*

**ANOVA**

Profit margin (%)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 10337.183 | 2 | 5168.592 | 21.469 | .000 |
| Within Groups | 40203.880 | 167 | 240.742 | | |
| Total | 50541.064 | 169 | | | |

Critical value of F = 3.050

As can be seen from the above table, a F-value well above the critical value of F suggests that the null hypothesis should be discarded, as there exist significant differences between the different analysed periods.

To establish what periods contribute to these variances, it is necessary to conduct a Scheffe's-test.

The hypothesis to be tested in the following Scheffe's test:
*$H_6$: The ATO based PPC system led to an increase in profit margin.*

**Multiple Comparisons**

Profit margin (%)

Scheffe

| (I) Period | (J) Period | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|
| Pre-period | Series production | -32.61583* | 5.12668 | .000 |
| | Post-period | -25.79871* | 5.36606 | .000 |
| Series production | Pre-period | 32.61583* | 5.12668 | .000 |
| | Post-period | 6.81713 | 2.63231 | .037 |
| Post-period | Pre-period | 25.79871* | 5.36606 | .000 |
| | Series production | -6.81713 | 2.63231 | .037 |

*. The mean difference is significant at the 0.025 level.

The Scheffe-test strongly indicates, with a significance level well below 0.05, that there are significant differences in profit margins obtained between these periods. The result show that there is a clear indication that the ATO based PPC system has led to an increase in profit margin of the roughneck unit.

There is a sign of maturity effect, as the test show that the roughneck unit experienced significantly higher profit margin in the post-period, compared to the pre-period. This indicates that there exists maturation effect that decreases the likelihood of the result that has been derived above.

The result of the quasi experiment and its supported hypotheses are summarised in the figure below:

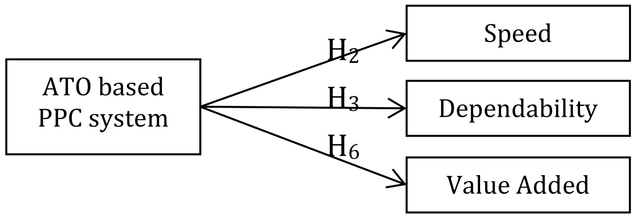



**Figure 6.2:** Research model with significant impacts

Findings of the interviews do not support all the results from the quantitative analysis. In terms of cost per roughneck, two of the key informants claim that the roughneck unit experienced cost reduction during series production due to ordering in larger quantities, which is not in line with the result of the conducted analysis. This indicates that the key informants have an incorrect perception of the performance of the ATO based PPC system in terms of cost. The key informants claim that there was an increase in fast track projects during series production. It is therefore appropriate to make the inference that part of the increase in contract prices during the period of series production can be attributed to the increased amount of fast track projects. As the increased flexibility of the roughneck unit's production capacity allowed them to take on more urgent projects, short delivery lead-time led to additional value added. This resulted in higher contract prices, which the customer was willing to pay. The key informants also confirm that the profitability went down after series production was shut down, and that this reduction was related to an increase in special requirements per order. This had significant implications on operations, and furthermore it limited the possibility to order components in large quantities and thus reduce cost.

In sum, the ATO based PPC system is considered to have had a significant positive impact on the performance of the roughneck unit. However, the results of the quasi experiment show that the improvements experienced in terms of quality and flexibility are not significant enough to attribute them to the success of the ATO based PPC system. Even though, the findings of the interviews suggest that the roughneck unit achieved greater flexibility during the period of series production. The result indicates that the ATO based PPC system has had significant positive impact on dependability, cost and value added. In terms on dependability, delivery reliability was reduced by nearly fifty percent during series production. In terms of cost, the result indicates that despite the fact that cost per roughneck increased significantly during series production, a larger increase in value added resulted in higher contract prices and thus higher profit margins. Only a small reduction in lead-times was achieved. It therefore remains unclear whether this reduction should be attributed to the ATO based PPC system or not.

## 6.3 Qualitative measures

During the collection of data a number of qualitative aspects, elaborated on in Section 2.3, was measured to provide a better understanding of the performance of the ATO based PPC system. The goals of the new system, as well as education of personnel and gaining acceptance and support, will therefore be evaluated based on findings from the interviews. As no raw material or components were ordered on speculation, forecasting and accuracy is not applicable to the evaluation during the period of series production.

### 6.3.1 Education of personnel

Both ahead and during start-up with the roughneck unit's employees, several meetings were held and formal procedures and guidelines for use of the ATO based PPC system were developed. However, the general interpretation of the employees employed in the roughneck unit during the use of the ATO based PPC system is that no formal training program was set up for the users of the system when the system was implemented. As one of the key informants explained:

> *A "learning by doing" approach was applied for education of the system (...) it was not organised systematically.*

The three interviewed key informants that worked in the roughneck unit at the time of the ATO based PPC system claim that the time dedicated to education and the level of training they received was adequate. Even so, two of the key informants pointed out that it could have been organised more systematically.

### 6.3.2 Goals

There is some disagreement as to what the goals of the ATO based PPC system was and how well the goals were communicated from the head of the roughneck unit to the employees. While one of the key informants claim that the goals of the system were well communicated to other colleagues, the remaining two key informants could not render the specific goals of the system. This suggests that there was a lack of communication between the head of the unit and its employees.

