



NTNU – Trondheim
Norwegian University of
Science and Technology

Capability Maturity Model for Organizational Competence in Production Scheduling and Control

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Mechanical Engineering

Submission date: June 2015

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MASTER THESIS
SPRING 2015
for
stud. techn. Sven Vegard Buer

**CAPABILITY MATURITY MODEL FOR ORGANIZATIONAL
COMPETENCE IN PRODUCTION SCHEDULING AND CONTROL**

Most studies have solely focused on technical aspects of production scheduling and control, addressing the development and implementation of new or existing analytical models for different types of manufacturing environments. However, recent studies have shown that organizational factors have a significant impact on the production scheduling and control performance, regardless the industry type. Hence, there is a growing need for research in this area.

Through a project thesis conducted in the autumn of 2014, the student has proposed a capability maturity model for organizational competence in production scheduling and control. This framework aims to aid different production scheduling and control environments in measuring their competence of taking organizational factors, which may have an impact on the effectiveness, into account. The model is supposed to be used both as a measuring tool and as an improvement tool, by giving guidelines for improvement.

This master thesis focuses on further development of the capability maturity model for organizational competence in production scheduling and control. The model proposed in the project thesis is solely based on theoretical data from literature. In order to capture the complexness of real-world environments, multiple case studies should be conducted in order to obtain empirical data to refine the model.

The student will perform the following tasks:

1. Elaborate the addressed problem and describe the scope of the project.
2. Conduct a literature study to develop the model further based on theoretical data and prepare the case study (-ies).
3. Conduct the case study (-ies) to obtain relevant empirical data.
4. Refine the model based on the observations made in the case study.
5. Conclude the project with a final report.

Preface

In the last semester of the Master of Science in Engineering program at the Norwegian University of Science and Technology (NTNU), the students are required to write a master thesis. This master project was carried out in the spring semester of 2015 by stud. techn. Sven-Vegard Buer at the Department of Production and Quality Engineering, as part of a two-year master program in Mechanical Engineering.

I would like to thank my teacher Jan Ola Strandhagen who gave me the possibility to write about this subject, and for giving informative and interesting lectures throughout my NTNU years.

I would also like to thank my supervisor Emrah Arica. His valuable guidance, feedback, patience, and encouragement have helped me to complete this master thesis. He has motivated me to always take the extra step in order to get the most out of this master project.

Thank you to Pipelife Surnadal and Anne Ragnhild Ljøkelsøy for letting me gain insight to their production scheduling and control processes and answering all my questions thoroughly.

Lastly, a big thank you to my family for all the support through the years, and to my dear Camilla for being so caring and supportive despite all the time I have spent writing this thesis.

Trondheim, June 2015

Sven-Vegard Buer

Summary

Literature on production planning and control has focused almost exclusively on technical aspects, addressing the development and implementation of new or existing analytical models for different types of production environments. Recent studies have however shown that organizational factors have a significant impact on the production planning and control performance. The aim of this study has been to develop a capability maturity model that evaluates an organization's ability to take into account the organizational factors in performing the production scheduling and control process. This study advances the understanding of how organizational factors influences production scheduling and control. This study is motivated by two research questions: (1) *How to evaluate the organizational competence in production scheduling and control?* (2) *What is the current level of organizational competence for production scheduling and control in a selected case company?* To answer these questions, the study utilized a qualitative literature study to examine organizational factors discussed in literature. The capability maturity model is based on these findings and on the organizational maturity levels defined in ISO/IEC 15504-7:2008. In order to test out the model, a case study at the pipe manufacturer Pipelife Surnadal was conducted.

The findings from this research show that organizational factors have a significant impact on production scheduling and control performance. Organizational factors should therefore not be overlooked. Nine organizational factors of production scheduling and control were identified in this study: 1) *decision autonomy between shop floor and schedulers*, 2) *department structure and scheduler location*, 3) *scheduler training*, 4) *knowledge and communication facilitation of scheduling interconnections*, 5) *collaboration during rescheduling*, 6) *common understanding of problems and constraints*, 7) *fit between context and scheduling and control systems*, 8) *synchronization of performance indicators*, and 9) *reduction of compensation tasks*.

The capability maturity model for organizational competence in production scheduling and control evaluates scheduling environments on a five-level maturity scale. The model specifies characteristics and criteria for each level, which make it easy for an environment to evaluate itself and get suggestions for improvement.

By using the developed model, the organizational competence of Pipelife Surnadal's scheduling and control function was evaluated. The theory-testing and evaluating case study showed that the model is well fitted for real life situations, and identified some organizational aspects that they should focus on in order to improve their scheduling and control performance.

The findings in this report support the idea that organizational factors have an influence on production scheduling and control performance. This study presents a number of relevant organizational factors, and introduces a model that helps scheduling and control environments to evaluate themselves and get improvement suggestions regarding handling organizational factors.

Sammendrag

Forskning på produksjonsplanlegging og –kontroll har fokusert nærmest utelukkende på tekniske aspekter, slik som utvikling og implementering av nye eller eksisterende analytiske modeller for ulike typer produksjonsmiljøer. Nylige studier har imidlertid vist at organisatoriske faktorer også har en betydelig innvirkning på effektiviteten til produksjonsplanlegging- og produksjonskontrollprosessene. Målet med denne studien har vært å utvikle en «capability maturity model» som evaluerer en organisasjons evne til å ta hensyn til organisatoriske faktorer relatert til detaljert produksjonsplanlegging og –kontroll. Denne studien fremmer forståelsen for hvordan organisatoriske faktorer påvirker detaljert produksjonsplanlegging og –kontroll. Denne studien er motivert av to forskningsspørsmål: (1) *Hvordan evaluere den organisatoriske kompetansen for produksjonsplanlegging og –kontroll?* (2) *På hvilket nivå ligger den organisatoriske kompetansen for produksjonsplanlegging og –kontroll for en utvalgt casebedrift?* For å kunne svare på disse spørsmålene bruker denne studien en kvalitativ litteraturstudie for å undersøke organisatoriske faktorer diskutert i litteraturen. Modellen er basert på disse funnene, og på de forskjellige nivåer av organisatorisk modenhet definert i ISO/IEC 15504-7:2008. For å teste ut modellen ble det gjennomført en casestudie hos rørprodusenten Pipelife Surnadal.

Resultatene fra dette forskningsprosjektet viser at organisatoriske faktorer har en betydelig innvirkning på effektiviteten til detaljert produksjonsplanlegging- og produksjonskontroll, og bør derfor ikke bli ignorert. Ni forskjellige organisatoriske faktorer relatert til disse prosessene ble identifisert i denne studien: 1) *beslutningsautonomien mellom produksjonsoperatører og planleggere*, 2) *avdelingsstruktur og planleggerens lokasjon*, 3) *opplæring for planleggeren*, 4) *kjennskap til planleggerens kontakter og tilretting av kommunikasjon med disse*, 5) *samarbeid i replanleggingssituasjoner*, 6) *felles forståelse av problemer og begrensninger*, 7) *samsvar mellom organisasjonskontekst og planleggings- og kontrollsystemer*, 8) *synkronisering av prestasjonsindikatorer* og 9) *redusering av kompensasjonsoppgaver*.

Modellen for organisatorisk kompetanse i detaljert produksjonsplanlegging og –kontroll evaluerer planleggingsmiljøer på en femtrinns modenhetsskala. Modellen spesifiserer karaktertristikker og kriterier for hvert trinn, noe som gjør det enkelt for brukeren å evaluere seg selv og få forslag til forbedringer.

Ved å bruke den utviklede modellen, ble den organisatoriske kompetansen til Pipelife Surnadals detaljerte produksjonsplanlegging og -kontroll evaluert. Gjennom en teoritestende og evaluerende casestudie, ble det vist at modellen er godt egnet for virkelige miljøer, samt at den identifiserte noen organisatoriske aspekter som bedriften bør fokusere på for å forbedre effektiviteten i disse prosessene.

Funnene i denne rapporten støtter ideen om at organisatoriske faktorer har betydning for effektiviteten til detaljert produksjonsplanlegging- og produksjonskontrollprosessene. Studien presenterer en rekke relevante organisatoriske faktorer, og introduserer en modell som hjelper planlegging- og kontrollmiljøer å evaluere seg selv, samt få forbedringsforslag vedrørende håndtering av organisatoriske faktorer.

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Abbreviations

APS	Advanced planning systems
CMM	Capability maturity model
ERP	Enterprise resource planning
FMS	Flexible Manufacturing Systems
HPP	Hierarchical production planning
HTO	Human, technology, and organization
ICT	Information and communications technology
JIT	Just-in-time
MES	Manufacturing execution system
MESA	Manufacturing Enterprise Solutions Association
MRP	Material requirements planning
OPT	Optimized Production Technology
PE	Polyethylene
PP	Polypropylene
PPC	Production planning and control
PSC	Production scheduling and control
PVC	Polyvinyl chloride
TPE	Thermoplastic elastomer
TQM	Total Quality Management
WBS	Work breakdown structure

1 Introduction

This chapter introduces this master thesis and presents relevant background information and the motivation behind doing this research. This chapter also analyzes the official problem description for this master thesis, which is presented at the very beginning of this report. The project scope is stated, and lastly the structure of the thesis is explained.

1.1 Background and motivation

In an increasingly competitive market with increasing customer expectations and intense global competition, manufacturing companies need to continuously look for ways to enhance their competitiveness in order to remain profitable (Powell, 2012). Many improvement techniques and tools have been developed over the years to improve production companies. Just-in-time (JIT), Optimized Production Technology (OPT), Flexible Manufacturing Systems (FMS), Total Quality Management (TQM), and Lean manufacturing are just a few of many new paradigms that have emerged in the later years (MacCarthy and Wilson, 2001). These improvement techniques aim to make production more efficient by lowering costs and increasing the quality.

Researchers do not rest on their laurels, and new studies are constantly carried out in order to explore the possibilities of increasing the production planning and control performance. These studies have helped production companies to get increasingly efficient and get more out of their resources. Most of these production planning and control studies have solely focused on technical aspects, addressing the development and implementation of new or existing analytical models for different types of manufacturing environments (Berglund and Karlton, 2007, de Snoo et al., 2011a). However, since recent studies have shown that organizational factors have a significant impact on the production planning and control performance, regardless of the industry type (McKay and Wiers, 2006a, MacCarthy, 2006, Crawford and Wiers, 2001, Berglund and Karlton, 2007), there is a need for research on organizational factors in production planning and control (McKay and Wiers, 2006b).

The aim of this study is to develop a capability maturity model for organizational competence in production scheduling and control. Production scheduling and control is a part of production planning and control, which is explained in chapter 3.3. Organizational competence is defined in this thesis as *an organization's ability to take into account the organizational factors in performing the production scheduling and control process*. As well as developing this capability maturity model, it should also be tested on a real-life production environment.

The term *production scheduling and control performance* are used several times in this thesis. Briefly explained it means how efficiently the production scheduling and control task is carried out. This can be defined either purely qualitative as an overarching term, or as a more specific quantitative measurement. In this thesis, the qualitative view of performance is used and represents the effectiveness of the production scheduling and control function.

The motivation behind developing a model for organizational competence in production scheduling and control is based on the topic of organizational factors. Through the project thesis conducted in the autumn of 2014, the precursor to this master project, organizational factors were defined as factors that relate to humans in an aggregated sense, and covers aspects such as how work is organized and structured, together with rules, procedures, and cultural factors. Through a qualitative literature study in the project thesis, organizational factors were identified, and their impacts on production scheduling and control investigated.

Some examples of possible organizational factors within production scheduling and control are:

- How do functional interconnections influence scheduling?
- Which impact has organizational support on the scheduling and control process?
- How is the physical location of the schedulers affecting the scheduling and control process?

Based on these organizational factors, an initial draft of a capability maturity model was proposed in the project thesis. This master thesis focuses on further development and testing of the capability maturity model for organizational competence in production scheduling and control.

1.2 Problem description

This chapter consists of an analysis of the different tasks defined in the problem description that is handed out to the student, with comments regarding how to solve them.

Elaborate the addressed problem and describe the scope of the project.

This relates to the start-up phase of a project, and relates to issues typically treated in the pre-study report. The actual problem should be analyzed; objectives, research questions, and refinements should be defined, in order to get an overview of *what should be done*. In addition to knowing *what should be done*, it is also essential to know *when to do it*. Project planning is therefore also important in this phase.

Conduct a literature study to develop the model further based on theoretical data and prepare the case study (-ies).

In order to develop the initial model presented in the project thesis further, a literature study is required. This is needed to obtain theoretical data that might improve the model further. This could be either completely new information or other views on a particular topic. Preparation for the case study is also important in order to get the most out of it. This could for instance be to prepare a set of questions or mapping the information needs.

Conduct the case study (-ies) to obtain relevant empirical data.

The aim of the case study is to test the validity of the model by evaluating a case company. Since the developed model up until this point is based solely on theoretical data, it is very useful to be able to test it in a real word environment. Through the testing, possible weaknesses of the model might be discovered and dealt with. The collected information should be logged in a proper manner so that it can easily be used later in the project.

Refine the model based on the observations made in the case study.

This part of the assignment is not carried out. Because of limitations in time and in the number of case companies, it was deemed more relevant to test the model for validity through evaluating a single case company. This is because it is difficult to draw strong conclusions that might change the model from a single case study.

Conclude the project with a final report.

The report is written in parallel with the other tasks during the whole project. After all of the other tasks are completed, the report can be finalized and delivered.

1.3 Project scope

1.3.1 Objectives

The main objective of this study is to develop a capability maturity model for organizational competence in production scheduling and control. This chapter briefly presents some of the stated objectives of this master project. The outcome objectives represent major milestones that should be completed at some point in the project period. The process objectives represent smaller objectives that should be completed in order to make it easier to complete the major milestones.

Outcome objectives:

- Develop a capability maturity model for production scheduling and control
- Test the model in one or multiple case studies
- Evaluate a company using the capability maturity level
- Write a report and deliver it by 10 June 2015

Process objectives:

- Write a pre-study report
- Make a project plan
- Keep contact with supervisors and report on the progress of the project
- Conduct a literature study to further develop the model
- Prepare questions for case studies

1.3.2 Research questions

Based on the main objective of the project, research questions can be defined. Defining research questions are essential in a research process. They define what the point of the study is, and which questions it seeks to answer. In this project, the following research questions are proposed:

1. How to evaluate the organizational competence in production scheduling and control?

Organizational factors relate to humans in an aggregated sense, and therefore cover aspects such as how work is organized and structured, together with rules, procedures, and cultural factors. As mentioned, recent studies have shown that organizational factors have a significant impact on the production planning and control performance. However, as organizational factors tend to be abstract and diffuse, these are easily overlooked when looking for process improvements. This research aims at increasing the awareness of organizational factors within production scheduling and control. To do this, an evaluation model for production environments will be developed, which will evaluate the specific environment's ability to consider and handle different organizational factors, which have an influence on the scheduling and control performance. This model should increase the understanding of the concept of organizational factors, and help to point out improvement areas related to these aspects. The model will give a more practical view on these factors that otherwise might be difficult to get a grip on.

2. What is the current level of organizational competence for production scheduling and control in a selected case company?

After developing the evaluation model, it should be put to test on a real life company. This case study is necessary to test the model for validity and usability. The model is based solely on

theoretical data, and there is no guarantee that it automatically can be used directly in practical situations. Through testing the model in a selected case company, the results will show if the model reflects real life situations, and therefore can be proved useful as a process improvement tool. In addition to testing the model itself, the case study will also give an indicator on the case company's level of organizational competence in production scheduling and control. After mapping the current maturity level of the company, improvement suggestions will be provided based on the guidelines in the model.

1.3.3 Limitations

To complete the description of the project scope, it is necessary to not only talk about what will be done, but also the aspects that limit the project.

Time

The project is carried out during the spring semester at NTNU. The project corresponds to 30 credits, and the delivery deadline is 10 June 2015. Since the project was officially started at 14 January 2015, the timeframe of the project is 21 weeks. This includes one week of Easter holiday, so the effective project period is 20 weeks. The time limit will naturally lead to limitations on how extensive the project is.

Literature

Even if the literature study is comprehensive, the possibility of leaving out some of the relevant literature is significant. The used literature is also limited to what NTNU's library can offer through physical copies and online databases. Several research schools exist within scheduling, and this creates some challenges in the process of choosing literature and extracting its information. Because of these different research schools, conflicting frameworks exist, and one must exercise caution when mixing literature findings from different researchers. Possible differences in terminology must be investigated and taken into account in the literature study.

Case study

The case study will be limited in time. If some of the variables are changing over time, the case study will not be able to capture it.

1.4 Thesis structure

This section describes the structure of the thesis and provides a brief introduction to the contents of the different chapters. The structure of the thesis is based on the IMRaD-structure, which stands for *introduction, methods, results, and discussion*. This is a widely recognized way to structure reports, and is the predominant format of scientific writing (Wu, 2011). Figure 1 illustrates the structure of this thesis.

Chapter 2 introduces the research *methodology* that is used in this project. This chapter describes the different research methods that are used in the different phases of the project, which together forms the specific methodology for this project.

The next two chapters introduce the theoretical background for this thesis. Chapter 3 introduces *production planning and control theory*, which is narrowed down to scheduling and control theory. *Organizational theory* is presented in chapter 4. This chapter is divided into two main parts: organizational concepts and organizational communication. Both of these are important to gain an understanding of the concepts that are discussed later in the report.

Chapter 5 presents the main literature findings in this report. These are related to *organizational factors of production scheduling and control*. Each of the nine factors presented are described, their importance is stated, and there are some comments regarding how they should be handled.

The *capability maturity model for organizational competence in production scheduling and control* is presented in chapter 6. The model is based on the findings in the literature study. It consists of five different levels, and each of these levels is described thoroughly in this chapter.

By using the developed capability maturity model, an *empirical study* was conducted. This was a case study aimed at evaluating a real-life scheduling and control process at a Norwegian manufacturing company. The findings from this study are presented in chapter 7.

Discussion around the literature findings, the capability maturity model, and the case study are presented in chapter 8. There is also an assessment on whether the objectives are met and the research questions are answered. Lastly, this chapter comments on the limitations of the study and give recommendations for future research within the field.

The *conclusion* is presented in chapter 9.

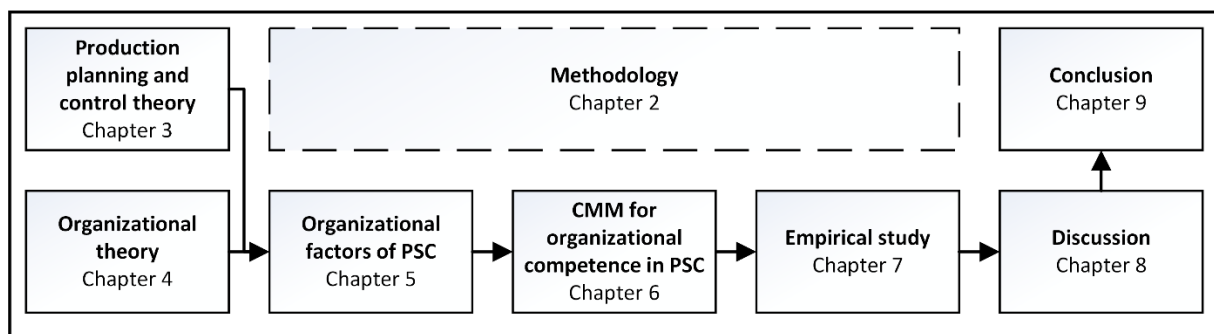


Figure 1: The structure of this thesis.

2 Methodology

This master thesis is conducted as a research-based project with defined project objectives and research questions. In order to meet the project objectives and answer the research questions, the project should have a clear plan for achieving this and choose a methodology that fits this purpose. This chapter describes the methodology that is used in this master project in detail. First, some general information about different research methods are presented, before looking at the methods used at each distinctive phase of the project.

2.1 Research methods

Research methods represent the various procedures, schemes, and algorithms used in research. These methods help the researcher to collect samples, data, and find a solution to a problem (Rajasekar et al., 2006). Research methodology, on the other hand, is defined as a systematic way to solve a problem. The research methodology represent the research methods and procedures that researchers use in their work in a specific project (Rajasekar et al., 2006). Methodology can be seen as a research recipe, which states the steps in the research together with the respective methods and techniques utilized throughout the research.

Research is often differentiated on whether it uses quantitative or qualitative methods. A quantitative approach uses mathematical and statistical tools to analyze numerical data. Quantitative research often follows a common, structured process, and the quantitative research is often evaluated in terms of the validity of this research process (Croom, 2009). The results of a quantitative research is essentially a number or a set of numbers (Rajasekar et al., 2006). Data collection is normally done through controlled experiments, simulations, or structured surveys (Croom, 2009).

The qualitative approach, by contrast, is more concerned with interpretation and perception, rather than identification of a rational objective truth (Croom, 2009). The goal of qualitative research is to gain understanding of a problem, and the research is therefore more based on text than numbers (Rajasekar et al., 2006). Common qualitative methods include case studies, interviews, and action research (Croom, 2009). The differences between quantitative and qualitative research are further shown in table 1.

Table 1: The main differences between quantitative and qualitative research (Adapted from (Rajasekar et al., 2006))

Quantitative research	Qualitative research
Numerical	Non-numerical
Non-descriptive	Descriptive
Applies statistics or mathematics and uses numbers	Applies reasoning and uses words
Iterative process where evidence is evaluated	The aim is to get the meaning, feeling, and describe the situation
Results often presented in tables and graphs	Qualitative data cannot be graphed
Conclusive	Exploratory
Investigates the <i>what</i> , <i>where</i> , and <i>when</i> of decision making	Investigates the <i>why</i> and <i>how</i> of decision making

The rest of this chapter describes the methods used for four different phases of this project, as well as the continuous process of project planning and follow-up. These phases are illustrated in figure 2.

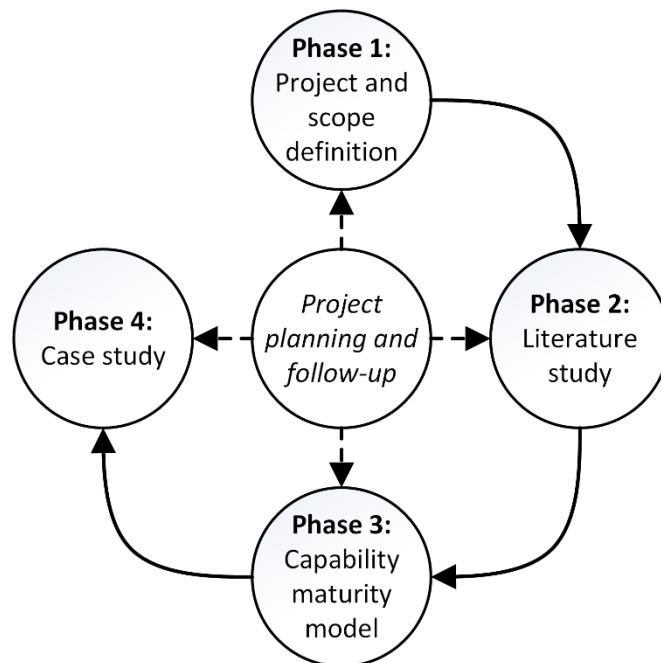


Figure 2: The different phases in this project.

2.1.1 Project definition and determination of scope

This paragraph briefly describes the methodology that was used in the start-up phase of the project when establishing the project definition and determined the scope of the project. Since this project is a continuation of the project thesis carried out earlier, it is important that the scope of this master project is different from the scope in the project thesis. The project definition and project scope is mainly based on analysis of the official problem description for the master project, which is presented at the very beginning of this thesis. Initial discussion with the teacher and supervisor also influenced this process. The important aspects to consider when deciding the scope is to make sure that the extent of the project fits to a master project, a project type that constitutes 30 credit points and has a duration of 20 weeks. It is also important to have in mind that the deliverables in the project should be of scientific interest within the research area.

2.1.2 Literature study

The literature study methodology used in this master project is based on the methodology presented by Brereton et al. (2007). They present a ten-stage review process called *systematic literature review*. The process is grouped into three main phases: *planning*, *conducting*, and *reporting the review*. The systematic literature review process is illustrated in figure 3.

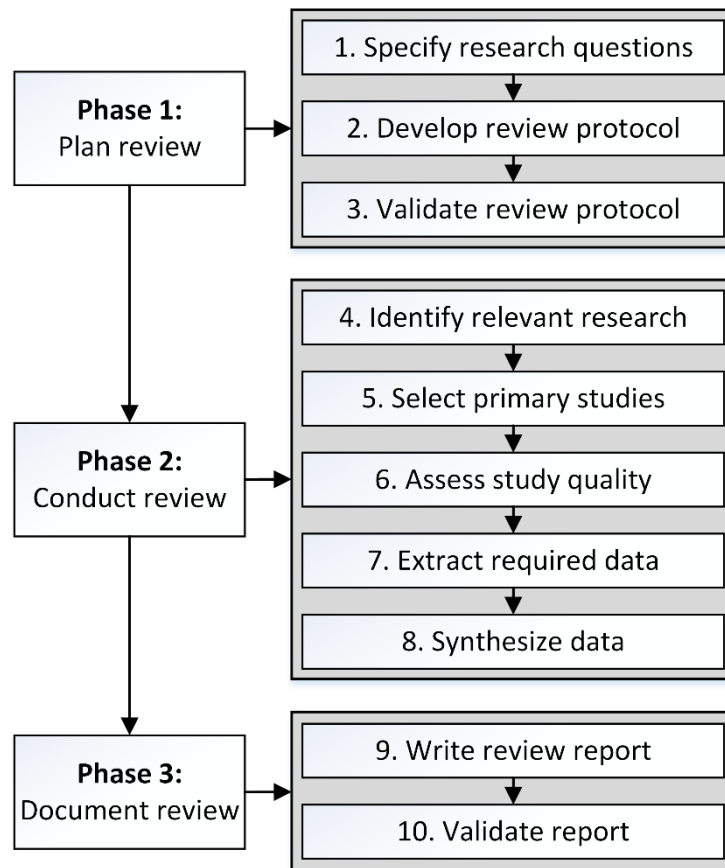


Figure 3: The systematic literature review process (Brereton et al., 2007).

The three phases of the ten-stage review process will now be briefly introduced and described, together with comments on how it is used in the literature study part of this project.

Plan review

The first phase is *plan review*, which is mainly about preparing the literature study. The first stage in this phase involves specifying the research questions, the most critical element of a systematic review. The research questions are important in constructing search strings and deciding the data that should be extracted from the discovered literature. The second stage involves developing the review protocol. This protocol presents the details of the review plan, including planning the search process and the conditions to apply when selecting the primary studies. The third stage is to validate the review protocol. The validation process is usually done by doing a pilot run with the initial review protocol. By doing this, the review protocol can be evaluated and necessary adjustments can be made before conducting the review.

This paragraph describes the planning phase of the literature study in this project. Firstly, the research questions were determined. These were based on the problem description, input from supervisor, and own thoughts regarding the issue. The established research questions formed the basis for the search plan, and helped defining search phrases. For the part of the thesis that describes the background, data were mainly gathered from well renowned textbooks. These books are known from the study, through advices from the supervisor, or through searches in the library database.

When looking into the organizational factors of production scheduling and control, recent data are desired. These data were mainly gathered from journal articles. In order to find relevant

articles, online databases such as Engineering Village, Scopus, ScienceDirect, and Google Scholar were used. In addition to searching through databases, so called "snowball searches" were used. This method involves investigating the references of relevant articles. This is a two-way method, which means that it is relevant both to investigate the references that have been used by the particular article, and other articles that have cited that article. After establishing search phrases, identifying the relevant sources of information, and deciding on the search methods, the search protocol was ready for use for conducting the literature study. The literature study protocol can be found in appendix A.

Conduct review

The next phase in the review process is to conduct the literature study. Identifying relevant research studies is the fourth stage of this ten-stage review process. In this stage, the search strategy defined in the review protocol should be used. By doing this, a number of possible studies should be identified and taken further into stage five. The fifth stage is selecting primary studies among the studies identified in the last stage. This selection is usually a two-step process. The first step of this process is to review the title and abstract of the studies. The irrelevant studies are then rejected. The studies that are still regarded as relevant are then obtained in full text. The second step is to read and review these to investigate if they really are relevant. Assessing the study quality is considered the sixth stage. This is an important stage as it assesses the quality of the selected studies. This quality assessment is important to support the inclusion/exclusion process of the different studies and which weighting the individual study should be allocated. There is no universal definition of how to define the quality of a study, but it is important that the study has minimal bias and that external and internal validation of the study is maximized. The seventh stage is to extract the required data from the selected studies. This information should be accurately extracted from the studies with minimal bias. The data that are required should be stated in the review protocol. The eighth stage is to synthesize the data. This involves making the data suitable for answering the research questions that were established in stage one.

By using the literature study protocol established in the first phase, the literature searches returned a large number of results. A big part of the work after identifying the seemingly relevant literature was to sort out the actual relevant from the not so relevant literature. When conducting the sorting process, the method described in stage five was used. This implies first looking at the title and abstract of the article to identify noticeable irrelevant literature. Thereafter, the presumed relevant literature was read, and important topics were highlighted for later use.

After identifying relevant literature, reading it, and assessing the study quality, the last stages of this phase involved processing and structuring the extracted information. In order to do this, the chosen literature was read through again, with the previous highlighting in mind. Relevant information was then extracted in accordance with the study plan that identified the most critical data to investigate.

Throughout the literature study, approximately 90 scientific sources including articles, book chapters, etc., have been considered relevant and have been noted or saved for future information gathering. Around 35 of these articles have been read through entirely.

Document review

The last phase is to document the literature study and summarize the findings. Writing the review report is the ninth stage. The review report should document the systematic literature

review that has been carried out. The tenth and final stage is to validate the literature review. This should preferably be done by someone external.

The last phase involves documenting the literature study, which in this case means to write the parts of the thesis that are based on literature findings. These chapters fit into a pre-planned logic that focuses on achieving a natural progression through the report. Chapter 3, 4, and 5 are mainly based on results from the literature study. Chapter 3 and 4 are considered as background chapters, where concepts and terms are introduced. These chapters are mainly based on textbooks. Chapter 5 presents organizational factors of production scheduling and control, a chapter that is mostly based on journal articles. This is because this is a relatively “new” subject, and it is important to have as recent data as possible.

2.1.3 Capability maturity model

Organizations continually face pressure to gain and retain competitive advantage. Identifying ways of cutting costs, improving quality, reducing time to market, and so on, become increasingly important. Maturity models have been developed to assist organizations to achieve this (de Bruin et al., 2005). Maturity can be defined as “the state of being complete, perfect, or ready”, and are often used in relation to an evolutionary progress of a specific ability from an initial to a targeted end state (Mettler, 2009). One of the advantages of maturity models are their simplicity, they are easy to understand and communicate (Klimko, 2001).

Maturity models are used as an evaluative and comparative basis for improvement, and can be used to derive an approach for increasing the capability of a specific area within the organization (de Bruin et al., 2005). It may be used by an organization to choose a certain target level of maturity, and then work towards that level. The maturity model will mark out an evolutionary improvement path from an immature process to a mature process (Kaner and Karni, 2004).

Even though there exists lots of different maturity models, there exists little documentation on how to actually develop one (de Bruin et al., 2005). Many maturity models simply build on their predecessors without critical discourse about how appropriate the assumptions that formed the basis for the previous models are for the new model (Kohlegger et al., 2009). To address this issue, de Bruin et al. (2005) have designed a maturity model development framework that is applicable across a range of domains. This methodology was used for the development of the capability maturity model presented in this thesis. The methodology consists of six distinctive phases, and these will be briefly described followed by comments on how it relates to the model developed in this project. The six phases are also depicted in figure 4.

According to de Bruin et al. (2005), the six phases of the maturity model development methodology are:

1. **Scope:** Determine the scope of the model. What is the focus of the model and who are the stakeholders?
2. **Design:** Determine a design or architecture of the model. The design incorporates the needs of the intended audience and how these needs will be met.
3. **Populate:** After deciding the scope and design, the content must be decided. What needs to be measured in the maturity assessment and how can this be measured?
4. **Test:** When a model is populated, it must be tested for relevance and rigor. It is normal to test for validity, reliability, and generalizability.

5. **Deploy:** Following the testing, the model should be made available for the relevant users.
6. **Maintain:** Following a successful implementation, the relevance of the model should be maintained with necessary updates over time.

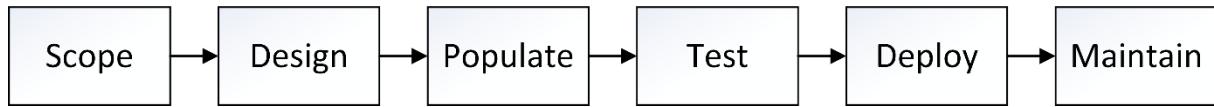


Figure 4: Six phases of developing a capability maturity model (de Bruin et al., 2005).

This project only utilized the first five phases of this methodology. This was because maintaining the model has a longer time perspective than this project. The first three steps may be done solely based on theory, while the fourth stage requires some sort of empirical study. The term capability maturity model will be used from here on. This is the most famous type of maturity model (Netland and Alfnes, 2011). Capability maturity models fits well for improving processes in an organization and assessing organizational maturity (Software Engineering Institute, 2010), and this project will therefore use this type of maturity model. The following sections describe the phases in the development of the capability maturity model for organizational competence in production scheduling and control.

The capability maturity model for organizational competence in production scheduling and control aims at evaluating different organizations regarding their ability to consider organizational factors. This is the *scope* of the model. The most relevant stakeholder for this model is of course production scheduling and control environments. The people responsible for these groups could evaluate their own ability and obtain guidelines for improvement.

This model is *designed* as a five-stage ladder to improvement, which can be used as both an evaluation and improvement tool. The model describes the characteristics of the different levels, and present criteria that must be fulfilled in order to be evaluated to that specific level. The intended audience wishes to have a tool for evaluating their own ability, and get suggestions on what they could do better. By presenting criteria that should be fulfilled, the model should be able to satisfy this need.

The content of the model are based purely on theoretical literature. The levels of the maturity model are adapted from a well-recognized maturity model (ISO/IEC 15504-7:2008), so it is firmly grounded in acknowledged research. The characteristics of each level are based partly on the descriptions of each level in ISO/IEC 15504-7:2008, and partly on findings regarding organizational factors in production scheduling and control. Lastly, the model is *populated* with criteria that are based on the organizational factors identified in the literature study.

After it had been developed, the capability maturity model was *tested* through a case study. In the case study, the model was used to evaluate a real-life production scheduling and control environment. This way, in addition to evaluating a company and giving it suggestions for improvements, the model was tested for relevance and validity. By conducting an interview with a real-life scheduler, it quickly became evident whether the model was realistic or not.

Following the testing, the model should be *deployed*. This means making it available for the relevant users. The capability maturity model for organizational competence in production

scheduling and control will be published through this master thesis, and it will hopefully be of use for different production scheduling and control environments.

Maintaining the model is not a theme for this project. If the model is considered useful, it will hopefully be updated and developed further by the scientific community.

2.1.4 Case study

In order to test and validate the model, a case study was planned and carried out. There exist numerous different theories regarding case studies and therefore numerous definitions of the case study. Thomas (2011) has reviewed a number of different definitions and presents a general definition of the case study:

Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. The case that is the subject of the inquiry will be an instance of a class of phenomena that provides an analytical frame – an object – within which the study is conducted and which the case illuminates and explicates.

As well as the numerous definitions of the case study, there is also a jungle of definitions regarding the different types of case study. Through a literature review conducted by Thomas (2011), he presents a list of over 30 different types of case studies that is collected from the research of seven different renowned analysts. Based on these findings, Thomas (2011) stresses the need for a common typology for classifying case studies. This typology is illustrated in figure 5, and will be used to classify the case study in this project. This classification typology uses six categories to differentiate different case studies from each other: *subject, purpose, approach, process, object, and methodological choices*. Within the first four of these categories, there are different alternatives that describe the nature of the particular case study. The *object* and *methodological choices* will differ very much from case study to case study, and it is therefore not relevant to list up alternatives for these two categories. This section briefly describes the different categories, but will not go further into the different alternatives in each of the categories.

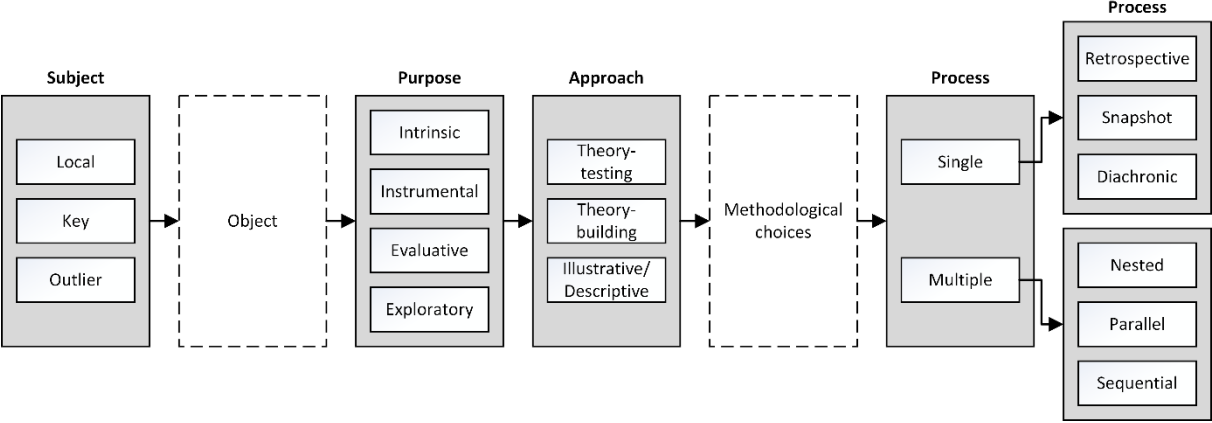


Figure 5: A typology of case study (Thomas, 2011)

The six categories in the classification typology for case studies are (Thomas, 2011):

- Subject:** What type of population or item is investigated in the case study?
- Object:** What is the analytical focus of the case study?
- Purpose:** What is the purpose of the case study?
- Approach:** Which approach is adopted in the case study?

Methodological choices: Which methods are used in the case study?

Process: How many cases are investigated and for which time period is the data collected?

This chapter now looks more specifically into the case study that was conducted in this project. The case study was planned and carried out according to the methodology presented by Yin (2009). This case study methodology consists of six different stages that are depicted in figure 6. This section briefly presents the stages, how they link together, and how they are utilized in this project. Lastly, this chapter return to the case study classification typology by Thomas (2011), and classify this case study based on the information presented throughout this chapter.

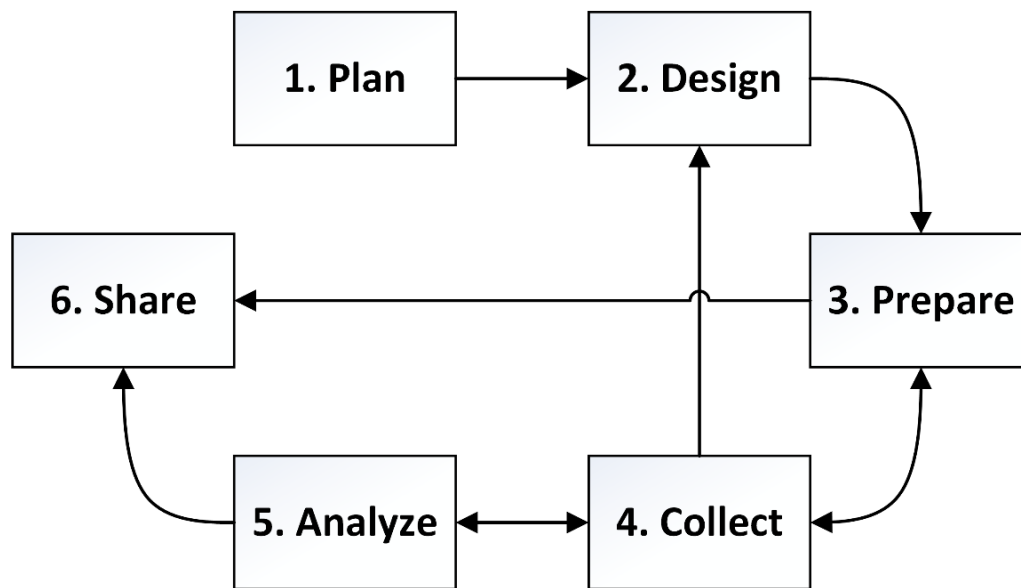


Figure 6: Six phase case study methodology (Yin, 2009).

The first stage of the case study methodology is to *plan* the case study, or more specifically, to plan whether or not a case study is the preferred method in the particular case. Case studies fit situations where the research is on contemporary events that the researcher does not require control over.

In this research, the first research question seeks to investigate how scheduling and control environments deal with influential organizational factors. The second question seeks to evaluate the organizational competence of different manufacturing companies, and this could possibly have been investigated through other methods, such as a survey. However, since these two research questions are highly interrelated, and the case study regarding how to evaluate the different environments' organizational competence also will uncover the current organizational competence of the respective environment, a case study is considered fitting for investigating both of the research questions. The fact that the research aims at investigating contemporary events and that control over these are not needed supports this choice.

The second stage is to *design* the case study. This stage aims at establishing the logic that links the data to be collected to the initial questions of the study. Firstly, the unit of analysis and the likely case(s) to be studied must be defined. Theory, propositions, and issues underlying the anticipated study must then be described. Based on this, the case study design should be identified. In addition to this, it is important to define procedures to maintain the case study quality.