### 6.3.3 Support

The general interpretation is that most disciplines and support activities that were affected by series production, and whose support the roughneck unit was dependent on, found it difficult to adapt to the new ATO based PPC system. As one of the key informants put it:

> *As this was a new system, it was hard for the other disciplines and support activities to adapt to it.*

The hydraulic- and electrical department were at first reluctant to adapt to the new system as the new system required a dedicated employee within the departments to handle the hydraulics and electrical components of roughnecks produced in series. Other departments facilitating support activities, such as inventory-, cost and controlling-, and the purchasing department, also found it difficult to adapt to the new system. This was because the system forced these departments to change their routines to accommodate the roughneck unit. As one of the key informants explained:

> *The inventory department found the new system difficult to adapt to. This was due to the fact that instead of grouping all components to one specific project number, as they used to do earlier, the components were grouped into boxes per module. Inventory therefore had to manage considerably more boxes, before the different modules eventually got linked to a specific project number.*

The cost and controlling department on the other hand found the new system to be problematic as they were not able to transfer the cost from the modules to the project before it was delivered to the customer. And as modules for the projects were ordered early in the project phases it lead to increased inventory costs. The fact that the department was not able to immediately expense these inventory costs to a project, contributed to their frustration with the ATO based PPC system. The purchasing department also found the new system somehow difficult. They often approached the ER's at the roughneck unit to check if the necessary components had been ordered, as the purchase orders were not linked to a project number. These other departments simply could not understand why the roughneck unit needed to do things differently than the rest of the company.

### 6.3.4 Gaining acceptance

When it comes to the new ATO based PPC system gaining acceptance, the employees within the roughneck unit seemed to embrace the changes necessitated by the system relatively fast. While two key informants claim there were no employees that showed any signs of reluctance, the third claimed that those who appeared to be reluctant at first, quickly saw the benefits of the system and ended up embracing the system as well.

The evaluation of the roughneck unit during series production have resulted in a number of key findings with regards to the way production of roughnecks was planned and controlled during the time of the ATO based PPC system. Overall, the quantitative analysis complimented by the findings of the interviews, largely supports that the ATO based PPC system have in fact had an effect on the performance of the roughneck unit. The quantitative analysis concludes that the most significant changes experienced were in terms of increased dependability and profitability of the roughneck unit. However, the quantitative analysis does not conclude that the ATO based PPC system supported the overall objective of the ATO operations strategy, which should become evident by an increase in speed and product quality. The qualitative aspects analysed uncovered some weaknesses of the ATO based PPC system and how it was implemented. The main findings was that the goals of the ATO based PPC system were not communicated well to the employees of the roughneck unit and that there was a lack of support from other departments within NOVN. This is in line with the most frequent problems encountered during PPC system implementation, as explained in Section 2.3. There is reason to believe that these problems have had a negative impact on the performance of the ATO based PPC system. In sum, it can be concluded that the roughneck unit's ATO operations strategy, in comparison to the current ETO operations strategy of NOVN, appeared to be more effective in meeting customer requirements in terms of dependability and value added. However, it did not sufficiently support the overall objective of the operations strategy. Therefore, the ATO operations strategy did not successfully serve as the interface between the overall objective and operations.

# 7 RQ2: MRP IN AN ETO ENVIRONMENT

As mentioned in Section 2.4, an MRP system is largely constrained by a company's product-, market- and process characteristics. These characteristics will therefore influence how well the MRP system is able to accommodate the PPC needs of NOVN, and hence the implementation of an MRP system into an ETO company, such as NOVN. This chapter gives an extensive review on the applicability of a MRP system within NOVN, thus answering RQ2.

The stages that add most value to NOVN's customers, and that are considered to be NOVN's competitive advantage, are the enquiry-, design- and engineering stages. As mentioned in Section 5.1.1.2.3, these stages are also considered to be NOVN's main bottlenecks, and they are therefore subject to PPC. Information regarding cost of inputs, processing cost and contract price are considered to be of paramount importance for NOVN to be able to execute PPC of its operations. In respect to this, the PPC needs of NOVN throughout these stages have been identified and explained. An analysis of how an MRP system will accommodate these and further support NOVN's operations strategy will follow. Lastly, the MRP's effect on the company objectives of NOVN will be discussed.

Ideally, the new PPC solution should have been implemented as part of this research so that the impact of the MRP system could have been measured and verified. Unfortunately such a research strategy was not possible within the available time of the study. Instead, expected impact was substantiated through a combination of logic reasoning and joint reflections with key informants.

*Incomplete BOM's*

The product-, market- and process characteristic of NOVN makes NOVN highly dependent on operating with incomplete BOM's throughout project lifecycles. The importance of incomplete BOM's was further underlined by one informant, which predicted it to become the biggest challenge when implementing the MRP system. There are several factors that make NOVN dependent on operating with incomplete BOM's, and these will now be explained.

The high degree of customisation opportunities offered by NOVN, as well as their early involvement with the customer will lead to frequent engineering changes. This means that the

BOM need to be frequently updated and that it tends to not be complete before in the later stages of the project.

As NOVN ‘s products often consist of a combination of standard components and components that are customised, specific material with long lead-time is often necessary to purchase in the early stages of a project in order to reduce lead-time and stay competitive in the market. NOVN is therefore dependent on building the BOM while engineering is conducted, and for it to be released gradually with partial information so that engineering, purchase and production orders for long-lead items and components can be issued while others are still being defined. However, BOM’s at the early stages of a project tend to be inaccurate as the specifications and scope of an order is still uncertain.