The unit of analysis in this case study research is a production environment, and this should be investigated in order to measure their level of organizational competence in production scheduling and control. The case company in this study is the Norwegian manufacturing company Pipelife Surnadal. The theory regarding the model that is used is mainly based on a qualitative literature study that investigates the organizational aspects of production scheduling and control. The type of case study design are in short based on two types of characteristics; whether the case study is *holistic* or *embedded* and whether it is *single-* or *multiple-case*. *Holistic* case studies refer to case studies where there is only one unit of analysis, while *embedded* case studies refer to cases studies where there are multiple units of analysis. *Single-case* and *multiple-case* refers to the number of different cases in the research. This case study has one unit of analysis and will look into a single case, and is therefore classified as a single-case holistic design. When focusing on maintaining the study quality, the two key concepts *validity* and *reliability* are central. *Validity* refers to constructing a case study that captures accurate and relevant information, while *reliability* refers to documenting the case study such that it can be repeated and verified. This case study will focus on keeping its validity by, among others, using well-established theories, multiple sources of information, and continuous assessment of the work together with supervisors and other key informants. The reliability of the case study will be ensured by a thorough description of the work, mainly through this methodology chapter.

Preparing the case study is considered the third stage in this methodology. It is important for the case study investigator to be properly trained and prepared. A case study is a complex type of research, and the investigator should be well prepared in order to get the most out of it. The case study protocol is a useful tool when preparing a case study. This protocol defines the procedures of the case study and is especially useful in multiple-case studies, where there are requirements on repeatability. This stage also includes the final screening of candidate cases and the possible execution of a pilot case study.

The company in this case study was chosen together with the supervisors as they are regarded relevant for this research. Further screening of the candidate case was not carried out. Because of the limited extent of this project, a complete pilot case study was not conducted. Instead, the interview questions were discussed and evaluated together with the supervisor prior to the case study in order to ensure their appropriateness. To develop a case study protocol was not considered relevant in this study since there is only a single company in the case study, and therefore no requirements to repeatability. If there were several companies to be investigated in this study, a case study protocol would certainly be relevant.

The fourth stage is called *collect*. This stage represents the part of the case study where the investigator collects the required information. In this stage, it is important to understand which type of sources the information will be collected from, and in which way this information should be extracted. In addition, some overriding principles are important to keep in mind when collecting data from case studies in order to maintain quality and validity of the extracted data. These principles include (a) the use of multiple sources of evidence when possible, (b) creating a case study database with the collected data, and (c) establishing a chain of evidence between the questions, the collected data, and the conclusions drawn from the case study.

The data from this case study were collected through a semi-structured interview with a production scheduler at the case company. This interview was built around the developed maturity model, and the aim of the interview was to collect enough information to be able to

evaluate the company regarding their organizational competence in production scheduling and control.

The fifth stage in the case study methodology is *analyzing* the case study evidence. In short, this stage involves using the collected data to draw empirically based conclusions. A general analytic strategy should define priorities regarding what data to analyze and why. Further, different analytic techniques can be used to draw conclusion from the data.

By using the data collected from the interview, it was possible to evaluate the company. This was done by analyzing the collected information with the established criteria from the capability maturity model in mind. It then became evident whether or not the company satisfies the different level requirements, and it was possible to draw a conclusion based on this.

The sixth and final stage is *reporting* the case study. This means to bring the results and findings to closure. Firstly, it is important to define the audience for the report. This will influence how the case study should be presented. For instance will differences in previous knowledge of the subject influence how much theory that should be presented together with the case study. After this, it is important to develop the compositional structure of the report. The structure should be logical and easy for the reader to understand. When writing the report it is important to have in mind that enough evidence from the case study is displayed so that the reader have the possibility to reach own conclusions, which will increase the validity of the report. Lastly, it will be useful having the drafts of the report reviewed by others so that possible errors might be detected and corrected before the final submission.

The case study is reported in chapter 7 in this report. The terminology used in this thesis suggests that the reader should have a basic understanding of production planning and control concepts. In order to secure a logical structure and make it easily understandable, the layout from the capability maturity model is transferred to the case study chapter. This means that the chapter is based on the different criteria that are listed in the capability maturity model. The chapter presents the findings regarding each criteria and draws a conclusion whether or not the requirements are met. The findings will be presented in such a detail that it is possible for the reader to draw own conclusions regarding whether or not the company satisfies the requirements.

Classification of this case study

Lastly, this chapter classifies this case study according to the classification typology by Thomas (2011). The classification is also illustrated in figure 7.

The *subject* of this case study is the manufacturing company Pipelife Surnadal. This company is considered as an appropriate case company since they are thought to be representative for a typical production scheduling and control environment. This means that they are of natural interest for the theories in this study and therefore classified as a *key case*.

The *object* of this case study is to test the capability maturity model for organizational competence in production scheduling and control. This enables both the possibility to validate the model and evaluate the case company.

The *purpose* of this case study is twofold. The main aim of this case study is to test the validity of the model, which is regarded as *instrumental* research. The other aim is to evaluate the case

company’s organizational competence in production scheduling and control, a type of research that is considered *evaluative*.

The *approach* utilized is also similarly twofold. Testing the validity of the model is considered as *theory-testing*, while the evaluation part is considered as an *illustrative* or *descriptive* approach.

The *methodological choices* in this case study are presented in the sections above.

The final category says something about the case study *process*. This study looks into a *single case*, Pipelife Surnadal. The case study is considered *retrospective* since it looks at past events or phenomena and does not look at changes that may happen over time. The relevant data in this case was to look at how their processes currently are doing.

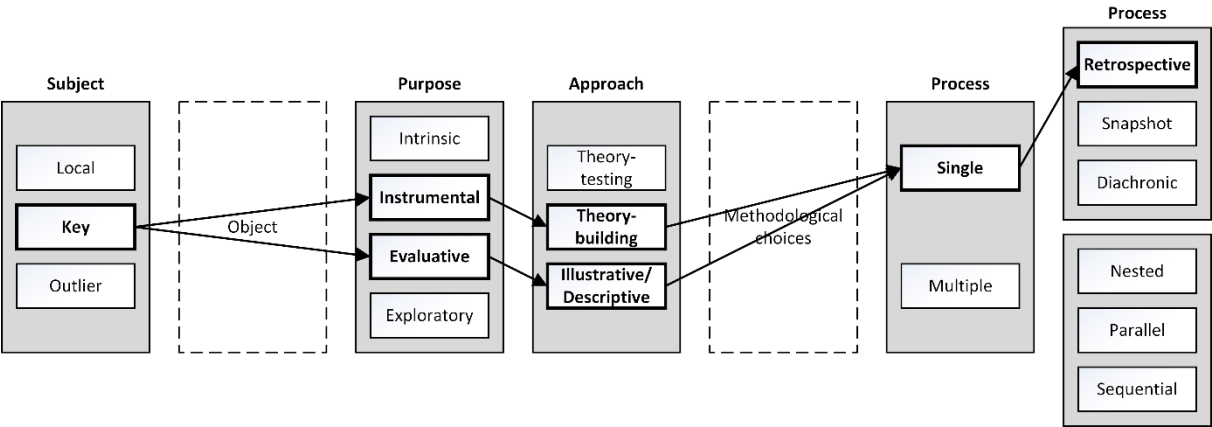


Figure 7: Classification of the case study conducted in this master thesis.

2.1.5 Project planning and follow-up

Throughout all phases of the project, it is important to have clear plans to ensure a steady progress of the project. In the start-up phase of this project, a project plan was developed according to the Gantt chart methodology using the software Microsoft Project. This project plan presents the necessary activities that must be performed in the project, with deadline dates set accordingly to ensure that there is enough time to carry out all of the activities. Together with this, a work breakdown structure (WBS) was developed, which shows the work packages required to finish the project as planned. Both the initial project plan and work breakdown structure are presented in the pre-study report (Appendix B).

While the intent of plans is to follow them to achieve the goals, it is not realistic to follow them slavishly. Unexpected events will affect the plans and make them infeasible. It is therefore important to make allowance for these kind of events. This could either be done *proactively* by make extra space in the plans to make them more robust in case of delays, or *reactively* by adjusting the plans as the unexpected events occurs. The proactive method will most likely be sufficient for minor disturbances, but in the case of major disturbances, replanning is most likely necessary. With the inevitable unexpected events that will affect the progress of this master project, there are some “slack” integrated into the project plan, which are intended to ensure that small delays will not hinder the general progression of the project. If this however fails, and some kind of event leads to replanning, it is basically two ways to attack this problem.

Either, the work effort must be increased, which in this case means to increase the number of hours spent working on the thesis, or the workload needs to be decreased, by either rationalizing the work tasks or reducing the ambition level of the project. Reducing the ambition level is of course not desired, so this will only be a last resort if the other methods fail.

In addition to project planning and replanning, project follow-up and evaluation is another process that is required throughout the project. This process is essential to ensure that the project is on the right path. This is done by quality assuring the results. The evaluation process is normally based on either new information obtained through supervision or additional knowledge of the subject obtained through the literature study or practical studies. Since the understanding of the topics discussed in the thesis will become better throughout the project period, it is important to allocate time at the end of the project period to look back at material that was written earlier in the project period. With an increased understanding of the topics, the material should be evaluated and necessary adjustments should be made in order to achieve a best possible result.

3 Production planning and control theory

This thesis consists of three theory chapters. The first two deal with background theory: *production planning and control theory* and *organizational theory*, respectively. These two chapters introduce terminology and concepts that are used later in the report, and these chapters aim to form a solid theory background that the report can be built on. The last theory chapter, *organizational factors of production scheduling and control*, is based on both of the two preceding theory chapters. That chapter presents organizational factors of production scheduling and control that were identified through the qualitative literature study conducted in this project. The Venn diagram in figure 8 shows the structure of the theory chapters.

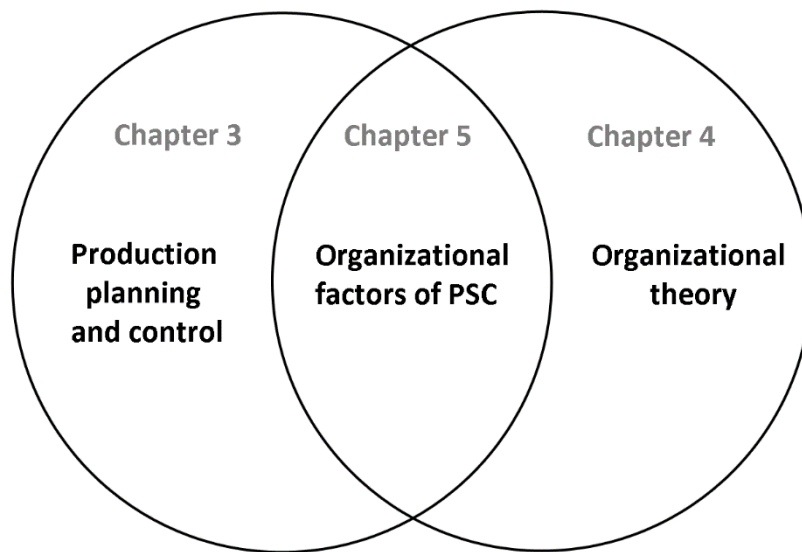


Figure 8: The structure and link between the theory chapters.

This chapter introduces relevant terminology within production planning and control used later in the report. The chapter starts with a general introduction to production planning and control, before describing the production planning and control function based on a framework by Bertrand et al. (1990). Relevant information is extracted from this framework in order to describe the most important features of production planning and control. After the introduction, this chapter looks more specifically into the *scheduling function*, the part of production planning and control is investigated further later in this thesis in relation to its organizational factors. *Scheduling in theory and practice*, *performance measurement*, and *technological systems used in scheduling and control* are discussed in this part of this chapter.

3.1 Introduction to production planning and control

Production planning and control is essential in every type of industry. Without it, the shop floor will have no idea what to produce and when to produce it. The purpose is to make a connection between supply and demand, together with ensuring a efficient production process (Slack et al., 2010). Production planning and control organizes the production and makes sure that the objectives are achievable.

Both in theory and in practice, the distinction between *planning* and *control* is not clear. *Planning* can be seen as a formalization of what is intended to happen in the future. However,

a plan does not guarantee that an event will actually happen, and must therefore be seen as a statement of intention (Slack et al., 2010).

Many events may make a plan infeasible, *changed customer orders*, *supplier problems*, *machine failures*, and *staff problems* are some of the many potential events that might influence the plan. *Control* can be seen as the process of coping with changes in the plan. By redrawing plans in the short term, control can make the necessary adjustments to ensure that the production still may achieve the stated objectives in the plan (Slack et al., 2010).

The degree of uncertainty in demand will affect the balance between planning and control. The greater the uncertainty, the harder it is to plan, and more emphasis must therefore be placed on control (Slack et al., 2010).

Production planning and control can be divided into three main activity levels: *planning*, *scheduling*, and *dispatching*. These levels can be differentiated from each other by looking at the time horizon and decision type, together with the decision-making context (McKay and Wiers, 2003).

3.2 Production planning and control framework

There exist a number of different frameworks on how to view production planning and control. For instance, Vollmann et al. (2005) presents a manufacturing planning and control system framework that presents planning and control functions ranging from the overarching activities such as sales and operations planning, all the way down to the shop-floor systems. Another famous framework for production planning and control is the framework by Pinedo (2012). It depicts the different functions in production planning and control, and presents the information flow between these functions. This thesis is however using the production planning and control framework by Bertrand et al. (1990) in order to describe the different levels within planning and control. The framework is useful to get a general overview of the different production planning levels. This framework originates from the concept of hierarchical production planning (HPP) approach, which is a way to decompose the planning problem into manageable pieces (McKay and Wiers, 2006b). One of the reasons to use HPP is because it is regarded impossible for a single individual to construct schedules for a whole production system in a reasonably sized factory. The problem is therefore decomposed along hierarchical lines, and this creates various levels of control. The higher the control level, the wider the scope. The lowest level corresponds to a part of the production system, which only focuses on a single resource or department. These plans are therefore naturally more detailed (McKay and Wiers, 2006b). Figure 9 shows an example of a hierarchical planning schema. The levels on the left represent the different organizational levels, and the levels on the right are their corresponding planning detail.

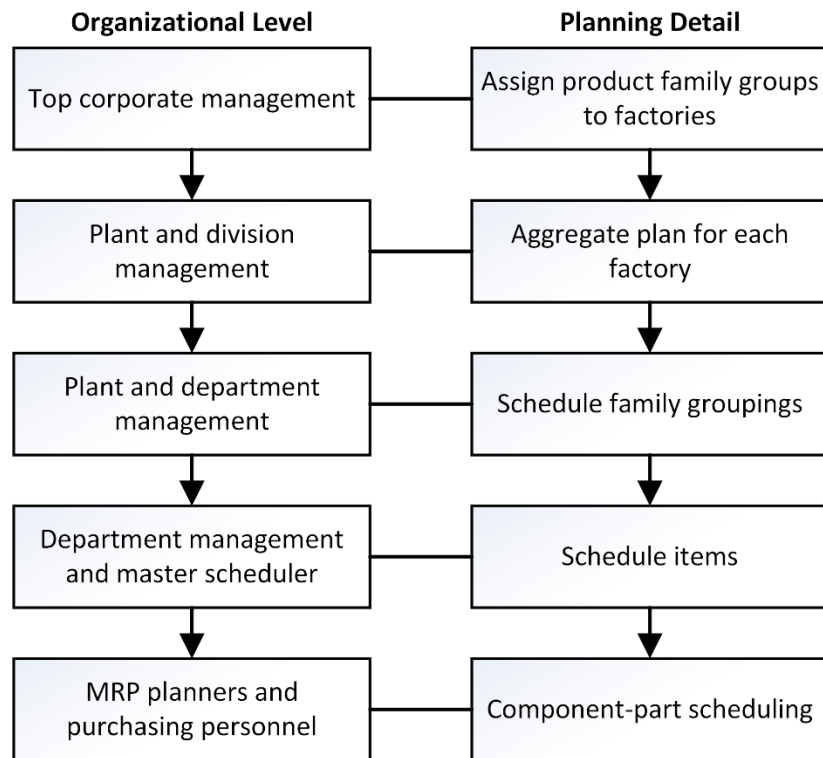


Figure 9: Hierarchical planning schema (Vollmann et al., 2005).

3.2.1 Functions

The main function of production planning and control is to make sure that the shop floor knows what to do and at which time. Usually, the input to the planners and schedulers is new customer orders or forecasts of demand, usually communicated from the sales department. By utilizing information from production and purchasing departments, production planning and control can obtain details about capacity, inventory levels, and supply of raw materials. By using this information, production planning and control can together with the sales department agree about a due date for the customer order (McKay and Wiers, 2006b).

The framework by Bertrand et al. (1990) distinguish between *goods flow control*, and *production unit control* (figure 10). A production unit refer to a production department which on short-term is self-contained with respect to the use of its resources. The production unit could consist of everything from a single machine to an entire production hall with many different types of machinery and personnel. The production unit is then responsible to produce a specific set of products from a specific set of materials and components (Bertrand et al., 1990). *Production unit control* is related to the control of the different production units. On the other hand, *goods flow control* is considered as a level above production unit control, in the sense that it coordinates and releases work orders to the production units. It also coordinates with sales (Bertrand et al., 1990).

The term *operational characteristics* relates to the “behavior” of a production unit as part of the goods flow, and refers to variables such as work order throughput times and capacity restrictions. The operational characteristics of the different production units influences the goods flow control (Bertrand et al., 1990).

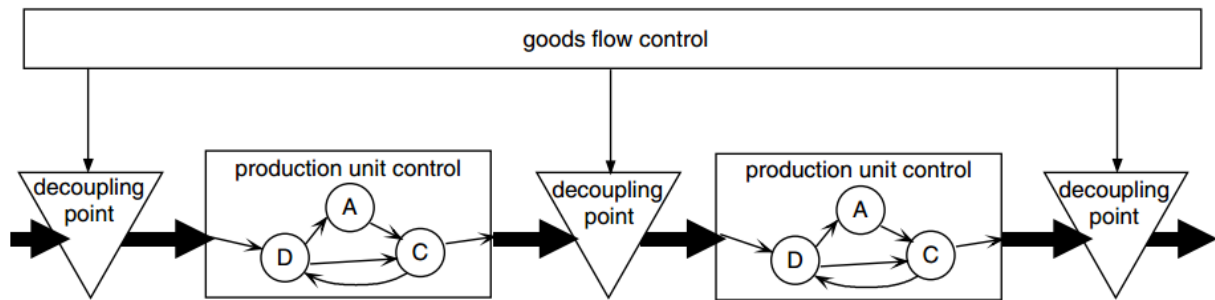


Figure 10: Goods flow control and production unit control (McKay and Wiers, 2006b).

3.2.2 Activities

As mentioned earlier, the framework by Bertrand et al. (1990) splits production planning and control into two parts: *goods flow control* and *production unit control*. The former relates to *long term planning and control*, which deals with plant level material planning and control. The latter relates to *short term planning and control*, which deals with detailed planning and control. These terms can be related to the well-known terms *planning* and *scheduling*. Goods flow control is associated with *planning*, while production unit control is associated with *scheduling*. Some researchers also use the term *dispatching*, which in this case would be part of the production unit control (McKay and Wiers, 2003). In addition to some introductory information about the production planning and control problem, this chapter further defines the concepts of planning, scheduling, and dispatching.

There are several inputs and outputs affecting the production system, and therefore the planning and control function. Inputs include incoming materials, demand information, and actual changes in the production capacity. Main outputs are materials procurement orders, the shipments of finished products, and actions to change the production capacity of the system (Bertrand et al., 1990). These represent the overall inputs and outputs and support the idea that production uses incoming materials and capacity to produce products.

In order to be able to plan and produce a product, some key information has to be known (Bertrand et al., 1990):

- The product structure (Bill of Materials).
- Manufacturing steps required for each component and assembly.
- The types of capacity needed.
- The amounts of capacity required for each manufacturing step.

For standard products, these routines are well established, while for new products, the routines have to be developed as part of the design and engineering process (Bertrand et al., 1990).

Based on this, the production planning and control problem can be defined as this (Bertrand et al., 1990):

Given certain consistent objectives regarding customer delivery performance and manufacturing costs, how should we:

- 1) Accept customer orders.
- 2) Place production and procurement orders.

- 3) Vary the capacity.
- 4) Allocate available capacity to manufacturing steps.

The actual activities performed in production planning and control will differ from one production situation to another, but will be related to the four fundamentals named in the list above.

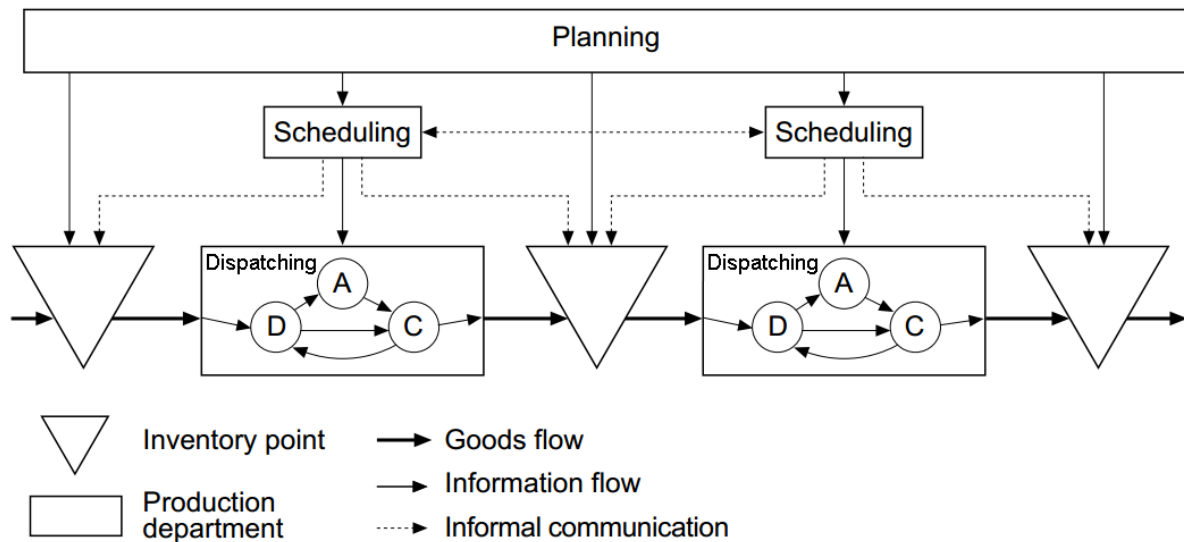


Figure 11: Production planning and control levels (Adapted from Stoop and Wiers (1996)).

As mentioned previously, production planning and control can be said to consist of three distinct levels: *planning*, *scheduling* and *dispatching*. These are shown onto the framework by Bertrand et al. (1990) in figure 11.

In practice, it is however unusual to assign the roles of production planner, scheduler, and dispatcher to specific persons. Normally, a single individual will be doing some planning, some scheduling, and some dispatching, all depending on the situation at hand and it is not possible to identify or specify clear boundaries between the three (McKay and Wiers, 2006a). This is also supported by Berglund and Karlton (2007) who states that the distinction between planning, scheduling, and dispatching is somewhat unclear, but it is justified to assume that it represent a continuum of activities across time and space.

Table 2: Differences between planning, scheduling and dispatching (McKay and Wiers, 2003).

	Horizon	Availability of information	Interaction with lower level	Time pressure
Planner	Multiple, bucketed	High	Low	Low
Scheduler	Single, real time	Lower	High	Higher
Dispatcher	Single, real time	Low	N/A	High

Table 2 shows some differences between planning, scheduling, and dispatching in terms of typical factors that influence the work execution. It provides information on how to identify and differentiate the three different tasks.

Table 3: Task delineation model for differentiating between planning, scheduling and dispatching (McKay and Wiers, 2003).

	Input driven by	Output represented by
Planner	Expectations of the future	Volumes/bucket
Scheduler	Expectations of the future	Orders, assignments, or jobs/real time
Dispatcher	Reality	Orders, assignments, or jobs/real time

The task delineation model in table 3 can be utilized in order to identify the task or role by using data from the work situation (McKay and Wiers, 2003). For example will a person that has input driven by *expectation of the future* and output represented by *orders, assignments, or jobs*, have the role of a scheduler. From here on, this report will not look further into planning and dispatching.

3.3 Short term planning and control

Short term planning and control, from here on known as scheduling, is the main focus in this thesis when investigating influential organizational factors. Scheduling can be seen from two different angles: *theory* and *practice*. *Scheduling in theory* is about generating a seemingly feasible schedule to meet the overall objectives with the available resources. On the other hand, *scheduling in practice* centers around the facilitation and implementation of the schedule and reacting to unforeseen events (MacCarthy, 2006). This chapter looks further into the aspects of *scheduling in theory*, *scheduling in practice*, *performance measurement in scheduling*, and *technological systems used in scheduling*.

3.3.1 Scheduling in theory

Scheduling in theory deals with detailed sequencing and scheduling of jobs. Given a collection of jobs that requires processing in a certain machine environment, scheduling is about sequencing these jobs, subject to given constraints, in such a way that one or more performance criteria are optimized (Pinedo, 2012). In order to carry this out, a large number of mathematical scheduling models have been developed. Scheduling models can be grouped into two main groups, *deterministic models* and *stochastic models* (Pinedo, 2012). *Deterministic models* represent the simplest scheduling models that assume a specific value of the variable, e.g. constant processing time, while *stochastic models* use ranges of values for each variable to account for the inherent uncertainty (Pinedo, 2012).

3.3.2 Scheduling in practice

While scheduling in theory is based on allocating and sequencing decisions and on algorithmic solutions, scheduling in practice emphasizes on social and organizational processes (Jackson et al., 2004). Scheduling in practice first ensures that the conditions that enable a schedule to be carried out are present (facilitation) and then accomplishes the schedule (implementation). If a schedule cannot be implemented, scheduling is the function of facilitating acceptable alternatives and implementing a strategy to complete the planned work (Jackson et al., 2004, MacCarthy and Wilson, 2001).

Jackson et al. (2004) observed that schedulers do not often sit down and work through the generation of a schedule in a sequential or structured way. Mostly the schedule is produced by the computer system, and the scheduler's main role is to transfer the virtual production plan

into production reality. In any case, it is obvious that real world scheduling problems are usually very different from the mathematical models studied by researchers in academia (Pinedo, 2012). Perhaps the single most important task in scheduling practice is *rescheduling*.

Rescheduling

Mostly schedulers deal with dynamic, complex, and relatively unstable production situations. This instability has a major influence on scheduling and schedulers (Crawford and Wiers, 2001). Unplanned or exceptional events that influence the production will consequently also affect the production plans and schedules. These events are situations that can make a supposedly feasible plan into an infeasible plan that might not be trusted. Other names on unplanned or exceptional events are *uncertainties*, *disruptions*, *disturbances*, and *rescheduling factors*. It is uncertain when this type of event will happen and what the consequences will be (de Snoo et al., 2011c).

It is important to accept that it is impossible to safeguard completely against events that affect the initial schedule. Therefore, it is important that schedulers are trained in the management of these situations (MacCarthy and Wilson, 2001). If events lead to deviations from the initial schedule, rescheduling is necessary.

According to de Snoo and van Wezel (2014), rescheduling can be defined as “the process of updating an existing schedule in response to unexpected disruptions”. Examples of disruptions are *machine failures*, *material shortages*, *order changes*, and *operator absence*. These can cause schedule infeasibilities that often require a quick response. One should be aware of that because of interrelation and interdependencies between different schedules, a change in one schedule can easily affect other schedules. Rescheduling events are strictly time constrained, and therefore, complete rescheduling is in many cases impossible (de Snoo et al., 2011c). There are several known techniques for rescheduling, such as *affected operation rescheduling* and *right-shift rescheduling*. These techniques help the scheduler to recreate a feasible schedule (de Snoo et al., 2011c).

Centralized rescheduling of each and every change would result in nervousness on the shop floor and an information overload of the scheduling department. Therefore, shop floor schedules are normally made robust so that small changes can be handled within a department without affecting other departments (de Snoo et al., 2011b). However, if a schedule change involves multiple departments, and complete rescheduling is not possible, efficient coordination and communication between the different departments is crucial to ensure rescheduling on time (de Snoo and van Wezel, 2014).

3.3.3 Performance measurement

The basic goal of business improvement is essentially the same: *to do more better and faster with less*. A critical enabler and success factor when using improvement strategies is the ability to quantitatively measure performance (Harbour, 2009). Quantitatively measuring the performance can help drive desired results at any level, and help identifying problem areas and drivers of performance within an organization. The goal of a performance measurement system is to provide the right people with the right performance-related information at the right time to make the right decision (Harbour, 2009). The key to a successful performance measurement system is to collect only those measures that can help to better understand, manage, and improve the performance of the organization (Harbour, 2009).

Regarding production scheduling, performance is normally measured as the extent to which the scheduling goals are realized and the constraints are violated. The metrics that are commonly used to measure scheduling performance are related to the projected execution of the schedule, for instance *total completion time*, *lateness*, *earliness*, *tardiness*, and *machine utilization* (de Snoo et al., 2011a). Choosing appropriate performance indicators for scheduling helps the employees to track the efficiency of their work and get feedback on the effects of their decisions. This way, it is easier for the schedulers to improve their scheduling and control processes.

There are plenty of relevant scheduling performance indicators. de Snoo et al. (2011a) have mapped different scheduling performance indicators and developed a framework that shows 16 different performance indicators that are often used by scheduling environments. The framework is presented in table 4. In addition, they also identified five factors that influence scheduling performance: *organizational planning structure*, *scheduler knowledge/skills*, *information technology*, *information quality*, and *complexity and uncertainty*.

Table 4: Examples of scheduling performance indicators (de Snoo et al., 2011a).

Indicators focused on the scheduling product	Indicators focused on the scheduling process	Indirect scheduling performance indicators
Schedule errors	Timeliness of initial release	Realized performance of the scheduled process
Costs of execution of the schedule	Reliability of initial release	Complaints and feedback from schedule users
Fulfillment of constraints and commitments made to external parties	Flexibility of schedule adaption	
Fulfillment of resource utilization constraints	Accessibility of schedulers	
Fulfillment of preferences and wishes of employees using the schedules	Communication quality	
Schedule robustness / information completeness	Harmonization quality	
Information presentation and clarity	Cost and efficiency of the scheduling process	

3.3.4 Technological systems

Enterprise resource planning (ERP)

An ERP system is an enterprise-wide information system that integrates all the information from many functions that are needed for planning and control of the production activities (Slack et al., 2010). ERP can be defined as (Slack et al., 2010):

A complete enterprise wide business solution. The ERP system consists of software support modules such as *marketing and sales*, *field service*, *product design and development*, *production and inventory control*, *procurement*, *distribution*, *industrial facilities management*, *process design and development*, *manufacturing*, *quality*, *human resources*, *finance and accounting*, and *information services*. Integration between the modules is stressed without the duplication of information.

The ERP system allows decisions and databases from all parts of the organization to be integrated. This means that the consequences of decisions in one part of the organization are reflected in the planning and control systems of the rest of the organization (Slack et al., 2010). This is illustrated in figure 12. ERP can be compared to a central nervous system, sensing information about the condition of different parts of the business and relaying the information to other parts of the business that need it. This information is updated in real time and is always available to everyone connected to the ERP system (Slack et al., 2010). Some of the general accepted benefits of ERP are (Slack et al., 2010):

- Excellent visibility of what is happening in different parts of the business.
- If the ERP implementation forces business process changes, it is a good opportunity to make the processes more efficient.
- An increased “sense of control” of the operations makes continuous improvement easier.
- Enables the possibility of giving more accurate and timely information to customers, suppliers, and other business partners.
- The capability of integrating whole supply chains, including suppliers’ suppliers and customers’ customers.

By using the gathered information, an ERP system is able to develop production plans and schedules. However, since the ERP systems remain centered around old material requirements planning (MRP) logic, capacity constraints are ignored and fixed lead times are assumed. This means that there is no guarantee that a feasible production schedule will be developed from the generated production plan (Arica and Powell, 2013). In order to overcome these challenges, more sophisticated planning systems have emerged, such as advanced planning systems (APS) (Arica and Powell, 2013). This thesis does not however look into these types of planning systems since it is considered to be outside the scope of this thesis.

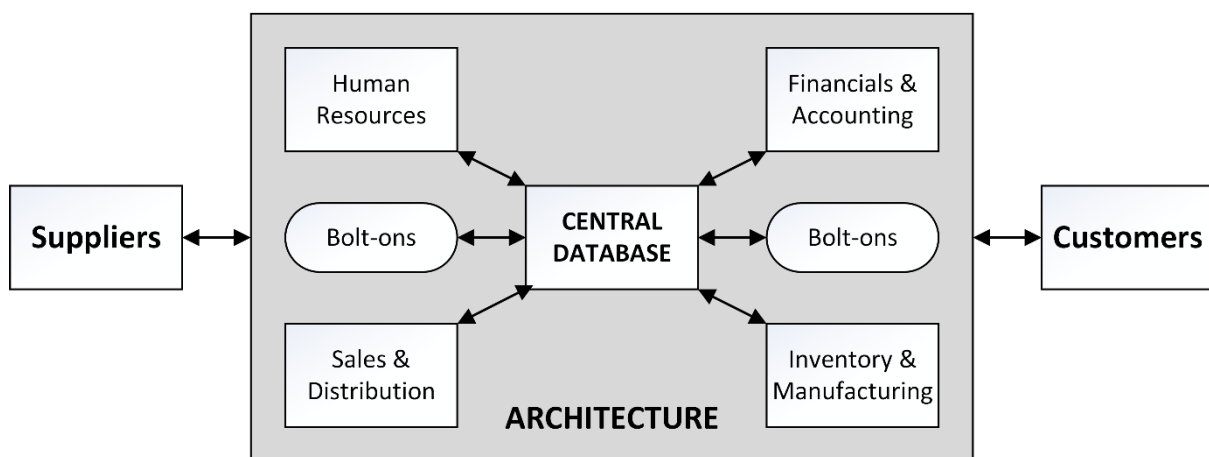


Figure 12: Overview of an ERP system (Mabert et al., 2001).

Manufacturing execution system (MES)

In its early days, there was no clear definition on what a MES was. At this time, each software vendor had their own definition of MES generally based on the capabilities of their own tools or on the expectations of their customers (Saenz de Ugarte et al., 2009). However, in 1997 the

Manufacturing Enterprise Solutions Association (MESA) suggested a formal definition of MES (Saenz de Ugarte et al., 2009):

MES deliver information that enables the optimisation of production activities from order launch to finished goods. Using current and accurate data, an MES *guides, initiates, responds to and reports* on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non-value-added activities, drives effective plant operations and processes. The MES improves the return on operational assets as well as *on-time delivery, inventory turns, gross margin and cash-flow performance*. An MES provides mission-critical information about production activities across the enterprise and supply chain via bidirectional communications.

Together with this, MESA also identified eleven principal MES functions. These are as follows (Saenz de Ugarte et al., 2009):

1. Operations/Detail scheduling
2. Process management
3. Document control
4. Data collection/acquisition
5. Labor management
6. Quality management
7. Dispatching production units
8. Maintenance management
9. Product tracking and genealogy
10. Performance analysis
11. Resource allocation and status

In short, MES is a system for data support and production monitoring and management. MES is an extension of planning tools such as ERP, with an emphasis on carrying out the plan. The MES takes input from the planning system and translate that plan into a language that fits the plant floor and the resources required to execute the plan (McClellan, 2001, Arica and Powell, 2013).

4 Organizational theory

The word *organization* comes from the Greek word *organon*, which means *tool* or *instrument* (Modaff et al., 2008). An organization can be defined as “a tool people use to coordinate their actions to obtain something they desire or value” (Jones, 2010). Organizations are created so that people can work together and be able to satisfy their needs and achieve their goals.

Organizational theory is “the study of how organizations function and how they affect and are affected by the environment in which they operate” (Jones, 2010). Value creation in organizations takes place at three stages: *input*, *conversion*, and *output*. *Inputs* represent resources such as raw materials, machinery, information and knowledge, human resources, and money and capital. Human resources and technology are used to *convert* inputs into outputs. These resources creates *outputs* such as finished goods and services (Jones, 2010).

Organizations and communication are highly interrelated. Communication is essential for the existence of the organization and influences the structure that constitutes the organization. On the other hand, the structure affects the nature and flow of communication within the organization (Modaff et al., 2008). This chapter therefore first looks into organizational concepts such as organizational structure and culture, and thereafter investigates the theory behind organizational communication. The chapter structure is illustrated in figure 13.

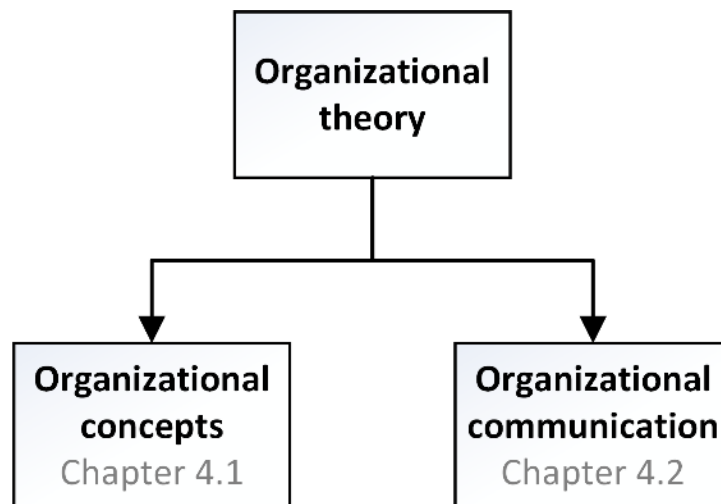


Figure 13: The structure of the organizational theory chapter.

4.1 Organizational concepts

According to Jones (2010), three of the main concepts within organizational theory are *organizational structure*, *organizational culture*, and *organizational design and change*. While the first two can be viewed as two aspects that characterize an organization, *organizational design and change* relates to changing an organization to fit its needs. Figure 14 shows the main features of each concept and how they are related.

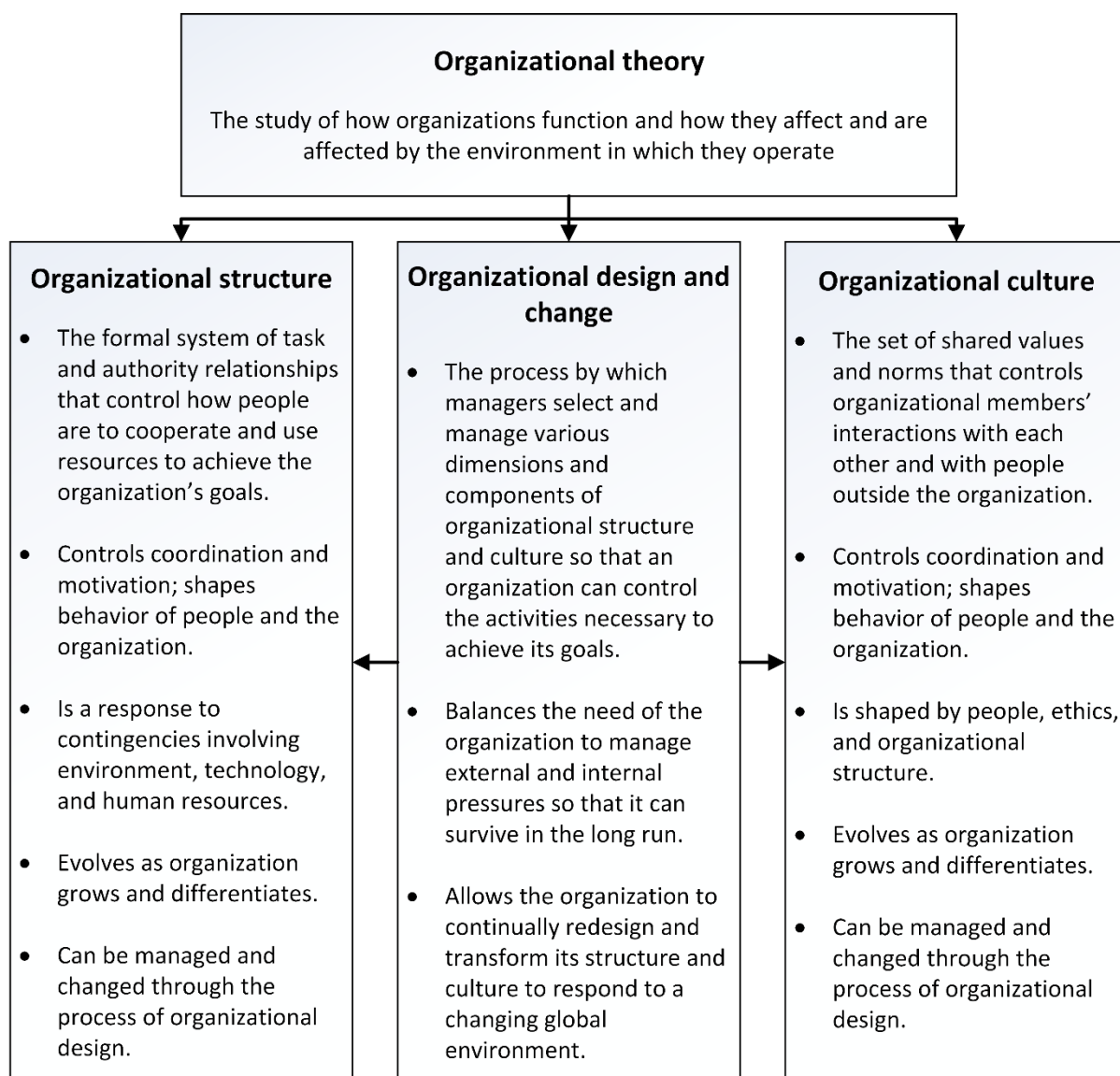


Figure 14: The relationship between organizational concepts (Jones, 2010).

4.1.1 Organizational structure

After a group of people has established an organization to accomplish collective goals, the next step is to develop an organizational structure to increase the effectiveness of the organization's control of the activities necessary to achieve its goals (Jones, 2010). Organizational structure can be defined as "the formal system of task and authority relationships that control how people coordinate their actions and use resources to achieve organizational goals" (Jones, 2010). The principal purpose of the organizational structure is to control the way people coordinate their actions to achieve organizational goals and to control the means used to motivate people to achieve these goals. An appropriate structure facilitates effective responses to problems of coordination and motivation (Jones, 2010).