One of the assumptions of the MRP system mentioned in Section 2.4.4 is that the file data, which consist of the input into the MRP system, is accurate and complete to facilitate full traceability of a products items. In the case of NOVN, as explained in the previous paragraphs, this will not be fulfilled until the later stages of the project. Although it is possible to release several BOM’s in the MRP system as specifications of the customer order becomes gradually known, the items cannot be reconciled back into one BOM. Incomplete BOM’s will therefore not provide full traceability. Another important concern is that when a project progresses, the BOM is continuously updated. Such frequent updates of the BOM will lead to MRP system nervousness, as mentioned in Section 2.4.6.

*Non-physical processes*

Within NOVN there are various projects that are run simultaneously, all at different stages of completion. To monitor the development of a project it is therefore important that all processes can be measured in terms of progress. Processes within enquiry-, design- and engineering stages in NOVN are of non-physical character. While physical processes are easy to measure, the partly creative non-physical processes makes it is difficult to distinguish production phases similar to the physical processes. The fact that products are customised to customer requirements and necessary processes tend to be different for every project, complicates this matter even further. An MRP system cannot cope with non-physical activities, and is therefore not able to accommodate the need for determining the progress of projects.

Non-physical processes have implications for cost allocation as well. Overview of actual cost and resources per project is considered to be important information for NOVN as it provides the basis for future contract prices for similar projects, measure company performance, summarizes contract information and provides the basis for cost reduction programmes. For every project within NOVN a cost budget is made followed by an actual cost budget after the project is completed. However, the MRP system is not able to link for instance production hours and used material to a given project. Thus the MRP system does not facilitate an accurate computation of the actual cost of projects, and this will therefore need to be performed manually.

*Continuous processes*

Due to the product characteristics of NOVN, customer orders are handled as projects. Its production processes are therefore considered to be continuously interdependent on each other. For instance, the design of a product may appear inadequate during the assembly process, and therefore needs to be modified before it can be furthered assembled. However, one of the assumptions of the MRP system is that processes are independent from each other and can be completed on its own. The MRP system will therefore be constrained by the processes of NOVN, as it will not be able to accurately calculate when a component is needed.

*Non-interchangeable items*

While an MRP system regards every item with identical item number as interchangeable between customer orders, this is not straightforward within NOVN. For instance, when there is a breakdown of a component on an urgent project, it is not necessarily straightforward to consume identical components of another project. This is due to the fact that every component has its own set of documentation and is linked to a specific project. The MRP system however will treat these items as being identical, which will lead to the MRP system reporting incorrect inventory status. Furthermore, it may lead the MRP system to not issue necessary purchase orders, as the system will report that the item is already in stock.

*Uncertainty in supply*

There is considered to be high uncertainty in supply of critical components, such as long lead items necessary to finalise NOVN's projects. The data relating to lead-times and production times of components supplied to NOVN are therefore based upon estimates. Because of this, the unpredictability of the market often leads to variances between planned and actual lead-times. In the MRP system lead-times for each component is considered to be deterministic, and the uncertainty is therefore not accommodated by the MRP system. Wrongful predictions will therefore lead to either excess inventory or longer lead-times for the final product. Furthermore, frequent changes in lead-times within NOVN will lead to frequent updates of the MRP system, which in turn will result in MRP system nervousness.

*Uncertainty in capacity*

When NOVN receives a customer order, specifications and scope is only partially known, and will become more certain as the project progress. As required capacity is determined by the order specifications, the required capacity to fulfil a customer order remains uncertain as well. A corresponding PPC system must therefore facilitate capacity planning under uncertainty. Furthermore, a relative high fraction of the available engineering capacity is applied for quotation preparation at the customer enquiry stage. This may interfere with the amount of engineering capacity required for realising the already placed customer orders. This makes available production capacity for current orders uncertain. However, the MRP system does not take this variation in capacity into consideration, thus leading to either a clogged up production chain, or excess capacity.

*Lot-sizing technique*

As the customer orders of NOVN are one-of-a-kind, inventory are mainly directly related these customer orders. Because of this, NOVN does not keep stock of materials and components as the risk of inventory becoming obsolete is considered to be too high. NOVN therefore applies the lot-for-lot technique, which minimizes the holding costs and reacts to all schedule changes in an MRP system, as mentioned in Section 2.4.6. Because of this, the lot-for-lot technique increases MRP system nervousness, and will thus not be applicable to an MRP system.

From the above discussion it is clear that many of the MRP drawbacks identified in Section 2.4.6 will become evident when implemented in an ETO company such as NOVN. The most evident drawback is the MRP system nervousness, which relates to the main feature of an MRP system, namely the rescheduling function. Although this function is an important technique for quickly responding to the market, its associated nervousness can destroy well-planned MRP schedules.