4.1.2 Organizational culture

While organizational structure relates to formal procedures within an organization, organizational culture represents the set of shared values and norms that members of the

organization have in common (Jones, 2010). These values and norms affect how the members interact with each other and with people outside of the organization, such as suppliers or customers. The organizational culture is shaped by the members of the organization, the ethics of the organization, the employment rights given to employees, and the organizational structure (Jones, 2010)

4.1.3 Organizational design and change

Both organizational structure and organizational culture evolves and can be managed through organizational design and change. Organizational design relates to managing aspects of the structure and culture in an organization so it can control the activities necessary to achieve its goals (Jones, 2010). Organizational structure and culture can be seen as the means the organization uses to achieve its goals, and organizational design is about how and why the various means are chosen. Organizational change is “the process by which organizations redesign their structures and cultures to move from their present state to some desired future state to increase their effectiveness” (Jones, 2010). Organizational design and change are highly interrelated; an organizational change can be understood as the process of organizational redesign.

Because of increased global competitive pressure, organizational design has become one of the top priorities to stay competitive, by searching for new and better ways to coordinate and motivate the employees to increase the value creation (Jones, 2010).

Jones (2010) presents four reasons for why organizational design and change are important:

Dealing with contingencies

A contingency is an event that possibly can happen, but cannot be predicted with certainty. The organizational design determines how effectively an organization is able to respond to various events that influence its operation. A well-designed organization should be able to maintain control over its environment and adapt to market changes, new laws, and paradigm shifts.

Gaining competitive advantage

Organizations are increasingly discovering that organizational design and change could be a source of competitive advantage. Many sources of competitive advantage, such as state-of-the-art technology, evaporate because it is easy for competitors to imitate. Good organizational design and carefully managed change is much more difficult for competitors to imitate, since the structure and culture are embedded in the way people in an organization interact and coordinate their actions to get a job done. An organization’s strategy is always changing in response to changes in the environment, and organizational design must be carried out continuously to stay ahead of competition. Since there is never a single optimal or “perfect” design to fit an organization’s need, managers must constantly evaluate how well their structure and culture work, and change and redesign them continually to improve them.

Managing diversity

Gender and cultural differences have important implications for the values of an organization’s culture and for organizational effectiveness. An organization needs to design the structure to make optimal use of the talents existing in a diverse workforce and develop cultural values that encourage people to work together. In an increasingly globalizing world where companies operate in different countries with different cultures, organizational design becomes even more important to harmonize national culture with organizational culture.

Promoting efficiency, speed, and innovation

Organizational design involves a constant search for better ways of coordinating and motivating employees, since different structures and cultures cause employees to behave in different ways. The organizational design influences the efficiency of the organization's operations, the speed of the decision-making, and the innovation ability of the organization.

4.2 Organizational communication

Organizational communication can be defined as “the study of why, how, and with what effects organizations send and receive information in a systemic environment” (Zaremba, 2010). It is the process of creating, exchanging, interpreting, and storing messages within a system within a system of human interrelationships (Modaff et al., 2008).

4.2.1 Interpersonal relationships

Interpersonal relationships represent the connection between the different people within an organization (Modaff et al., 2008). Communication between coworkers creates one of the strongest connections between an employee and their job and organization. As people feel more connected, morale and organizational commitment increase (Modaff et al., 2008). Basically, there are two types of interpersonal relationships: *organizational* or *personal*. *Organizational interpersonal relationships* are based on the organizational structure, a form of connection that later is referred to as an *interconnection* (chapter 5.2.2). Persons participating in an organizational interpersonal relationship have to do this because the organizational structure dictates that they must work together to solve a mutual task (Modaff et al., 2008). On the contrary, *personal relationships* develop because people voluntarily choose to spend time with each other because of mutual emotional needs (Modaff et al., 2008). While an *organizational interpersonal relationship* might start out as a required association, it can later develop to also become a *personal relationship*, in other words a friendship (Modaff et al., 2008).

Modaff et al. (2008) describe five basic principles of developing interpersonal relationships in organizations. These five principles help us to understand how these relationships function.

Proxemics

Proxemics is the area of research that relates to the social effects of the distance between people. Research within this field has found that people often develop friendships with individuals that happen to share the same space. Therefore, in an organizational context, individuals are more likely to develop personal relationships with those who they have regular contact with, rather than with others who they seldom see or hear. Managers could utilize this phenomenon and place individuals who they need to cooperate well within the same physical space. This relocation increases the likelihood that these individuals develop a personal relationship.

Relational communication

Messages could be divided into two levels. The *content* of a message conveys the actual information that should be communicated. The *command* aspect is the second level of communication, and defines the relationship between the two individuals. By analyzing the timing and presentation of the message and the tone of voice and facial expression of the sender, it is possible to say something about the relationship between the sender and the receiver. Two

persons who like each other are certainly going to communicate in a different way than two persons who have a poor relationship.

Relation balance

The balance of interpersonal relationships could be either *symmetrical* or *complementary*. *Symmetrical relationships* are characterized by two partners that are equal in the relationship. They participate equally in the decision-making and share control over what they are doing. *Complementary relationships* are the opposite, meaning that one person's behavior complements the other person's behavior. For instance, one person could be dominating, while the other is submissive. Usually, superior-subordinate relationships appear complementary, while coworker relationships appear symmetrical. This could however vary depending on the situation.

Interpersonal needs

In an interpersonal relationship, both partners come to the relationship with the same psychological needs. These are *the need for inclusion*, *the need for affection*, and *the need to control others*. The magnitude of these needs will however vary depending on the individual person. The first need, *inclusion*, is an expression of the human desire to be a member of some relationship or group. Secondly, everyone has a need to give and receive *affection* from other people. The third need, *control*, reflects the fact that people want to feel that they have power to influence outcomes in relationships. Everyone feels these needs, but to a different degree. Research argues that the better the fit between individuals and their respective needs, the more productive the relationship between these will be. For instance, a person that has a high need for inclusion will have a satisfying relationship with someone who has a high need to include others.

Relational control

The fifth, and last, principle deals with control. Research has shown that coworker relationships can serve as a powerful control over an employee's behavior. If the employees feel that their own effort affects others, and that the effort of others affects their own possibilities of success, the coworkers will together make an effort to maximize the productivity. In these cases, the coworkers control one another's behavior.

4.2.2 Communication support

In order to increase the effectiveness of the communication within the organization, some measures could be carried out. Modaff et al. (2008) present some approaches to improve the workplace relationships, or in other words, support the organizational communication.

Provide positive feedback

An individual that provides positive feedback does not only raise the morale among his or hers contacts, it will also increase the possibility that he or she will receive similar support from others in the future.

Mediate conflict

A person who is able to mediate conflicts between others is often chosen as the leader of a group. Diversity in the organization may require additional skills at developing coworker relationships. The possible positive effects of a diverse workforce, such as increased creativity and increased responsiveness in diverse markets, only apply if the diversity is managed well

within the organization. The organization should be aware of this and support this diversity by being sensitive to the different cultures and use appropriate methods to resolve conflicts.

Discuss communication

Metacommunication means talking about how you talk to each other, to discuss the communication process itself. In this way, it is possible to identify possible sources of misunderstandings, and discuss how the communication routines could be changed in order to avoid misunderstandings in the future.

Another factor that influences the organizational communication is the proximity of employees. This is an important factor in fostering productive relationships, and there is good evidence that reducing the distance and physical barriers between people increases the amount of communication between them (Galbraith, 2014). The organization designer should therefore give careful thought to location patterns. The designer should be familiar with the interconnections of the different groups and use this when deciding the location layout (Galbraith, 2014).

4.2.3 Communication media

The advancements within ICT the last decades have greatly changed the communication possibilities within organizations. New communication technologies have been introduced and these have altered the way people communicate with each other. Some examples of ICT-based communication media are *e-mail*, *instant messaging*, and *video conference* (Modaff et al., 2008). The new technologies introduce many new possibilities, and Modaff et al. (2008) present five of the advantages of ICT-based communication technology:

1. Increase in the speed of communication.
2. Dramatic reductions in the costs of communication.
3. Increases in communication bandwidth, i.e. the amount of information that can be pumped through a communication line.
4. Vastly expanded connectivity, which is the extent to which people and computers are linked.
5. Integration of communication computing technologies, which enables groups of people to share information and develop a community.

This section introduces two aspects that most likely will determine when and how a particular communication medium is used. The first aspect is *social presence*, which refers to the degree of sociability present in the use of the media. Warmth, sensitivity, and “personalness” are some of the factors that say something about the social presence of a communication medium (Modaff et al., 2008). Face-to-face communication is the communication medium with the highest degree of social presence, since it supports the use of facial expressions, touch, posture, and numerous nonverbal cues to communicate a message. The people who participate in the conversation feel that they are involved and present in the dialogue (Modaff et al., 2008). On the other hand, written messages such as e-mail and letters offer the lowest level of social presence. This makes it harder for the recipient to interpret the message, and the recipient may feel that a dialogue is not occurring, just a one-way message answered by another one-way message (Modaff et al., 2008). Different messages require different levels of social presence depending on the situation. For instance, conflicts are one type of situation that should be dealt with face-to-face, i.e. a medium with high social presence.

5 Organizational factors of production scheduling and control

Two key areas are typically overlooked in production planning and control research (McKay and Wiers, 2006b):

- 1) Cognitive processes of the actual planner and scheduler
- 2) The organizational environment within which planning and scheduling is undertaken

This chapter looks into the second point, *the organizational environment within which planning and scheduling is undertaken*, with an emphasis on scheduling. Other researchers support the need for research in this area as well. MacCarthy (2006) points out that production planning and control processes should be carefully designed in a way that addresses organizational structure, planning levels, and roles in particular. Jackson et al. (2004) state that both social and organizational factors support and influence the scheduling function.

Berglund and Karlton (2007) investigated how production scheduling processes are influenced by human, technological, and organizational aspects. To do this, Berglund and Karlton (2007) utilized the HTO-concept. HTO stands for *human, technology, and organization*. This concept was first developed during the 1980s by the nuclear power industry to improve overall safety. It was realized that all of the three HTO components in a system need to be addressed to improve safety (Berglund and Karlton, 2007). This concept has later been used as a meta-concept that can be applied to analyze and further develop the understanding of highly complex work activities (Berglund and Karlton, 2007). The three components are now introduced with brief comments on how they relate to production scheduling.

The human component focuses on the individual's contribution to the business process. In production scheduling and control, it represents the scheduler's individual contribution. This could for instance be *individual skill, knowledge, or experience* (Berglund and Karlton, 2007).

The technology component focuses on the technological systems that are available for use. In production scheduling and control, the technological systems can be divided into two parts: *primary* and *secondary system*. *The primary system* represents the production equipment of the company. *The secondary system* assists the administration and procedures of the company, but is not directly value adding. In production scheduling and control, this is usually planning and decision support software tools (Berglund and Karlton, 2007).

The organization component represents humans in an aggregated sense. It covers how the work is organized and structured, both formally and informally. The organization component also includes rules, procedures, and cultural factors as well as relations between system components and subsystems. Physical aspects are also relevant, such as where people are located and how premises are designed (Berglund and Karlton, 2007).

The H-, T-, and O-components interact in different ways. Berglund and Karlton (2007) believe that many interesting characteristics of the schedulers' work can be found in the interaction between the components.

All three aspects introduce conditions and limitations for the scheduling process, which suggest that all three components need to be addressed when aiming for an overall improvement of the scheduling process (Berglund and Karlton, 2007).

Definition of organizational factors

There have been few attempts to explicitly define the term *organizational factors*. Usually they are defined by examples of “non-technical” aspects of a system that might have an impact on its effectiveness (Doherty and King, 1998). Berglund and Karlton (2007) argues that an organization represent humans in an aggregated sense, and organizational factors therefore covers aspects such as how work is organized and structured, together with rules, procedures, and cultural factors. Several other factors may also be included in this definition. The first definition is more general as it refers to organizational factors as purely “non-technical” aspects. This definition is not completely accurate since it is possible that a “non-technical” aspect instead is related to individual human aspects (cf. HTO-concept). This has been taken into account in the second definition, and therefore this definition is the one that is used throughout the thesis.

This chapter consists of four subchapters presenting relevant findings related to organizational factors in production scheduling and control. The findings are structured and categorized according to the HTO-concept. The HTO-concept is visualized in figure 15, with intersections between the components. There are therefore four relevant areas to investigate further when looking into organizational factors: the organizational component and the intersections with the other two components. As pointed out by Berglund and Karlton (2007), many interesting characteristics might be found in these intersections. It is assumed that the concept of a Venn-diagram is known. The intersections between the components represent aspects that relate to all of the intersecting components.

By utilizing this method, four categories are established, each in one of the four relevant “slots” in the HTO-diagram. All of the four categories contain organizational factors identified through the literature study, but they are categorized regarding whether they relate to any of the other components as well.

The first category, *organizational factors related to formal structures and procedures* (chapter 5.1), contains factors that are considered only to relate to organizational aspects. These kind of aspects relates to how work is organized and structured together with related rules, procedures, and cultural factors (Berglund and Karlton, 2007).

Organizational factors related to human and human tasks and interaction is the second category (chapter 5.2). This category is for organizational factors that relate to human behavior and human communication.

The third category is *organizational factors related to technological systems* (chapter 5.3). Organizational factors in this category are closely linked to the technological systems that are being used by the organization.

Some factors relate to all of the three components, and they are categorized as *general organizational factors* (chapter 5.4). These are typically complex issues since they relate to both human, technological, and organizational aspects, and because of this, they may be challenging to handle.

The chapter presents nine different organizational factors identified through the literature study. Each factor is introduced, their importance is stated, and there are some comments on how they should be handled. The different factors were classified and placed in the seemingly most appropriate category, but some of the classification choices might be a theme of discussion.

The categorization is presented as a Venn-diagram in figure 15, which also shows the respective chapter numbers of the different categories.

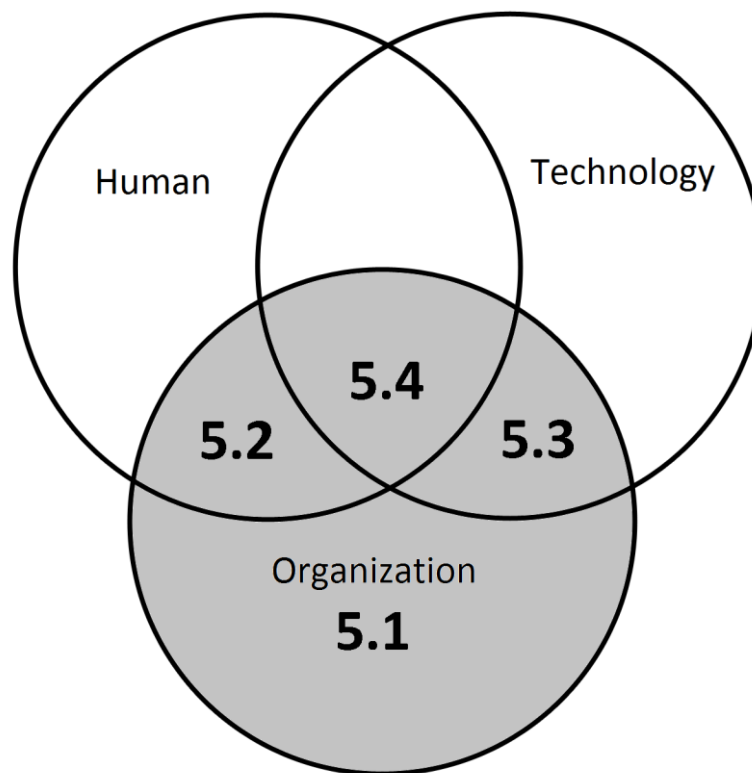


Figure 15: Categorization of the organizational factors in accordance with the HTO-concept.

5.1 Organizational factors related to formal structures and procedures

5.1.1 Decision autonomy between shop floor and schedulers

In this context, decision autonomy indicates the decision freedom regarding production control decisions (Wiers, 2009). Other words for autonomy are *independence* and *self-rule*, and the concept relates to how much a unit can decide for themselves, and how strict the commands from their managers are (McKay and Wiers, 2006b). When a unit carries out a mission, some kind of task list or other requirements can be considered as input, along with stated objectives. By using these, the unit takes decisions on how to solve the situation. The more detailed and constrained these instructions and guidelines from the higher authority are, the less autonomy exists (McKay and Wiers, 2006b). When designing decision support systems to support scheduling, autonomy is a crucial concept since it defines which decisions that should be taken by the schedulers and which decisions that should be taken by the shop floor (Wiers, 2009).

The decision on how much autonomy to allocate to the shop floor should be evaluated thoroughly (McKay and Wiers, 2006b). According to Wiers (2009), three main criteria are used in the discussion of how much autonomy to allocate to the shop floor: *uncertainty*, *sociotechnical paradigm*, and *optimization*.

Uncertainty relates to the inherent uncertainty in the production process. Because of their close connection with the production process, the shop floor personnel are often faster and better able to react to disturbances than the scheduler (Wiers, 2009). Especially if the shop floor operates outside the working hours of the schedulers, it is basically unavoidable to let the shop floor operators take some scheduling decisions (Wiers, 2009).

The *sociotechnical paradigm* affects how production control is organized. This paradigm supports the idea that decisions should be taken at the lowest possible level in the organization (Wiers, 2009). In addition, the shop floor personnel might become more motivated when they are allowed to make decisions about what to produce and when (Wiers, 2009).

From an *optimization* point of view, scheduling decisions should be centralized as much as possible. This is because scheduling requires an overview of the different production steps and future production orders, and shop floor operators normally only see a subset of these. If these aspects are not considered, a suboptimal scheduling decision is most likely taken (Wiers, 2009).

While the first two criteria can be seen as reasons to allocate scheduling decisions to the shop floor, the last criterion is an example of the opposite. This view is also supported by McKay and Wiers (2006b) who suggest that while the operators might have detailed manufacturing knowledge and will receive information earlier, they might miss the overall view of the process or other important pieces of information, such as customer priorities.

It is no proven “right” level of autonomy (Wiers, 2009). The appropriate level of autonomy differs between organizations and the above-mentioned criteria are important aspects to consider when deciding on the level of autonomy. Production characteristics and organizational culture are other important factors that influence the appropriate autonomy level (McKay and Wiers, 2006b). Inappropriate decision autonomy between shop floor and schedulers will most likely result in suboptimal production scheduling decisions.

5.1.2 Department structure and scheduler location

The organizational structure of the business will have an influence on the scheduler’s ability to deliver good schedules (McKay and Wiers, 2006b). For instance, which department the scheduler is a part of, might influence the possibilities of executing the schedule in its original form. This is illustrated by McKay and Wiers (2006b) who suggest that if a scheduler is part of the production department, it might be easier to have the schedule executed as it is. On the other hand, if the scheduler is in a logistical department between production and sales, and the production department focuses on efficiency, while sales focuses on service, it will be harder for the scheduler to implement a schedule.

In addition, the organizational structure of the business should reflect the requirements of both traditional scheduling and rescheduling. Rescheduling is a completely different situation than traditional scheduling, with intense time pressure and often an unclear overview of the situation (de Snoo and van Wezel, 2014). Because of this, the interdependencies of the schedulers will change, and this should be taken into account when designing the organizational structure. The structure should be robust and be able to handle different types of situations.

The physical location of the scheduler is a recurring theme in research, and a classical design variable in operations management (de Snoo et al., 2011b). Especially the distance between the schedulers and the shop floor is a frequently discussed subject (de Snoo et al., 2011b, de Snoo

and van Wezel, 2011, Berglund and Karlton, 2007). Proximity is seen as an important enabler of efficient communication, and studies have shown that a reduced distance between the schedulers and the shop floor have indirect organizational and behavioral effects that will influence rescheduling behavior and increase performance (de Snoo et al., 2011b).

If the scheduler is not part of the production department, the scheduler might have a hard job convincing the production to reduce the quantity on one job to help a job in next week's schedule, to use an alternative process, or to use different material. The production personnel might claim that it is technically infeasible to shorten the production runs, to use an alternative machine, or to use materials that are slightly off spec (McKay and Wiers, 2006b). It might be difficult for a scheduler to convince the production personnel to sacrifice an immediate objective for a future one (McKay and Wiers, 2006b).

It is important for the scheduler to be well connected with its contacts. If they are in an isolated situation without knowledge of the uncertainty in the forecasts and the production output, the future production will also be uncertain (McKay and Wiers, 2006b). This is because the scheduler will lack knowledge of the possible unplanned events that might occur, and the schedules might not be robust enough to handle these events.

Regardless of the scheduler's official position in the organizational structure, and how integrated they are with their colleagues, the scheduler will have some challenges in understanding the requirements of the different departments, trying to strike a compromise, and to convince everyone that the recommended solution is the best one. This puts requirements on the scheduler's knowledge and persuasiveness, but also the ability to keep a good relationship with key persons in all relevant parts of the organization (McKay and Wiers, 2006b).