Now that the PPC needs of NOVN and the MRP system ability to accommodate them have been explained, the system's impact on NOVN performance will be evaluated. Flexibility and quality have been identified as the most important company objectives of NOVN, which are also among the identified benefits of an MRP system. A successful implementation should therefore maintain or improve NOVN's level of flexibility and quality. This flexibility is enabled by the rescheduling effect of an MRP system; as the MRP system easily react and adapt to changes in the market place by rescheduling material requirements for a specific change in a customer order that it provides. However, the high supply and demand uncertainties, as well as the product characteristics of an ETO company such as NOVN, is expected to lead to too frequent updates of the system. This will further lead to MRP system nervousness, which is expected to inhibit the flexibility of NOVN's operations strategy. In terms of product quality, the MRP system is not expected to have direct impact on this company objective, as the system is only concerned with providing the right part, and to meet the schedules for completed products. However, the MRP system is expected to free up resources, which in turn can be redirected to improve product quality. In respect to NOVN, the set of actions required to implement the changes prompted by the MRP system followed by frequent updates of the system, are expected to be too comprehensive and demand too much resources, and thus consume any eventual freed up resources. The MRP system is therefore expected to weaken the overall performance of NOVN in terms of flexibility and quality.

*Other factors affecting implementation of MRP system*

The education level of employees is expected to have an effect on the implementation of an MRP system. Most of the workforce of NOVN consists of employees with higher education, especially within engineering. In this regard, key informants claim that NOVN's highly skilled workforce have a need to unfold themselves creatively by being able to perform product innovation, regardless of whether it is required in order to meet customer requirements or not. Such product innovation leads to frequent engineering changes. The education level of NOVN's employees can therefore inhibit a successful implementation of the MRP system, as frequent engineering changes leads to MRP system nervousness.

The education level of NOVN's workforce is also expected to have an impact on the MRP system being able to gain acceptance of the employees. Information gained in the interviews indicates that employees will be reluctant to adapt to the new system. This is further complicated by the high education level of employees, which suggests that NOVN's workforce is autonomous. It is therefore expected that employees of NOVN will find it difficult to adapt to a rigid system, like an MRP system, as such a system has lower requirements for autonomy of the workforce.

As previously mentioned in Section 2.4.7, company size may have an impact on the company's expectations of the MRP system. As NOVN is considered to be a large company, it is reasonable to believe that NOVN has higher expectations of the MRP system than smaller companies. In the conducted interviews with key informants of NOVN it became clear that the informants' expectations to the new MRP system are that the new system will contribute to making it easier to keep an overview of multiple projects simultaneously. The interviews also revealed that the system will make it easier for the employees to do their job more efficiently. Considering that several literature studies (cf. Table 2.2) have found MRP systems to be non-applicable to an ETO company, this suggests that the result of the implementation will result in large gaps between the NOVN's expectations and the MRP systems actual performance.

NOVN's employee's previous experience with similar PPC systems is also expected to have an impact on the implementation of the MRP system. The shutdown of series production of roughnecks is well known among the employees of NOVN. It is therefore reason to believe that these incidents can lead to the employees having negative attitudes towards the new MRP system, or any new system for that matter. A successful implementation requires employees' competence and willingness to change, and employees are more prone to support changes if they are ready to make these changes and if they believe in them.

One informant underlines the importance of culture in relation to implementation of an MRP system. He further explains that his experience with NOVN's colleagues in the US tells him that Americans have very different work attitudes compared to Norwegians. Culture and its impact on MRP implementation will therefore be further elaborated in Chapter 8.

From the above discussion it is clear that product-, market-, and process characteristics is too much of a constraining factor to the MRP system; The PPC needs in the continuous cycle of engineering as well as the need for updating BOM's and recalculating schedules within NOVN is not accommodated by an MRP system and thus makes the system prone to MRP system nervousness. MRP system nervousness will further lead to the system becoming inflexible. Furthermore the frequency of updates and the set of actions required to implement these changes are too comprehensive and could therefore lead to fluctuating capacity utilisation resulting in costly instability. It is therefore a clear misalignment between the decision support provided by MRP systems and the decision support required by NOVN at the customer enquiry-, design - and engineering stages, which are the stages within NOVN that are regarded as their competitive advantage. Other factors, such as the education level of NOVN's employees, company size and culture, which will be elaborated on in the following chapter, has also been identified as factors that can have a negative impact on implementation of the MRP system. This clearly indicates that the MRP system will not function optimally in an ETO company, which is consistent with findings from the literature study in Table 2.2.

# 8 ADDITIONAL ELEMENTS TO CONSIDER WHEN IMPLEMENTING AN MRP SYSTEM

During one of the interviews a key informant answered culture, when asked what is the biggest difference between NOV in the US and NOVN. The informant further elaborated this by saying that the two countries have different work attitudes. Because of this response it was decided to further investigate different aspects impact on MRP implementation, with a particular focus on culture.

Section 8.1 describes the need for considering culture differences when implementing an MRP system. Section 8.2 elaborates on why it is important for NOVN to take culture into consideration when implementing the new MRP system. Section 8.3 concludes the chapter and elaborates on other aspects that are important for NOVN to take into consideration when implementing the new MRP system.