In relation to the physical location of the schedulers, Berglund and Karlton (2007) state that physical proximity enables schedulers to more easily obtain information from the production and other employees, and, therefore, to efficiently solve scheduling problems. A central physical location contributes to the scheduler's role as an information node and problem solver. A good relationship between schedulers and operators seems to be essential to handle the many events and schedule adaptations efficiently, and research have shown that proximity have positive effects on social commitment, cooperation, consensus, and work satisfaction (de Snoo et al., 2011b).

A suboptimal department structure and physical location may result in communication issues, which will have a negative effect on the production scheduling and control performance.

Normally, scheduling and production are seen as two separate, hierarchically related departments. However, as recent research has shown, there might be benefits if these two are merged together (de Snoo et al., 2011b). McKay and Wiers (2006b) also highlight the possible positive effects of merging these two departments, but suggest that the interdependencies between the different business functions should be the focus when deciding the department structure. If the interdependencies between scheduling and production are of a certain degree, it might be desirable to merge these two departments.

The interdependencies are also an important aspect to consider when deciding the scheduler location. The schedulers do not only communicate with the shop floor, they also communicate plenty with other departments. Companies should therefore investigate the interdependencies between the departments and analyze these in order to identify the optimal scheduler location.

5.2 Organizational factors related to humans and human tasks and interaction

5.2.1 Scheduler training

A step towards more efficient scheduling is to ensure that the schedulers have a thorough understanding of the process and product(s) they are being asked to schedule (Berglund and Karlton, 2007). This is to ensure that the scheduler has the ability to recognize hidden relationships, be aware of possible problems that can occur, and identify possible alternative resource assignments (Crawford and Wiers, 2001).

Previous shop floor work experience is also a major benefit for the scheduler, since it ensures thorough knowledge of the production resources and its constraints. This way, the scheduler may easily understand the implications of machine failure. It also gives the scheduler good legitimacy at the shop floor (Berglund and Karlton, 2007).

Effective scheduler training enhance the scheduling performance (MacCarthy and Wilson, 2001, Crawford and Wiers, 2001). A well trained scheduler is able to produce robust schedules that anticipate events that might influence the schedule, take these into account, and have an understanding of the necessary actions in case of schedule-influencing events.

Companies should have a good selection process for new employees and provide the necessary training to their schedulers (MacCarthy and Wilson, 2001). The organization should also facilitate the possibility for experience exchange between the schedulers and the shop floor. The operators have plenty of valuable information about the production situation that will benefit the schedulers in their work.

5.2.2 Knowledge and communication facilitation of scheduling interconnections

Schedulers do not work alone and are dependent on information from other parts of the organization in order to conduct their work. A scheduler that is well acquainted with his colleagues will know how to utilize these people in the best manner in order to solve problems (Karlton and Berglund, 2010). The most basic example of a scheduling interconnection is that schedulers need situational information about the production from the operators to maintain feasible schedules, while operators need information about production schedules and schedule changes (de Snoo et al., 2011b). Other examples of functional interconnections for schedulers are *purchasing, sales, quality, finance, human resources, support groups, industrial engineering, and information technology* (McKay and Wiers, 2006b). These interconnections are illustrated in figure 16.

Relevant and timely information is essential for the scheduler in order to make good decisions (Crawford and Wiers, 2001). Scheduling decisions are tasks that necessarily have to involve risk and uncertainty, and relevant information help decrease this risk and uncertainty (McKay and Wiers, 2006b). It is therefore important that the scheduler have knowledge about whether or not a specific problem can be solved individually or if it requires coordination with other people. For instance, changes in one schedule might influence schedules created by other schedulers for other production units (de Snoo et al., 2011c).

It is important that the scheduler is well acquainted with his colleagues and know when to contact whom. The scheduler should be able to analyze the situation and determine what sort of information that is needed and where this information may be obtained. Often there is significant physical distance between individuals in the organization, and in some way or another, this will hinder the communication. Geographical dispersion should be compensated by using procedures to encourage communication and suitable technologies should be put in place to facilitate it (MacCarthy and Wilson, 2001). Together, knowledge of the interconnections and communication facilitation of these will ensure an efficient information flow, and thereby positively influence the production scheduling and control performance.

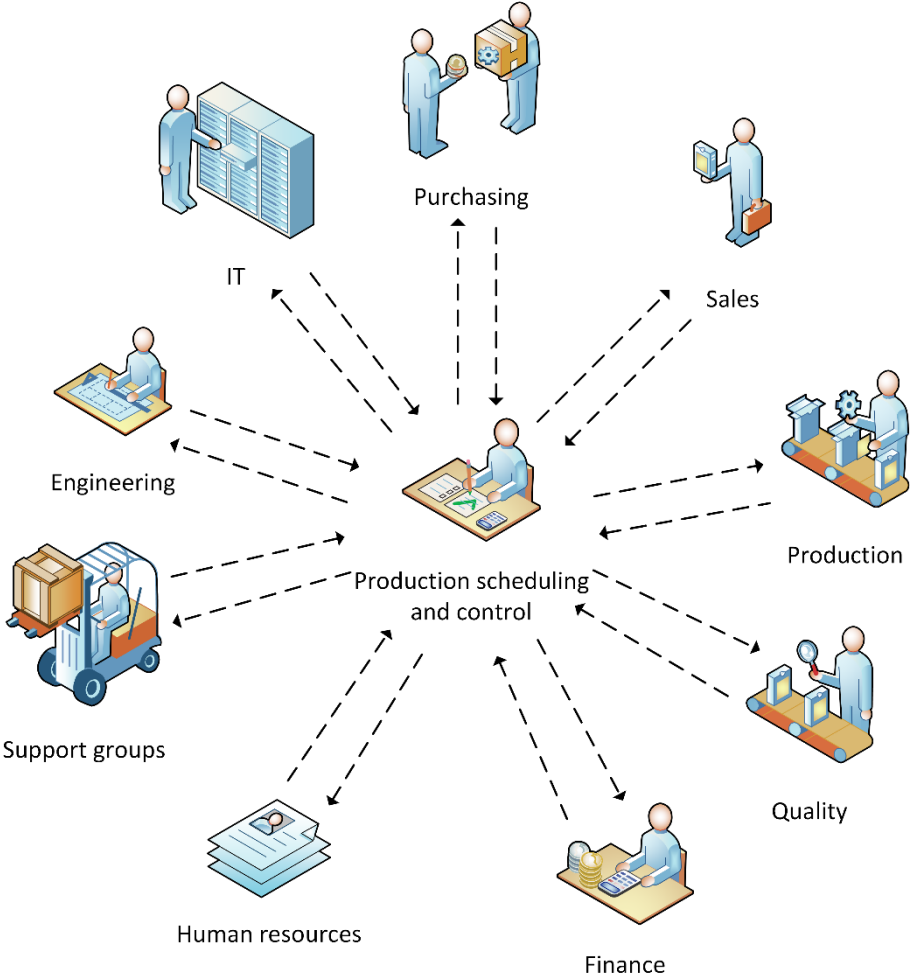


Figure 16: Some of the scheduling interconnections (Adapted from McKay and Wiers (2006b))

5.2.3 Collaboration during rescheduling

As mentioned earlier, rescheduling can be defined as “the process of updating an existing schedule in response to unexpected disruptions” (de Snoo and van Wezel, 2014). Examples of disruptions can be *machine failures, material shortages, order changes, and operator absence*. These can cause schedule infeasibilities that often require a quick response. Because of interrelation and interdependencies between different schedules, a change in one schedule can easily affect other schedules. When multiple schedulers develop the schedules, efficient

coordination and communication are crucial to ensure rescheduling on time (de Snoo and van Wezel, 2014).

During regular scheduling, which refers to the initial construction of the schedule, interdependencies can be managed using simple rules and agreements. This could for instance be that the schedulers develop their schedules sequentially. If problems occur, there is sufficient time to coordinate and fix the problems (de Snoo and van Wezel, 2014). Rescheduling is a completely different situation with intense time pressure and often an unclear overview of the situation. The interdependency requirements will therefore change, and other coordination modes might be necessary (de Snoo and van Wezel, 2014).

Decision-making theory distinguish between two alternative modes of coordination between interdependent decision makers: *distributed decision making* and *group decision making* (de Snoo and van Wezel, 2014). *Distributed decision making* refers to a decision mode where the problem is divided among the group members, where each one only deals with a subset of the problems. By using this model, the group members will most likely lack a global understanding of the problem (de Snoo and van Wezel, 2014). *Group decision making* refers to a decision mode where every decision is achieved through consensus among the group members, i.e. all group members treat the full set of problems (de Snoo and van Wezel, 2014). These two decision making modes are illustrated in figure 17.

Normally, scheduling situations are often too complex to be dealt with by a single scheduler, and the overall scheduling task is therefore normally broken down into several smaller scheduling tasks performed by different schedulers. Decomposition criteria of these tasks could for instance be departments, time buckets, and product families (de Snoo and van Wezel, 2014). The choice of coordination mode to support these interdependencies is therefore an important issue to consider. This thesis will not look into which coordination mode that is most fitting for regular scheduling, but in a normal situation with stable interdependencies and good procedures for schedule generation, *distributed decision making* seems sufficient. However, this might not be the case for rescheduling situations.

Rescheduling situations are characterized by time pressure and uncertainty. Previous research has found that in tasks with uncertainty, group decision making can outperform the best group member if the people involved are allowed to communicate freely (de Snoo et al., 2011b). A practical experiment conducted by de Snoo and van Wezel (2014) indicates that *group decision making* outperform *distributed decision making* with respect to rescheduling performance. The organization should therefore facilitate the possibility for the schedulers to meet and collaborate in order to achieve the best rescheduling decisions.

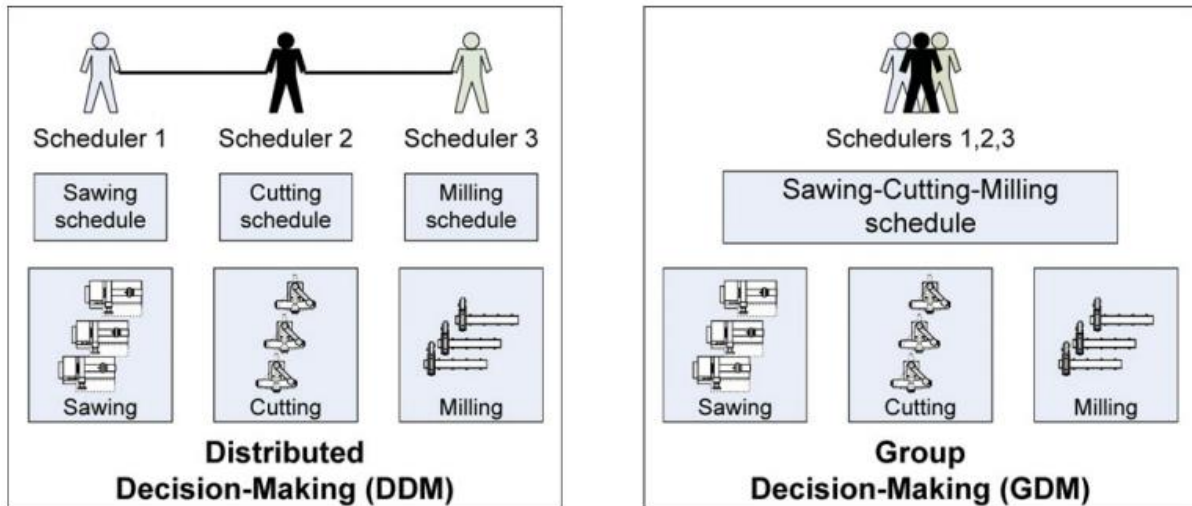


Figure 17: Decision making modes (de Snoo and van Wezel, 2014).

5.2.4 Common understanding of problems and constraints

It is important that schedulers make use of their colleagues, and the organization should facilitate this possibility. However, different departments usually have different logics in how to achieve the overall goals, and scheduling often takes place in the middle of this goal conflict. To some degree, this will hamper the communication (Berglund and Karlun, 2007). A typical observation from manufacturing plants is that one group is far from satisfied with the efforts of the other group. For instance, operators may be dissatisfied with the schedulers' understanding of the actual reality on the shop floor. On the other hand, schedulers may be frustrated by operators not following the schedules or that they are slow to communicate disturbances in the production schedule (de Snoo and van Wezel, 2011).

Environments where the schedulers are encouraged to interact with other departments and ensure a common understanding of each other's constraints will result in generation of more realistic schedules (MacCarthy and Wilson, 2001). A shared, common understanding of the production reality also helps to lessen the "friction" between departments, for instance between production and scheduling.

Organizations should promote environments where the planners, schedulers, and shop floor personnel are encouraged to interact and ensure a common understanding of each other constraints. Not only will it have a positive effect on the scheduling performance, but also on the social climate between the departments.

5.3 Organizational factors related to technological systems

5.3.1 Fit between context and scheduling and control systems

If there is a misfit between an organization and a technological system that is planned introduced, there is significant probability that the implementation of this system will fail (Morton and Hu, 2008). Most of the research of organizational fit has been focused on ERP or other enterprise systems. However, many of these findings are still relevant for other types of technological systems implemented in a business.

Strong and Volkoff (2010) present six main categories of potential misfits in an enterprise system implementation: functionality, data, usability, role, control, and organizational culture. When looking into organizational factors, *role* and *organizational culture* are relevant to look into. *Role misfits* occur when the roles in the enterprise system are inconsistent with the skills available, create imbalances in the workload, or generate mismatch between responsibility and authority. “*Organizational culture misfits* occur when the enterprise system requires ways of operating that contravene organizational norms” (Strong and Volkoff, 2010).

When introducing new scheduling and control systems, it is very important to take the context that the systems will be used into account. The inherent complexity of different production environments impedes the possibility of “one size fits all” solutions (MacCarthy and Wilson, 2001). If the context is not considered during implementation, the system might end up becoming less efficient than planned, or in worst case, the implementation might be a failure.

In order to achieve a fit between context and new scheduling and control systems that are planned implemented, it is important that the organization map and analyze the actual context and take aspects such as organizational roles and organizational culture into consideration (Strong and Volkoff, 2010). This analysis is important in order for the new system to be implemented and utilized in the best manner.

5.4 General organizational factors

5.4.1 Synchronization of performance indicators

Performance measurement is steadily gaining popularity, and help businesses to focus on efficiency and promote continuous improvement of their business processes. However, performance measurement of production planning and scheduling is rarely carried out. This is because of often conflicting performance criteria and the fact that the outcome of the decisions may not be apparent for hours, days, or sometimes weeks (MacCarthy et al., 2001).

In production scheduling and control, performance indicators should be chosen with great care. In practice, the most appropriate performance indicators may not be obvious (MacCarthy, 2006). Different departments often have different and conflicting performance criteria (MacCarthy et al., 2001, MacCarthy, 2006, Stoop and Wiers, 1996). Conflicting performance criteria could be that different departments have different views on what measures that indicate a “good” production. Production scheduling and control will have to juggle between these, and this is of course not optimal.

In order to achieve an increase in the overall business efficiency, the organization should focus on synchronization of the performance indicators of the different business functions. By having synchronized performance indicators, there should no longer be any conflicting performance criteria. The chosen performance indicators should reflect the business’ overall goals, and they should work together to achieve an overall improvement.

5.4.2 Reduction of compensation tasks

Compensations tasks are activities that are necessary to compensate for some kind of problem, limitation, or failure in the overall system (Jackson et al., 2004). Within scheduling and control, this could for instance be data management because of a poorly designed information systems, use of compensatory systems because the formal system is inadequate, and duplication of effort

because of bad coordination (MacCarthy and Wilson, 2001). These are only a small sample of possible compensation tasks within scheduling and control.

Compensation tasks are non-value adding in the long term and should be identified and eliminated or reduced (MacCarthy, 2006). In accordance with lean thinking, these types of activities are wasteful and should be eliminated in order to free up time for the schedulers to perform value-adding tasks instead.

The organization should focus on the elimination of all types of compensation tasks. Because of the natural differences between organizational environments, there will be impossible to produce a list that presents all the compensation tasks that might occur. Therefore, each organization must focus on identification and elimination of unnecessary tasks. Procedures that help the employees to analyze their work tasks should be developed. If the organization succeeds in this, the scheduling and control performance should be increased.

5.5 Summary of organizational factors of production scheduling and control

This chapter has presented nine different organizational factors related to production scheduling and control. These have been identified through a qualitative literature study, and the information about the different factors is collected from the literature findings as well. This chapter gives a brief overview of how the discussed organizational factors are featured in the literature through the summarization presented in table 5. This table gives an indicator on which of the factors that are frequently discussed in literature and which that rarely are mentioned. Please note, however, that the references presented here are limited to the ones that were investigated in the literature study. Most likely, many of these factors have also been mentioned by other researchers that do not feature in this list.

- a) *Decision autonomy between shop floor and schedulers*
- b) *Department structure and scheduler location*
- c) *Scheduler training*
- d) *Knowledge and communication facilitation of scheduling interconnections*
- e) *Collaboration during rescheduling*
- f) *Common understanding of problems and constraints*
- g) *Fit between context and scheduling and control systems*
- h) *Synchronization of performance indicators*
- i) *Reduction of compensation tasks*

Table 5: The organizational factors discovered through the literature study.

Reference	Organizational factor								
	a	b	c	d	e	f	g	h	i
Wiers (2009)	x								
McKay and Wiers (2006b)	x	x		x					
de Snoo et al. (2011b)		x		x					
de Snoo and van Wezel (2011)		x				x			
Berglund and Karlton (2007)		x	x	x		x			
MacCarthy and Wilson (2001)		x	x	x		x	x		x
Crawford and Wiers (2001)			x						
Karlton and Berglund (2010)				x					
de Snoo et al. (2011c)				x					
de Snoo and van Wezel (2014)					x				
Morton and Hu (2008)							x		
Strong and Volkoff (2010).							x		
MacCarthy et al. (2001).								x	
MacCarthy (2006)								x	x
Stoop and Wiers (1996)								x	
Jackson et al. (2004)									x
<i>Number of times mentioned</i>	2	5	3	6	1	3	3	3	3

6 Capability maturity model for organizational competence in production scheduling and control

This chapter presents the capability maturity model for organizational competence in production scheduling and control. This model can evaluate an organization and give guidelines for improvements. The capability maturity model uses a ranking across five levels. The levels are adopted from ISO/IEC 15504-7:2008, which is a standard that addresses assessment of organizational maturity. The descriptions of these different levels are very general and can be utilized across a wide range of different organizations. Some of the work in this project has therefore been to “translate” these descriptions to production scheduling and control terms. These five levels are in ascending order: *basic*, *managed*, *established*, *predictable*, and *innovating*. The ISO/IEC 15504-7:2008 standard also defines a level 0, called immature. This level is for organizations that fail to achieve the criteria of level 1. The levels lay successive foundations for improvement of an organization’s organizational competence.

The model is built on three main parameters: *level*, *characteristics*, and *criteria*. The *levels* rank from one to five, and could be seen as a “stairway to success”. The higher level, the more competence the organization has in taking organizational factors of production scheduling and control into consideration. The *characteristics* describe the organizations that are evaluated to be at this particular level. These are based on the maturity levels from ISO/IEC 15504-7:2008 translated into production scheduling and control terms. To get a more practical understanding of organizations at the different levels, some *criteria* are presented. These should be seen as objectives that must be fulfilled in order for it to be ranked at the respective level. In the following chapter, the characteristics and criteria for the five levels of the capability maturity model for organizational competence in production scheduling and control are described. Lastly, table 6 summarizes them.

6.1 Level 1: Basic

An organization at level 1 demonstrates achievement of the purpose of the processes that are fundamental to support the organization’s business (ISO/IEC, 2008). This implies that the organization implements the required processes to support the organization’s business and that they performs the sets of activities and tasks that achieve the purposes of these processes (ISO/IEC, 2008).

Translated to scheduling and control situations, organizations at level 1 are able to schedule and control their production and they have dedicated roles associated with coordinating these processes. This corresponds to achieving the purpose of the fundamental processes. As the name suggest, this level represent the most *basic* level of production scheduling and control. Production environments that have some sort of production plan or other type of reasoning behind their production sequences, most likely also have dedicated roles regarding who should take scheduling decisions. This does not necessarily have to be a dedicated planner or scheduler, but there should be no doubt regarding who has the responsibility to decide what should be produced at any given time. Additionally, in order to take appropriate and reasonable scheduling choices, there should be systems in place to assist the person who has the responsibility for taking these decisions. As described further in the next paragraph, these systems should obtain and present relevant data so it is easier for the scheduler to take better decisions.

For level 1, two criteria are presented. The first is that it should exist an organizational structure for production scheduling and control. The principal purpose of having an organizational structure is to control the way people coordinate their actions and the means used to motivate people to achieve the organizational goals. An appropriate organizational structure ensures effective responses to problems of coordination and motivation (Jones, 2010). This means that the company should have clear roles regarding who should take the scheduling decisions in the different parts of the production, and that the company has a fitting decision hierarchy.

The second criterion relates to the support systems that ease the scheduling and control tasks. In today's modern information age, most production companies are expected to have implemented an ERP system that allows decisions and databases from all parts of the organization to be integrated. The database should be updated in real time, and help schedulers to make appropriate schedules and give them a better sense of control in the production. That the company has an ERP system is therefore listed as a criterion for achieving the basic level of organizational competence in production scheduling and control.

6.2 Level 2: Managed

According to ISO/IEC (2008), an organization at level 2 demonstrates management of the processes that are fundamental to support the organization's business. At this level, the organization shows a greater mastery of the required processes, and monitors these processes and takes action if they perform worse than planned.

Regarding scheduling and control, organizations at this level demonstrate greater understanding of the requirements behind an effective scheduling and control process. More specifically are organizations on this level aware of the potential benefits of utilizing coordination and collaboration between the different roles within the organization. Organizations at level 2 must therefore enable and facilitate this interdepartmental communication. By doing this, the organization shows that it *manages* the scheduling and control process to a larger degree than if the scheduler was "left alone".

The criterion for organizations at level 2 is that they facilitate the scheduling interconnections. This means arranging for communication between the scheduler and other organizational roles that might have valuable information or knowledge that can help the scheduler to make good decisions and decrease the risks and uncertainty of their decisions. There are several ways communication within the organization can be facilitated. The organizational structure, the physical location of the different actors, and the available communication tools all have influence on the communication patterns. Some of the principles discussed in chapter 4.2 can be utilized to develop organizational relations. The different types of facilitation will be discussed further in the next level. At this level, there are no specific requirements regarding how the organization facilitates the interconnections, as long as they have taken actions to assist these.

6.3 Level 3: Established

Organizations at level 3 demonstrate management of the processes that are fundamental to support the organization's business. This entails that the organization establishes standard procedures to ensure efficient execution of their routine processes. In addition, the organization should collect data and information from the processes that can be used to improve these procedures further (ISO/IEC, 2008).

Organizations measured at level 3 must have standardized procedures to handle the scheduling and control processes. Environments at this level show great understanding of these processes and have enough experience to have an idea about how these can be executed efficiently. These experiences are the basis for the *established* procedures. The procedures should address all the processes that are considered routinely for the scheduler. There should of course be procedures for extraordinary situations as well, but those will naturally be less specific than those for the routine processes. Examples of routine processes for a scheduler are for instance *initial schedule generation*, *rescheduling*, and *production follow-up*. The procedures must not remain static, but be continuously updated and improved based on the experiences with these. The procedures should be indoctrinated to new employees through their training, and all employees should have easy access to updated procedures.

There are several criteria at this level of maturity. Firstly, there should be clear procedures for the reactive control process in cases where disturbances affect the initial schedule, i.e. rescheduling. These procedures should clearly state what the shop floor personnel should do if situations occur that makes the original schedule not feasible. How should they report this incident? Whom should they contact? What can be done to minimize the effect of the disruption? These are just a couple of aspects that these procedures should deal with. By having thoroughly prepared procedures for rescheduling, the negative effects of disruptions on the overall production efficiency should be reduced.

The second criterion in this level is that the technological systems should present relevant information to support the different roles. Schedulers use many different types of information in order to produce robust schedules. Easy access to this information will reduce the workload and time that might otherwise have been spent on gathering this. Integrating the different production systems that are used, for instance ERP and MES systems, and encourage the users to always register events in these systems, will help the scheduler to obtain relevant information in an easy way. This will naturally also go the other way. For instance, it will be easier for the shop floor personnel to get information on what to do next.

As mentioned earlier, it is important for the scheduler to make use of its interconnections. Organizational structure and physical location of the actors influence the communication possibilities. Organizations at level 3 should have optimized both the organizational structure and the schedulers' location in order to reflect the actual communication needs. In order to meet this criterion, the company should have mapped or have a clear understanding of a scheduler's communication pattern. This knowledge should then be used to design an organizational structure and place the scheduler at an appropriate location to ease the communication and facilitate coordination and collaboration.

The other part of communication facilitation, as mentioned in level 2, is the availability of communication tools. The organization should make it easy to communicate with colleagues in order to obtain the desired information. Organizations at level 3 should provide their users multiple ways of reaching each other in situations where coordination is needed. Sending an e-mail is easy, but is it responsive enough in urgent situations? The company should ensure that those who may have valuable input are available on short notice in order to ensure an efficient information flow. In these kind of situations, phone calls are a much more responsive communication medium. It is important that the company does not solely rely on a single way of communicating, but have an integrated solution with several possible communication media.

6.4 Level 4: Predictable

At level 4, the organization demonstrates a quantitative understanding of the relevant fundamental processes in order to establish consistent and predictable performance. This implies that based upon business goals, quantitative objectives for process performance should be established. The organization should effectively collect, store, and analyze the performance data. These data are then used to identify special causes of variation in the process performance and the organization should take appropriate corrective and preventive actions to address them (ISO/IEC, 2008).

Organizations that wish to be at level 4 must measure their production scheduling and control performance. They also have to synchronize the performance indicators across the organizations so that they do not work counterproductive on each other. Performance measurement could be a good way to ensure focus on effective processes and use it as a tool to improve the processes further. Organizations that are able to measure the performance of their scheduling and control processes display a quantitative understanding of these processes and use this to achieve a consistent and *predictable* scheduling and control performance. Performance measurement of scheduling and control can be done in many ways (cf. 3.3.3). In order to obtain a business-wide performance increase, it is not enough to set individual performance goals for each department. These goals may interfere with each other. The performance indicators for the different departments should therefore be decided collectively to ensure that this issue is avoided.

The criterion for organizations at level 4 is therefore to have a cross-functional synchronization of performance indicators. It is implied that to meet this criterion, it has to be some sort of performance measurement of scheduling and control.

6.5 Level 5: Innovating

Organizations at level 5 demonstrate the ability to change and adapt the performance of the fundamental processes in a systematically planned and predictable manner. These organizations are able to identify weaknesses and implement improvements to address these. They are also able to identify innovations that have the potential to improve process performance and business success (ISO/IEC, 2008).

Organizations at the top level should continuously improve their production scheduling and control performance. They constantly set new performance goals and strive towards achieving these. These organizations are *innovative* and able to address weaknesses in their scheduling and control processes. The work procedures of the organizations at this level are very dynamic and any problems with these are constantly identified, examined, and handled. These organizations facilitate open discussions around problems and encourage people to come up with ideas that might improve the processes. Organizations at this level also focus on additional training for their employees to increase their competency even further.

Three criteria are presented for this level. The first one focuses on the organization's ability to consider compensation tasks. The organization should have procedures to identify and reduce these kind of tasks. Compensation tasks are activities that are necessary to compensate for some kind of problem, limitation, or failure in the overall system (Jackson et al., 2004). The employees should be encouraged to report when they identify these sort of tasks, and the organization should dedicate time and resources so that the actual problem can be addressed and fixed.

The second criterion relates to the organization's willingness to invest in their schedulers' competency by offering additional training. An organization at level 5 should offer training programs for their schedulers. This could for instance be training programs that aim to increase the scheduler's competency in using ERP software. This will in turn will lead to a scheduler that is able to use this software more efficiently.

The last criterion at this level is that the company should facilitate experience exchange between schedulers and shop floor personnel. Shop floor personnel might have plenty of valuable information that could benefit the schedulers in their work. The company should hold regular meetings where there are allocated time for these kind of issues to be discussed. Computer systems that feature reporting of incidents and improvement suggestions may also be introduced as a supplement. This kind of communication could also lead to a development of common understanding between these two groups, which in turn most likely will result in a better working and cooperation environment.

Table 6: Capability maturity model for organizational competence in production scheduling and control.

Level (from ISO/IEC 15504-7)	Key words (from ISO/IEC 15504-7)	Characteristics	Criteria
1 Basic	<i>Achieves the purpose of the fundamental processes</i>	There is a scheduling and control process with an organizational structure with associated roles	There exist an organizational structure for production scheduling and control
			An ERP system has been implemented to support the scheduling and control process
2 Managed	<i>Manages the fundamental processes</i>	The organization enables coordination and collaboration between the organizational roles	Facilitation of scheduling interconnections
3 Established	<i>Effective definition and deployment of the fundamental processes</i>	Standardized procedures to handle production scheduling and control are in place	Clear procedures for handling rescheduling situations
			Relevant information is available to support the different roles
			The department structure and the schedulers' location are optimized based on the actual interdependencies
			Integrated communication network to support the communication between the interconnections
4 Predictable	<i>Quantitative understanding of relevant fundamental processes</i>	Production scheduling and control performance is measured and synchronized across the organization	Cross-functional synchronization of performance indicators for effective decisions
5 Innovating	<i>Ability to change and adapt the performance of the fundamental processes</i>	The organization continuously improves its production scheduling and control performance	Procedures for compensation task identification and reduction
			Training programs for schedulers
			Facilitation of experience exchange and development of common understanding between schedulers and shop floor

7 Empirical study

The aim of the case study is to test the validity of the developed capability maturity model and evaluate a real life company regarding their organizational competence in production scheduling and control.

As described in the methodology chapter, the information was gathered through a semi-structured interview with one of the schedulers at the chosen case study company. The interview firstly aimed at getting to know the company, i.e. the company structure, production characteristics, number of employees, etc. The aim of this part of the interview was to gain knowledge about what type of company this is, which is important to be able to gain a deeper understanding of the context in which scheduling and control are carried out.

The next part of the interview focused on the production scheduling and control processes of the company. This part consisted of general questions about these processes in the company. The characteristics of their scheduling and control processes that were uncovered in this part would influence the later parts of the interview. What kind of input data the schedules are based on, what kind of enterprise system that is implemented in the company, and how the schedules are developed, are some examples of key questions in this part of the interview.

After obtaining general knowledge about the company and their scheduling and control processes, the interview focused on the organizational factors of scheduling and control. The questions in this part of the interview were based on the criteria in the developed maturity model in order to assess the organizational competence level of the case company.

7.1 Introduction to case company Pipelife Surnadal

The case company in this project is Pipelife Surnadal. This company is part of the Pipelife Group, which is one of Europe's leading producers of plastic pipes and accessories. The Pipelife Group is active in 26 countries and achieved a total sales of 872 million Euros in 2014 (Pipelife, 2015a). The group has a total of 26 production sites in Europe and the USA (figure 18), and employs around 2700 people worldwide. Their headquarters are in Vienna, Austria (Pipelife, 2015a).

“Pipelife Norway is Norway's largest producer and supplier of plastic pipe systems” (Pipelife, 2015b). A considerable portion of their production volume is exported, especially polyethylene (PE) tubes in large dimensions and the innovative drain system Smartline (Pipelife, 2015b).

Pipelife Norway has two factories. The factory in Stathelle produces large PE tubes, and has around 50 employees. The factory in Surnadal (figure 19) produces smaller pipes in polyvinyl chloride (PVC) and polypropylene (PP) used for water and wastewater, ventilation, cable protection, and electric installation. This factory has around 100 employees and also functions as Pipelife Norway's headquarter (Pipelife, 2015b).

Locations worldwide



Figure 18: Pipelife Group's locations around the world (Pipelife, 2015a).



Figure 19: Pipelife Surnadal (Pipelife, 2015b).

7.1.1 Production process

This section briefly introduces the production process at Pipelife Surnadal, with emphasis on the production of Smartline pipes, their flagship product. Smartline pipes are an innovative piping system that requires less number of parts, uses less material, no assembly is required, slim design, and are as robust as previous products. The Smartline products are made of PP, and some of the parts have a seal made of thermoplastic elastomer (TPE) (Alfnes, 2010).

There are two main groups of Smartline products: parts with thermoplastic elastomer seal, parts that from here on will be called TPE, and spigots, which do not have this seal. 89 % of the production volume is TPE, while the remaining 11 % are spigots. To produce these, Pipelife

Surnadal has two different types of machines. Spigots are produced through an injection molding process where the PP part is molded. TPE products, on the other hand, are produced through a two-step injection molding process. First, the PP part is molded, and then at the same time and in the same machine, the TPE seal is molded (Alfnes, 2010).

Currently, Pipelife Surnadal operates nine of these injection molding machines. Each machine can produce different product types by inserting different molds in the machine. These nine machines are part of their integrated Smartline production system. The injection molding machines are automated and packing robots and conveyor belts ensure that finished products are automatically marked and sent to the finished goods inventory (Lund and Bye, 2014). The layout of the Smartline production system are shown in figure 20.

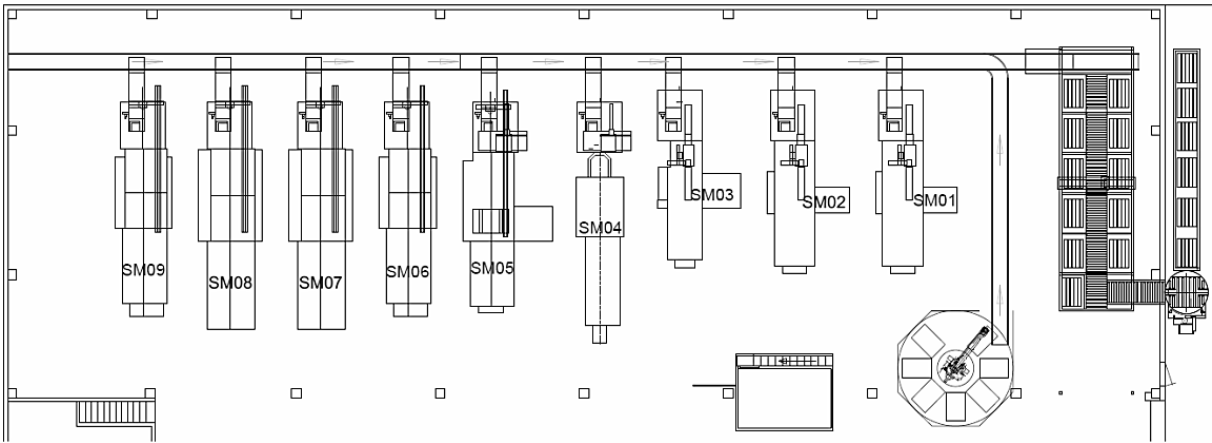


Figure 20: The integrated Smartline production system (Lund and Bye, 2014).

7.1.2 Production planning, scheduling, and control process

This section introduces the production planning, scheduling, and control process at Pipelife Surnadal, based on the information gathered from the interview at April 21, 2015 with production scheduler at Pipelife Surnadal, Anne Ragnhild Ljøkelsøy.

Pipelife Surnadal has two people who work with production planning, scheduling, and dispatching activities. One of them has responsibility for the automated part of the production, while the other has responsibility for the manual labor part of the production. The interview was conducted with the employee, from now on called scheduler, who had responsibility for the automated part of the production. This section will therefore mostly be about this part of the production.

Pipelife Surnadal does not sell their products directly to end customers. Mostly, their sales are to wholesalers and the retailer side. Most of Pipelife Surnadal’s production is based on forecasts, which are made on a yearly basis for each product group. This means that they mainly produce to stock, except for a production batch now and then that are based directly on customer orders. The sale quantity of their products vary a lot throughout the year, and past years have shown that they do not have enough capacity to cover the demand in high season, which typically is in the summer and autumn. To cover the demand throughout the year, they have to produce more than the corresponding demand in low season in order to build up their stock levels.

The forecasts are used in the ERP system, which give proposals on what should be produced when. However, because of the aforementioned problem with insufficient capacity in high season, the scheduler has to change the proposed production plan manually so that it produces a higher number of products in low season.

In addition to creating plans and schedules, the scheduler also follows up on the production and makes adjustments when needed. The scheduler meet with relevant actors on each morning of her working days (Monday to Friday), and situational updates are provided. In case of events that disrupt the plans and schedules to a large degree, the scheduler is normally contacted immediately. The scheduler must then assess the situation and make the necessary adjustments. More information on the production scheduling and control process is provided in the next section, together with the relevant criteria from the maturity model.

7.2 Company evaluation according to the criteria

CMM Level	Criteria	Pipelife Surnadal
1	There exist an organizational structure for production scheduling and control	x
	An ERP system has been implemented to support the scheduling and control process	x
2	Facilitation of scheduling interconnections	x
3	Clear procedures for handling rescheduling situations	x
	Relevant information is available to support the different roles	x
	The department structure and the schedulers' location are optimized based on the actual interdependencies	x
	Integrated communication network to support the communication between the interconnections	x
4	Cross-functional synchronization of performance indicators for effective decisions	
5	Procedures for compensation task identification and reduction	x
	Training programs for schedulers	
	Facilitation of experience exchange and development of common understanding between schedulers and shop floor	x
CMM level achieved		3

Level 1:

There exist an organizational structure for production scheduling and control

Pipelife Surnadal has a clear organizational structure regarding their responsibility areas and report hierarchy. They have two schedulers, and each of them responsibility for different parts of the production. Each of them also has the responsibility to follow up on their respective part of the production. The report hierarchy is also clear. They report to the head of the logistics department and the factory manager, while the schedules go directly from them to the production.

Verdict: Yes, Pipelife Surnadal has an organizational structure for their production scheduling and control.

An ERP system has been implemented to support the scheduling and control process

This report has previously highlighted the potential benefits of having technological systems that assist the schedulers to make better schedules. The schedulers at Pipelife Surnadal mainly use two systems: an ERP system (M3) and an MES system (Barco). The ERP system is used for orders, purchase of raw materials, and generating plans and schedules. The MES system is used in the factory for visualization of the schedules and reporting the production output. According to the interviewed scheduler, the schedules are mainly made in the ERP system, but there could be some minor adjustments to them through the MES system.

Verdict: Yes, the company has implemented an ERP system to support the scheduling and control process.

Level 2:

Facilitation of scheduling interconnections

Pipelife Surnadal is a relatively small company, and it is therefore easier for the scheduler to get to know her contacts. According to her, the most important contacts are the sales manager and the factory manager. They have a meeting every day, and there is no problem to get in touch throughout the day if it is needed.

Verdict: Yes, Pipelife Surnadal facilitates the interconnections of the schedulers.

Level 3:

Clear procedures for handling rescheduling situations

There are many reasons for why the initial schedules cannot be executed, and in these situations, it is important that everyone know what to do. Pipelife Surnadal has developed procedures on what to do in these situations. If this kind of situation occurs, the shop floor must contact the scheduler and inform about the problem. The scheduler then takes a decision based on the urgency of the order whether or not to address the problem immediately, or wait for a more suitable time, for instance the next morning. Depending on the time that is required to solve the problem, the scheduler might have to develop new and modified schedules. If the problems are extensive and delays unavoidable, they might ask the customer for an extended delivery time or get help from sister companies in Sweden and Poland.

Verdict: Yes, they have clear procedures for rescheduling.

Relevant information is available to support the different roles

Nearly all of the information that the scheduler uses are available through their ERP and MES systems. This makes it easy for the scheduler and lowers the time that would otherwise be spent on information gathering. Plenty of valuable information can easily be collected from the system: *due dates, available capacity, inventory level*, and so on. The scheduler also gathers lots of valuable information through the daily meetings. The schedulers have two regular meetings each day. The first is with the logistic department where they talk about the current production status. News about incoming orders, possible changes in delivery dates, stock levels, and status regarding delivery trucks are just some of the talking points at this meeting. The other meeting is a production meeting with among others the factory manager, maintenance

personnel, and employees responsible for different areas in the production. In this meeting, they discuss the schedules and talk about any problems with the production resources.

Verdict: Yes, the schedulers at Pipelife Surnadal have easy access to relevant information.

The department structure and the schedulers' location are optimized based on the actual interdependencies

As mentioned earlier, the scheduling department is small and it is easy for the schedulers to keep contact with each other and their other interconnections. The schedulers are also located very close to the production, by having office in the adjacent building. The other interconnections are also located closely, for instance the sales manager is “just down the corridor”. Pipelife Surnadal has good experiences with this layout. The scheduler mention that it is very easy to keep contact and meeting face-to-face could be very useful in many situations. There is clearly a thought behind this layout to facilitate the possibilities for coordination and collaboration.

Verdict: Yes, the department structure and scheduler location are optimized based on the interdependencies.

Integrated communication network to support the communication between the interconnections

Pipelife Surnadal is a relatively small company and the scheduler is well known with her contacts. She has no problems getting in touch with others when she needs information, and mentions both phone calls, text messaging, and e-mail as communication media that are used, in addition to face-to-face conversations.

Verdict: Yes, the company has facilitated a good communication network that makes it easier for the interconnections to communicate with each other.

Level 4:

Cross-functional synchronization of performance indicators for effective decisions

As of today, the company has no measurement of scheduling performance. They have formed a working group that will investigate the possibility of implementing such performance measurement in the future. The reality at this company also shows the problem of conflicting performance indicators. It seems like different departments are pulling in different directions, even if they fundamentally have the same overall goal. For instance, the finance department wants to have tied up as little money as possible, the sales department wants to have the shortest possible delivery time, and production wants to have the highest possible productivity. Individually these are of course good goals, but collectively they might work counterproductive.

Verdict: No, they are not measuring scheduling performance and the performance indicators seem to conflict.

What can be done? In order to achieve an increased overall business efficiency, the company should focus on synchronization of the performance indicators of the different business functions to avoid goal conflicts. The chosen performance indicators should reflect the company's overall goals, and they should work together to achieve an overall improvement.