## 8.1 Cultures influence on MRP implementation

Several authors argue that cultural preferences intensify MRP implementation problems as companies who implement these types of systems suffer a major change in their organisational information system (Davison, 2002; Olson et al., 2005; Sheu et al., 2004). Through a number of studies conducted on culture and its effect on MRP implementation the conclusion has been that it is necessary to take culture into account when implementing MRP systems in different countries as culture has a significant influence on MRP implementation (Davison, 2002; Hong & Kim, 2002; Olson et al., 2005; Sheu et al., 2004; Soh et al., 2000). Because earlier studies have identified culture as one of the most important factors in determining an MRP systems success or failure, and because research have shown that failure to adapt the MRP system to fit a company's culture can lead to large cost overruns and underperformance (Krumbholz & Maiden, 2001; Leidner & Kayworth, 2006; Sheu et al., 2004), the authors of this master thesis believes it is important for NOVN to focus on culture when implementing the new MRP system. This importance is further amplified as the MRP system that NOVN is going to implement is developed in America, and because Sheu et al. (2004) and Carton and Adam (2003) found, in their studies on national differences in MRP adoption of companies using MRP systems provided by global suppliers, that MRP implementations and adoption can be more difficult in Europe than in North America. The reason for this is that European companies have a more complex culture, compared to more homogenous standards in the US, which essentially makes a successful implementation of a multi-national MRP system in Europe very difficult. This argument is further supported by the results from Olhager and Selldins (2003) research on Swedish manufacturing firms. They found that because of cultural and national issues, Swedish companies, unlike companies in other countries such as the US, generally prefer European and Swedish MRP suppliers to large global suppliers. This suggests that culture differences in Norway and the US can affect the implementation of a US developed MRP system in a Norwegian based company.

## 8.2 The influence of culture on the implementation of an MRP system in NOVN

Hofstede developed a cultural dimensions theory consisting of five dimensions that is widely supported for capturing cross-country differences. These dimension are power distance, uncertainty avoidance, individualism, masculinity, and long-term orientation (Albers-Miller & Gelb, 1996; Baskerville, 2003; Fernandez et al., 1996; Lynn & Gelb, 1996; Soares et al., 2007; Yoo et al., 2011). Even though all of these dimensions are important to take into consideration, the authors of this master thesis believes three dimensions are relevant for explaining in what way cultural differences can affect the implementation of an MRP system. These three dimensions are power distance, individualism, and uncertainty avoidance, and the following sections discusses their relation to the US, Norway, and MRP implementation.

*Power distance*

Compared to the US, Norway scores relatively low on the dimension of power distance. This means that power is decentralised in Norway and that employees in Norwegian companies strive for equalisation of power and opportunity for everyone, whilst the members of a hierarchical society such as the US, accept that inequality of power and wealth will continue to grow within the society (Cebuc & Iosif, 2008; The Hofstede Centre, 2014). This suggests that MRP implementation can be affected by a company's structure due to the culture of each company, which characterises its way of doing business. If the MRP system requires that NOVN must change its organisation structure it can lead to an incorrect application of data, which increases NOVN's employees resistance to change. This can lead to the MRP system being configured with the existing system, thus making it difficult for the new system to offer the improvement it is meant to offer. When implementing a new system, it is therefore vital to have support from top management to achieve a successful implementation. Examples of support could be delegating and relying on the abilities of employees on lower levels, which can often be seen in Norwegian companies.

*Uncertainty avoidance*

Uncertainty avoidance can be seen as the extent to which people feel threatened by uncertainty and ambiguity and try to avoid these situations (Hofstede & Hofstede, 2014; Soares et al., 2007; Yoo et al., 2011). Even though both Norway and the US fall in the middle of the range with their scores on uncertainty avoidance, companies within these countries can still experience resistance towards change as most people dislikes change (Cebuc & Iosif, 2008; Hofstede, 2011; The Hofstede Centre, 2014). This suggests that the implementation of the MRP system can be affected by NOVN's employees' willingness to change. In regards to a new information system, this resistance among NOVN's employees can occur as they might believe that the new system will change the way they work and increase their workload, or that their job will be redundant as the new system automates their work. NOVN can reduce this resistance by informing its employees, as early as possible, about the change of PPC system, how the new system will affect the employee's jobs, as well as how the implementation is going to be conducted. This way the employees may feel more involved in the implementation process. However, it is important to be aware of that resistance to change and lack of adaptability are issues that are difficult to manage and that will require much energy, time and money from top management if an implementation is going to be successful.

*Individualism*

Both Norway and the US can be seen as individualistic societies. Being an individualistic society means that individuality and individual rights are crucial, that personal opinions are valued and expressed, and that self-interest comes before the interest of a group (Cebuc & Iosif, 2008; The Hofstede Centre, 2014). Individualism can be reflected in how the implementation of the MRP system can be affected by individual or group interests, including the selection of the implementation team and training activities. The choice of implementation team is a critical phase, and NOVN must not underestimate the importance of involving the right employees in this process. Another critical phase for achieving a successful implementation is the training phase. It is important that NOVN's employees are trained in how the new system works and how it can be fully exploited. This training process is, among others, dependent on the employee's perception of the new system, how open the employees are to change, and the ease with which the new system suits NOVN.

The above discussions show how different companies have a desire to retain their own strong cultural identity and way of doing things. For instance, NOV in the US carries out most of the work themselves, whilst NOVN outsource much of its construction work to countries with cheaper labour, such as Poland. Another example of cultural differences between Norway and the US is how engineers work: in Norway the engineers have a desire to use their education and be innovative and not to do the same thing over and over again, whilst engineers in the US do what is expected of them and do not try to make improvements all the time.[3]

Ignoring the differences in culture will not necessarily lead to failure of implementation, but awareness of these cultural differences and preferences will definitely improve the MRP implementation. This implies that a one-size-fits-all approach is not likely to be successful, which means that the MRP system must be adapted to fit NOVN's culture.

## 8.3 Other aspects that NOVN must take into consideration when implementing the MRP system

In addition to the arguments mentioned above, NOVN must also consider the importance of communication and sharing of information on all levels as lack of communication towards and from top management can generate misunderstandings that can lead to delays in the implementation process. Good communication, as well as global collaboration, will often lead to faster progress.

Several authors argue that positive organisational factors, in particular top management, in large extent contribute to success when adopting new technology (Bowonder et al., 1994; Hwang et al., 2004). The reason for this is that top management can stimulate change by communicating and reinforcing values for the organisation. This is possible as top management has the greatest capacity and status in influencing the behaviour of other members and in resource allocation in the organisation (Thong et al., 1996). With strong support from top management, the resources that are necessary for conducting the adoption and implementation of the new system can be mobilised when needed. This prioritisation can

[3] Source of information is collected from the conducted interviews.

encourage the entire organisation to focus on the implementation, as well as motivate employees to adapt to the new system (DeLone, 1981). This demonstrates that the greater the top management support is in NOVN, the easier it will be for NOVN to overcome the difficulties and complexities faced with the implementation and adoption of the new MRP system.

When implementing and adopting systems of large magnitude, which NOVN is about to do, it is important to remember to not rush the vendor selection process. In fact, this process should be given a great deal of attention. Most vendors are helpful in providing complete products and assisting in the adoption process, but it is still dependent on expertise of internal in-house employees. The most important reason for this is to make sure that the new system is customised and integrated into the company, and thus is compatible with the existing systems of the company (Michell & Fitzgerald, 1997). As NOVN already have selected their vendor of the new MRP system, and because they already are working on customising the new system to suit their needs and existing systems, this subject will not be further elaborated.

Another important factor for NOVN to consider is to what degree the new MRP system is consisting with the existing vision, past experiences, and needs of NOVN. The compatibility of the new MRP system and its users, as well as the operational procedures of NOVN, can influence the adoption of the new system as well as slow down the adoption process and discourage the end users (Thong, 1999). It is therefore particularly important for NOVN to consider as many scenarios as possible. This can be done by including the different departments in the adoption and implementation process and listen to their requirements and needs for being able to do their job. This is especially important for NOVN as they are about to implement an American developed program into a Norwegian based company. Because of this, the authors of this thesis recommend NOVN to take their time with the implementation process, listen to the employees concerns and needs, and do their best to make sure these concerns and needs are taken into consideration. It is also recommendable that NOVN specify to its employees that when the new system is implemented it will take some trial and error until the system works optimally. NOVN should also; to the extent it is possible, implement the new system in relevant departments as a trial run, before the system is implemented into the entire organisation. This trial run should cover at least an entire calendar year. By doing this, it will be possible to discover issues and weaknesses that must be resolved before the system is implemented in the entire organisation.

The above discussions emphasises that the early stage of implementation is the most critical. At this point the foundation of the implementation is laid down, and it is from these foundations that the system is customised to meet the requirements of NOVN. The training of the systems users, which here is NOVN's employees, is also essential because the employees are going to manage the system on a day-to-day basis. This means that the employees must be made fully aware of the MRP systems capabilities to exploit the system. The authors of this master thesis therefore recommend NOVN to give its employees thorough training of the new MRP system, as this will increase the chances for achieving a successful implementation.

# 9 CONCLUSION

This final chapter summarises the research findings of the master thesis. A concise answer to each of the research questions as well as a summary of the research findings in relation to the overall research objective is articulated in Section 9.1, along with a clear statement of the extent to which findings can be generalised in Section 9.2. Finally, the scope and limitations of the research conducted, and the avenues for further research are identified in Section 9.3 and 9.4, respectively.

## 9.1 Answers to the research questions

In this research the authors have investigated if implementation of an MRP system supports the operations strategy of an ETO company by conducting a case study of an ETO company that is about to implement an MRP system; NOVN. This case study has resulted in a better understanding of the research objective, as well as the specific research questions that the objective was broken down into. Therefore, this master thesis contributes new knowledge to the research literature and for other researchers. Moreover, the findings of this master thesis can be utilised as a guideline for future research in similar research areas.

The literature review that was carried out was first and foremost used to read up on relevant theory that was applicable for the research. Further work with the literature provided an insight into what previous research had been conducted on the research topic of this thesis. The authors found that a relatively little amount of research has been carried out on the impact of an MRP system in an ETO company. This resulted in both a challenging and time-consuming process of finding applicable literature.

The case study conducted required a profound understanding of NOVN's engineering processes. The case study was therefore time-consuming as the NOVN's processes are both complex and to some extent difficult to comprehend. To make it possible for the case study to be conducted, it was important that NOVN provided the necessary facilities for the research to be conducted in a satisfactorily manner.

### 9.1.1 RQ1: What is the impact of an ATO based PPC system on an ETO company?

The findings of RQ1 show that the roughneck unit's ATO operations strategy, in comparison to the current ETO operations strategy, was more effective in meeting customer requirements in terms of dependability and value added. However, the findings also suggests that the ATO based PPC system did not support the overall objective of the ATO operations strategy, which was to improve delivery lead-time and product quality. The main reasons for the ATO based PPC systems' performance has been identified to be miscommunication of goals and lack of top management support.

### 9.1.2 RQ2: How can an MRP system be used to support the PPC needs of an ETO company?

The findings of RQ2 show that there is a clear misalignment between the decision support provided by an MRP system and the decision support required by an ETO company. The product-, market- and process characteristics of an ETO company are too much of a constraining factor to the MRP system, which may lead to reduced competitiveness. Furthermore, the research suggests that organisational factors, such as education level of employees, company size and culture have significant impacts on implementation of an MRP system.

The result of this research supports the view of Bertrand and Muntslag (1993) and Little et al. (2000), which is that an MRP system does not perform satisfactorily in a company with an ETO operations strategy. The research findings suggests that the main challenge of implementing an MRP system in NOVN is MRP system nervousness, which could reduce the company's flexibility and hence its competitiveness. NOVN should also learn from past experiences with implementing PPC systems and avoid miscommunication of goals of the new MRP system, as well as ensuring a dedicated top management visible for the organisation as a whole. Culture and its potential impact on the implementation of an MRP system in NOVN have also been identified as an important factor affecting successful MRP implementation. Furthermore, findings suggest that additional elements, such as a supportive top management, early involvement of the employees and adequate training, will increase the chances of achieving a successful MRP implementation.

### 9.1.3 Summary of research findings in relation to the overall research objective of the thesis

Recall that the overall research objective is to *investigate if implementation of an MRP system supports the operations strategy of an ETO company*. Chapter 2, which makes up the theoretical background of the thesis, argues that achieving a strategic fit between a company's operations strategy and its product-, market- and production characteristics are a key determinant to increase the company's performance and achieve long-term success. Furthermore, the strong link between the market requirements and operations strategy concerns the choice of a PPC system. How to assess a PPC system's impact on a company's performance is further explained by using five performance measures and other subjective measures. A review of the PPC system MRP establishes the system's main functions, as well as its advantages and drawbacks. The main objective of the MRP system is to provide the right part at the right time and to meet schedules for completed products. This suggests that the MRP system's main advantage is its rescheduling function, while nervousness is its main drawback. Finally, a literature review on the use of an MRP system in an ETO environment is undertaken and unveils that there is a lack of literature on the MRP and ETO relationship. The small amounts of literature that have touched upon this relationship have concluded that an MRP system will not function optimally in an ETO company. Chapter 3 presents the overall research objective of the thesis and its specific research questions. It also explains the different variables used to test the formulated hypotheses. Chapter 4 expands Chapter 3, explaining how research methods are applied in the study and linking these with the research questions. The case study conducted is a mixed method research using both descriptive and exploratory research design in terms of quasi experiment and interviews. Collected data was analysed using ANOVA and Scheffe's test, as well as content analysis. Chapter 5 introduces the case study company NOVN and its product-, market- and production characteristics. This chapter also elaborates on the ATO operations strategy of the roughneck unit, and its ATO based PPC system. A relationship between the PPC systems impact on a company's performance and the five performance measures and other subjective measures was established in the theoretical background. Chapter 6 investigates what impact the ATO based PPC system had on the roughneck unit and the reason for this impact. Findings suggests that the ATO based PPC system did not support the main objective of the ATO operations strategy mainly due to miscommunication of goals and lack of top management support. Chapter 7 investigates the applicability of a MRP system within NOVN based on the main features of the MRP system defined in the theoretical background. Findings suggest that there is a clear misalignment between the decision support provided by an MRP system and the decision support required by an ETO company. Lastly, based on findings from the interviews, additional elements to consider when implementing an MRP system has been discussed in Chapter 8, with a particular focus on culture.

## 9.2 Generalizability

While this master thesis is grounded in the MRP and ETO literature, it focuses on the oil and gas industry. The case study and its related interviews are all conducted within the oil and gas industry. Therefore this thesis only focuses on the potential to generalise to the ETO oil and gas industry, rather than the wider ETO sector.

## 9.3 Scope and limitations

PPC and MRP is a large research area involving many aspects and variables on different planning levels, and while validity concerns were addressed in Section 4.5, there are inevitable limitations associated with the research and the methods adopted to conduct the research. Because the scope of this research is to investigate if implementation of an MRP system supports the operations strategy of an ETO company, this research brought with it the following limitations:

- Because the thesis has a broad research question, and because the case study only included one unit within a large company, the results must be viewed with some caution in regards to generalizability.
- The conducted research is based on a non-sophisticated manual system that is not found in any literature. However, the authors, in collaboration with their contact person at NOVN, have come to the conclusion that the system can be applied as a measure for the purpose of the research.
- Although parts of this research attempted to answer the research questions specific to the use of an ATO based PPC system, the thesis used traditional MRP theory as its basis. This meant that the focus would be on basic functionalities of a traditional MRP system, and not the ATO based PPC system. Because of this the results must be viewed with some caution. To the extent that these systems are found to adhere to MRP theory the results of this research can be applied to the ATO based PPC system.
- As the main competitive advantage of NOVN lies in its enquiry-, design- and engineering stages, which are also considered to be the company's main bottlenecks,

this research only focused on analysing the implementation of an MRP system in respect to the PPC needs at these stages.

- Due to NOVN's limited use of the ATO based PPC system; the long-term effects of an MRP system were not studied.
- To conduct the research requested by NOVN, the company granted the authors of this thesis access to facilities, key informants and data required to carry out the research. A contract has regulated the details of the use and publication of company data and information. Therefore, only certain information provided by NOVN is published in this research.
- The presented findings, based on the qualitative data gathered in this master thesis, are the authors' own interpretation and evaluation of the facts and research evidence. Interpretations must therefore be viewed with some caution.

## 9.4 Further research

This research has added structure to a relatively unchartered research field. Hence, a range of future research avenues can be identified. Constraint relating scope, time, finance and access prevented the uptake of these areas. Without these constraints, the authors of this thesis is confident that the results of a more extensive research would provide a more comprehensive framework that will give NOVN a much better understanding of how the implementation of an MRP system can support their ETO operations strategy.

For future research on this topic, the authors suggest that other researchers with larger resources and more available time go more in depth and use multiple cases and units. A more elaborated research would be possible to achieve by looking into other units within NOVN that also have used the ATO based PPC system. This would provide more data, thus making it possible to compare results from several units.

It would be of interest to perform the same research in different industries, such as shipbuilding, tool making and construction. From such research it would be possible to gain a more complete picture of the phenomenon and to generalise findings more than the authors were able to do in this research.

It would also be of interest to use other research methodologies, such as a survey and time series experiment, to see if they provide the same results, thus confirming the results received in this research. As well as make a more thorough analysis of some of the factors that may have had an impact on the results of this research. An example could be to investigate to what extent the financial crisis from 2007 had an impact on the decision to abandon the ATO based PPC system used by the roughneck unit.

As some of the informants indicated that culture and cultural differences could have a major impact on the implementation of an MRP system, it would be of interest to perform an extensive research on this topic and the obstacles it can lead to.

Another possibility would be to extend the research to also include how an ETO company can mitigate MRP system nervousness.

This overview of further research topics are far from complete, however it gives an idea of how extensive the research possibilities of ETO and MRP are. It also provides an indication of that MRP systems are here for the long haul and that their impact on different operations strategies will need to be studied on an on-going basis.

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# APPENDIX

# Interview guide

## General questions

<u>NOV</u>

- What do you think is the most important performance measure of NOVN?
- What do you think are qualifying and order winning factors?
- Where do you believe the majority of NOV's products are in the PLC?

## Roughneck

<u>Individual characteristics</u>

- How long have you worked at NOVN?
- What is your current position and responsibilities?
- What was your role during the implementation of the previously used serial production system?
- What were your specific responsibilities?
- How long were you in this position?
- How many employees worked in the roughneck unit during the use of the system?
- Can you explain what the roughneck unit do?

<u>MRP (serial production system)</u>

- What is your knowledge on serial production?
- What do you think are the main advantages and disadvantages of a serial production system?

<u>Motivation and support for implementing MRP</u>

- Who took the initiative to implement the serial production system?
- Why was it decided to introduce the serial production system in this unit?
- What was the goal?
- What did you think about the goals clarity and relevance?

### The evaluation of the implementation

Evaluation of system efficiency and user-friendliness

- In what way did you experience that it was easier to gain access to necessary information?
- In what way did you experience that the information you received from the system was reliable?
- In what way did you experience that employees became more efficient after the implementation?
- What kind of feedback did you receive from the employees regarding the system?
- In what way did you experience that the employees were reluctant to adapt to the system?
- In what way did you experience increased customer satisfaction after the implementation?

Evaluation of the results

- What were the results of the implementation, and how were they measured?
- Did you, in your opinion, experience better competitiveness through the usage of the system?
- Why was it decided to shut down the system?
- In your opinion, do you believe one could have achieved better results if you got to continue the production under the serial production system over a longer period of time, than what was the case?
- Describe how you feel the system satisfied the main goals?

## Oracle (The new MRP system)

Motivation and support for the implementation of Oracle

- Are you aware that Oracle will be implemented in NOVN?
- Based on what you know, who took the initiative to implement Oracle?
- Based on what you know, what are the main goals NOVN want to achieve by implementing Oracle?

### Planning the implementation of Oracle

- What specific results do you expect from this implementation?

**The use of MRP**

BOM / MPS / inventory

- In what way do you believe that Oracle will change the BOM's accuracy?
- In what way do you believe that Oracle will change the MPS's accuracy?
- In what way do you believe that Oracle will change inventory's accuracy?
- To what extent do you believe that departments must be computer based to support inventory, BOM and MPS, and why?

**Evaluation of implementation**

Evaluation of system efficiency and user friendliness

- In what ways can Oracle help make your job easier?
- Do you expect that the introduction of Oracle will contribute to easier decision making, and in what ways?
- In what way do you expect that the introduction of Oracle will make it easier to access necessary information?
- In what way do you expect that the information provided by Oracle is reliable?
- Do you expect that the employees will do a more effective and efficient job after the implementation?
- Do you expect that employees will be reluctant to adapt to Oracle?
- Do you expect increased customer satisfaction after implementation?

Evaluation of the results

- How do you think the result of the implementation of Oracle should be measured?
- Do you expect better competitiveness using Oracle?

Evaluation of Oracle

- In your opinion, what are the strengths and weaknesses of Oracle?
- In your opinion, in what way is Oracle compatible with the operations and production processes that are performed within NOVN?
- In your opinion, how must Oracle be tailored to fit NOVN?

- What do you believe are the critical success factors for the implementation of Oracle and why?
- In regards to the introduction of Oracle, what do you believe are the most significant implementation issues?

Lastly

What do you believe are the biggest differences between NOVN and the rest of NOV?