Level 5:

Procedures for compensation task identification and reduction

According to one of the schedulers, the employees in the scheduling department have focus on identifying and solving problems in their systems. This could for instance be operations in their computer systems that take unnecessary long time to complete. The employees are encouraged to report if they discover these kinds of imperfections, and the company will then assign people to try to solve them. One example is that they have developed an automated script that transfers data from the ERP system over to the MES system. If not for this, the data would have to be plotted manually, a task that would had required a lot of time.

Verdict: Yes, Pipelife Surnadal has procedures for identifying and reducing compensation tasks.

Training programs for schedulers

The company does not offer additional training to increase the schedulers' competency.

Verdict: No, they are not offering additional training programs for the schedulers.

What can be done? By offering additional training to the schedulers, it is possible to improve their efficiency in their work tasks. By gaining an increased understanding of the scheduling tasks, scheduling tools, and production characteristics, the scheduler should be better at recognizing hidden relationships, be aware of possible problems that may occur, and identify possible alternative resource assignments.

Facilitation of experience exchange and development of common understanding between schedulers and shop floor

The daily meeting where the schedulers and shop floor representatives are present facilitates the possibility of experience exchange. They talk about problems that have occurred, and they have an open dialogue where they discuss which aspects that work well, and which aspects that could work better. These discussions might establish guidelines on how to solve specific problems in the future. For instance, experience exchange has led to a practice where the company always tries to schedule modifications on production lines early on weekdays, when there are plenty of personnel available to assist this process.

Verdict: Yes, through their daily meetings, the company facilitates the possibility of experience exchange and development of common understanding.

8 Discussion

This discussion chapter consists of four different parts. The first part of this chapter lists the major findings of this study, and presents some discussions regarding their significance. Thereafter, there is given a verdict on whether or not the previously stated objectives are met, and the research questions are answered. The last part of the discussion chapter presents some thoughts around the limitations of this study and gives some proposals for future research within this field.

8.1 Discussion of findings

Major findings

1. Organizational factors influence production scheduling and control performance
2. It is possible to evaluate a scheduling and control environment's organizational competence through a capability maturity model
3. The case company's projected level of organizational competence in their scheduling and control processes are at level 3.

This thesis consists of three main parts contributing to the findings: *the literature study*, *the developed framework*, and *the empirical study*. This chapter presents the major findings from this research, explain the meaning behind these findings, and justify why these findings are important.

Finding 1: Organizational factors influence production scheduling and control performance

Through the literature study, it became evident that numerous organizational factors influence production scheduling and control. These kind of factors have traditionally been overlooked in favor of focus on technical solutions developed to improve scheduling. The findings in the literature study show that organizational factors influence production scheduling and control performance, and should be taken into consideration when aiming towards more effective scheduling and control processes. Chapter 5 presents nine examples of organizational factors that were identified through the literature study. This is of course far from a complete list of possible factors, but they are the ones that were considered to have most influence on the production scheduling and control performance of the ones that were identified in the literature study.

One of the aims of this research was to investigate the subject of so-called organizational factors. These are factors that relates to aspects such as how work is organized and structured, together with rules, procedures, and cultural factors (Berglund and Karlton, 2007). In chapter 5, the presented organizational factors are introduced, their importance is stated, and some comments on how they should be handled are provided. In order to categorize the different organizational factors, the HTO concept is used. This was mainly because it can be difficult to relate many of the factors to a single category, and the literature study did not uncover any guidelines on how these kinds of factors can be categorized. The HTO concept proved to be a valid method to classify the different organizational factors, and the intersections between the human, technology, and organization components proved useful to categorize the organizational factors that related to several aspects. The factors that are presented may have negative influence on the scheduling and control performance if they are not handled correctly. These negative influences are mainly related to *extra time usage* and *suboptimal decisions*. *Extra time usage* will naturally lead to decreased performance since the employees have less time for other tasks, and therefore less work will be done. Examples of factors that could lead

to extra time usage are *a suboptimal scheduler location* and *extensive compensation tasks*. *Suboptimal scheduling decisions* could have several effects. It might influence the delivery time of the products, the production efficiency, the cost level, or in some cases even the quality of the products. A scheduler will always have several of these metrics to take into account when scheduling, and should be able to find the most optimal solution that balances these. Organizational factors that could lead to suboptimal decisions are among others *inappropriate decision autonomy*, *insufficient coordination and collaboration*, *unsynchronized performance indicators*, and *a lack of common understanding regarding problems and constraints*. Some of the organizational factors may of course lead to both extra time usage and suboptimal scheduling decisions, for instance *lack of scheduler training*, *communication issues*, and *ineffective technological systems*.

Scheduling environments have traditionally had a strong focus on developing new technical solutions when looking to improve the scheduling and control processes. The findings presented in this thesis supports the theory that organizational factors have an influence on the performance of these processes, and correct handling of these can further improve the performance. This supports the idea behind the HTO concept, which states that both human, technological, and organizational factors should be focused on in order to achieve an overall improvement (Berglund and Karlton, 2007). Focusing on organizational factors should therefore be an alternative for companies' looking to improve their production scheduling and control processes. It might also prove to be a more cost-effective improvement solution than constantly investing in new technological systems.

Finding 2: It is possible to evaluate a scheduling and control environment's organizational competence through a capability maturity model

Another aim of this study was to investigate the possibility to create a tool that organizations can use to measure their ability to consider organizational factors influencing scheduling and control performance. This tool should be useful both as an evaluation tool, and as an improvement tool where the organization can identify their weaknesses and get specific suggestions on how to improve in these aspects. Chapter 6 presents the tool, which comes in a form of a capability maturity model with five different maturity levels.

When trying to decide what type of evaluation tool to develop, the supervisor gave a suggestion to look into capability maturity models. In addition to being an evaluation tool that is easy to use and understand, it also gives clear guidelines on how the user of the model can improve in that particular area. This fits well, since it was desired that the model should be easy to use and the threshold to use it low. Through the literature study, no similar model was found that deals with the same issue. The model was therefore pretty much built from scratch, with inspiration from the organizational factors identified in the literature study and by using organizational maturity levels from ISO/IEC 15504-7:2008. Each maturity level is presented through *characteristics* and *criteria*. The *characteristics* are a general description of a scheduling and control environment. These are adapted from the level descriptions in ISO/IEC 15504-7:2008 and translated into scheduling terms. The purpose of presenting characteristics is to be able, through a single sentence, to give the user a quick description of their scheduling and control process. On the other hand, the *criteria* presented in the model are supposed to give a practical feeling to the issue, and will make it easier for users without previous knowledge in organizational theory and similar to use the model. These criteria give practical examples on what minimum should be fulfilled for an organization to be evaluated at the particular level. A scheduler or someone else who is familiar with the company's scheduling and control processes could easily evaluate their organizational competence. The case study in this project also

showed that it possible for an outsider with no previously knowledge of the company processes to evaluate a company through an interview. When a company gets familiar with their own ranking, they can easily set a level target, and get inspiration from the criteria in the capability maturity model regarding which measures to implement.

As previously stated, there has been a lack of focus on organizational factors of production scheduling and control. By developing the capability maturity model for organizational competence in production scheduling and control, it should make it easier for companies to get an understanding of the potential influential factors and how they can be handled.

Finding 3: The case company's projected level of organizational competence in their scheduling and control processes are at level 3.

To test the developed capability maturity model, an empirical study was planned. The aim of this study was to investigate the scheduling and control processes of a real life company and give a verdict on their maturity by using the model. The case company that was investigated is Pipelife Surnadal, a producer of plastic pipes and accessories. Information about their processes was gathered through an interview with one of their production schedulers, and the results of this case study are presented in chapter 7.

The method that was chosen for collecting information in this case study was to interview one of Pipelife Surnadal's schedulers. Through a semi-structured interview where the goal was to evaluate how their processes are performing relative to the maturity criteria, it was possible to assess their production scheduling and control processes to a maturity level. After the interview, the work consisted of looking into each criteria, analyzing the obtained information relative to the criteria requirements, and give a verdict on whether or not the company fulfills the criteria. After doing this for each of the criteria, it became evident which maturity level they belong to. Pipelife Surnadal passed on all the criteria up to and including level 3. They also pass on two out of three criteria in level 5, but lack the requirements of level 4. Their organizational competence was therefore evaluated to be at level 3, which is named *established*. This implies that they have standardized procedures to handle production scheduling and control, but lack cross-functional synchronization of their performance indicators.

The testing of the developed model showed that it has relevance also in real life situations and that it is easy and quick to use. These features correspond with the initial planned characteristics of this model. Pipelife Surnadal was evaluated to be at level 3, and have still some way to go to be evaluated at the top level. If the company wants to improve their organizational competence in production scheduling and control further, they can get inputs on how to do it from the criteria in the model.

8.2 Objectives and research questions

This section looks into the objectives and research questions defined at the start of the report in chapter 1, and evaluate whether the objectives are met and answer the stated research questions.

Objectives

This section evaluates each of the four outcome objectives that were stated in chapter 1.3.1. The process objectives that were listed in the same chapter are all met, and will not be commented further.

Objective 1: Develop a capability maturity model for production scheduling and control

This model, known as the capability maturity model for organizational competence in production scheduling and control, has been developed and is presented in chapter 6.

Objective 2: Test the model in one or multiple case studies

The model has been tested through a case study at the manufacturing company Pipelife Surnadal. This has been described in chapter 7.

Objective 3: Evaluate a company using the capability maturity level

The aforementioned company was also evaluated using the developed capability maturity model. The results are shown in chapter 7.2.

Objective 4: Write a report and deliver it by 10 June 2015

This thesis describes the study and must be delivered before the deadline.

*Research questions***1. How to evaluate the organizational competence in production scheduling and control?**

This research has shown that it is possible to evaluate a production environment's ability to consider organizational factors influencing scheduling and control performance using a capability maturity model. This model is built up by characteristics and criteria that make it easy for an environment to assess themselves regarding how they are able to handle such factors.

2. What is the current level of organizational competence for production scheduling and control in a selected case company?

The selected case company to be evaluated was Pipelife Surnadal. By obtaining information about their scheduling and control process from one of their schedulers, their organizational competence level within production scheduling and control were assessed to level 3, *established*.

8.3 Limitations of study

Aristotle once said, "The more you know, the more you know you don't know". This fact is also transferrable to a research process. As you gain more knowledge throughout the study period, it is also easier to point out the limitations of the study. This chapter will discuss the most obvious limitations of this study, identified throughout the research process.

One limitation of this study is the fact that only one company is investigated in the field study. Preferably, several companies should have been investigated to give a more robust information background for validity of the model. There is a possibility that while the model worked well in the particular company that was investigated, it might not fit just as well in other companies. A multiple case study might have shown whether this is an issue. However, since there is only one case company, more time could be spent at studying the topic deeper, and go deeper into that particular case study. This might have resulted in a higher quality maturity model and a more in-depth analysis of the particular case company than might have been the result if there had been several case companies.

Another limitation is the fact that this study only looks at organizational factors that are discussed in literature. To conduct one or more empirical studies that aim at identifying other organizational factors might have improved the capability maturity model and the study in

general. On the other hand, as discussed above, the freed time enabled the possibility to go deeper into the literature and identify additional organizational factors that might not have been identified otherwise.

8.4 Suggestions for future research

Future research might be aimed at testing the developed maturity model at other practical scheduling and control environments. Other studies might give other results than those who are obtained in this study. These results might also give inspiration for aspects of the model that could be improve further.

Other future research may be aimed at investigating other organizational factors that might influence production scheduling and control, and which influence these have on the scheduling and control performance. New discoveries might be incorporated into the capability maturity model for organizational competence in production scheduling and control to improve its validity and usefulness of the model even further.

9 Conclusion

The aim of this study has been to develop a capability maturity model that evaluates an organization's ability to take into account the organizational factors influencing production scheduling and control performance. Through a qualitative literature study, relevant organizational factors were identified and mapped. This formed the basis for the capability maturity model that was developed. The finished model was tested through a case study at the Norwegian manufacturing company Pipelife Surnadal. Using this model, their organizational competence in production scheduling and control was evaluated and suggestions for improvement were provided.

This research has shown that organizational factors have a significant impact on production scheduling and control performance. Unfortunately, these factors tend to be overlooked, but these findings show that their impact should not be neglected. The organizational factors of production scheduling and control that are discussed in this report are: 1) *decision autonomy between shop floor and schedulers*, 2) *department structure and scheduler location*, 3) *scheduler training*, 4) *knowledge and communication facilitation of scheduling interconnections*, 5) *collaboration during rescheduling*, 6) *common understanding of problems and constraints*, 7) *fit between context and scheduling and control systems*, 8) *synchronization of performance indicators*, and 9) *reduction of compensation tasks*.

This thesis presents a capability maturity model for organizational competence in production scheduling and control. This is a five level maturity model where each level has distinctive characteristics and respective criteria. The five levels are *basic*, *managed*, *established*, *predictable*, and *innovating*. Each of these levels represents a certain level of maturity in the scheduling and control process. By using the characteristics and criteria, the user should easily be able to identify their own level of maturity, and, unless the user is at the top level, get suggestions for improvements regarding handling the organizational factors.

Through a theory-testing and evaluating case study, the Norwegian pipe manufacturer Pipelife Surnadal was evaluated regarding their organizational competence in production scheduling and control. This case study was the pilot run for the developed capability maturity model, and the company was measured against the specific criteria stated in the model. The case study showed that the company satisfies many of the criteria, but some of the requirements of the two top levels are not met. Therefore, Pipelife Surnadal was evaluated to be at level 3, which suggest that they have standardized procedures to handle production scheduling and control.

McKay and Wiers (2006b) stated that there is a need for research on organizational factors in production planning and control. This report has investigated this research gap by mapping numerous organizational factors within production planning and control, more specifically within production scheduling and control. The main deliverable in this report is the capability maturity model for organizational competence in production scheduling and control, which makes it easier for environments to understand the nature of organizational factors and focusing on these.

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Appendix A: Literature study protocol

A. Research questions

1. How to evaluate the organizational competence in production scheduling and control?
2. What is the current level of organizational competence for production scheduling and control in a selected case company?

B. Required data

- Production planning and control background theory
- Input on how to conduct a case study and how to develop a capability maturity model.
- Examples of organizational factors in production scheduling and control.
- Multiple views on the definition of organizational factors (within production scheduling and control).

C. Search strings

Required data	Search string				
	Part 1	Part 2	Part 3	Part 4	(Optional)
Production planning, scheduling and control theory	Production OR Manufacturing	Planning OR Scheduling OR Control			
Methodology theory - Case study - CMM	Production OR Manufacturing Capability maturity model OR Maturity model	Case study OR Field study Methodology OR Development	Methodology OR Preparation OR Research		
Examples of organizational factors in scheduling and control Definition of organizational factors/aspects	Production OR Manufacturing	Planning OR Scheduling OR Control	Organizational OR Organization OR Organisational OR Organisation	Factors OR Issues OR Aspects	Examples Definition

D. Conditions

- Preferably journal articles, recently published. “Pioneering” articles might be included even if they are not “recently” published.
- Only English or articles in one of the Scandinavian languages will be considered.

- The articles related to organizational factors should have a basis in production planning, scheduling, or control environments.

E. Databases

Google Scholar (scholar.google.com)

ScienceDirect (www.sciencedirect.com)

Engineering Village (www.engineeringvillage.com)

Scopus (www.scopus.com)

Appendix B: Pre-study report

Sven-Vegard Buer

Capability Maturity Model for Organizational Competence in Production Scheduling and Control

Pre-study report

Master thesis

TPK4930

Trondheim, February 2015

Teacher: Jan Ola Strandhagen

Supervisor: Emrah Arica

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Production and Quality Engineering



NTNU – Trondheim
Norwegian University of
Science and Technology

Preface

In the last semester of the Master of Science in Engineering program at the Norwegian University of Science and Technology (NTNU), the students are required to write a master thesis. This master project will be carried out in the spring semester of 2015 by stud. techn. Sven-Vegard Buer at the Department of Production and Quality Engineering, as part of a two-year master program in Mechanical Engineering.

The supervisors for this master project are Jan Ola Strandhagen and Emrah Arica at the Department of Production and Quality Engineering.

The deadline for the submitting the master thesis is 10 June 2015.

Trondheim, February 2015

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1 Introduction

The pre-study report will describe the planned project and define key aspects such as problem description and project scope. The pre-study will work as a guideline later in the project since it defines the goals and milestones of the project.

This pre-study report will first look into the background for the master project. This part will also justify why further studies are needed on this subject. Following this, the problem description will be presented along with the project scope. The methodology that is planned to use in the project will also be presented briefly.

Since the master project is not just about writing a report, but also conducting the project in a proper manner, a preliminary project plan is presented. This will include a list of important milestones in the project period, in addition to a work schedule that will give a rough overview of the planned work.

2 Background

In an increasingly competitive market, the need for efficient business processes is becoming more apparent. Manufacturing industry is no exception, and continuous improvement in all parts of the company is required if it is to remain competitive. Many improvement techniques and tools have been developed over the years to improve production companies. The improvement programs for the production process might be the most well-known and includes techniques such as Lean, Six Sigma, and Total Quality Management (Slack et al., 2010). These improvement techniques aim to make production more efficient by lowering costs and increasing the quality.

New studies are constantly carried out in order to explore the possibilities of increasing the production planning and control performance further. Unfortunately, most production planning and control studies have solely focused on technical aspects, addressing the development and implementation of new or existing analytical models for different types of manufacturing environments (Berglund and Karlton, 2007, De Snoo et al., 2011). However, recent studies have shown that organizational factors have a significant impact on the production planning and control performance, regardless of the industry type (McKay and Wiers, 2006a, MacCarthy, 2006, Crawford and Wiers, 2001, Berglund and Karlton, 2007). Therefore, there is a need for research on organizational factors in production planning and control (McKay and Wiers, 2006b).

Through the project thesis conducted in the autumn of 2014, the precursor to this master project, a capability maturity model for organizational competence in production planning and control have been proposed. This model aims to aid different production scheduling and control environments in measuring their competence of taking organizational factors, which may have an impact on the effectiveness, into account. The model is supposed to be used both as a measuring tool and as an improvement tool, by giving guidelines for improvement. Further work is however needed on this model, and the model needs to be tested in real-life environments.

The original motivation behind developing a model for organizational competence in production scheduling and control is based on the topic of organizational factors. Through the project thesis, organizational factors were defined as factors that relate to humans in an aggregated sense, and covers aspects such as how work is organized and structured, together with rules, procedures, and cultural factors. Some examples of possible organizational factors within production scheduling and control are:

- How do functional interconnections influence scheduling?
- Which impact has organizational support on the scheduling and control process?
- How is the physical location of the schedulers effecting the scheduling and control process?

Through a qualitative literature study in the project thesis, organizational factors were identified, and their impacts on production scheduling and control investigated. The identified factors were then used to create a capability maturity model that evaluates a production scheduling and control environment's competence to take into account the organizational factors related to scheduling and control. The model can also give guidelines for improvement.

3 Problem description

This master project will focus on further development of the capability maturity model for organizational competence in production scheduling and control. Organizational competence is defined as the ability to take organizational factors into account. Since the initial model is based exclusively on theoretical data from a literature study, further work is required in order to make the model more robust. This chapter will consist of an analysis of the different tasks defined in the project description that is handed out to the student, with comments regarding how to solve them.

Elaborate the addressed problem and describe the scope of the project.

This relates to the start-up phase of a project, and relates to issues typically treated in the pre-study report. The actual problem should be analyzed; objectives, research questions, and refinements should be defined, in order to get an overview of *what should be done*. In addition to knowing *what should be done*, it is also essential to know *when to do it*. Project planning is therefore also important in this phase.

Conduct a literature study to develop the model further based on theoretical data and prepare the case study (-ies).

In order to develop the initial model presented in the project thesis further, a literature study is required. This is needed to obtain theoretical data that might improve the model further. This could be either new information or other views on a particular topic. Preparations of the case studies are also important in order to get the most out of these. This could for instance be to prepare a set of questions or mapping the information needs.

Conduct the case study (-ies) to obtain relevant empirical data.

The exact plans for the case studies are not yet decided, but the objective is to obtain empirical data that can help developing the model further. The collected information should be logged in a proper manner so that it can easily be used later in the project.

Refine the model based on the observations made in the case study.

The obtained data is then used to develop the model further, and increase its validity. Up to this point, the model is only based on theoretical data, which will limit its practicality. During this phase, the model should be reevaluated thoroughly and compared against the empirical observations.

Conclude the project with a final report.

The report will be written in parallel with the other tasks during the whole project. After all of the other tasks are completed, the report can be finalized and delivered.

4 Project scope

4.1 Research questions

Based on the main objective of the project, research questions can be defined. Defining research questions is essential in a research process. It will define what the point of the study is, and which questions it seeks to answer. In this project, the following research questions are proposed:

1. How to evaluate the organizational competence in production scheduling and control?
2. What is the current level of organizational competence for production scheduling and control in a selected case company?

4.2 Objectives

Outcome objectives:

- Develop a capability maturity model for production scheduling and control
- Test the model in one or multiple case studies
- Refine the model based on the empirical observations
- Write a report and deliver it by 10 June 2015

Process objectives:

- Write a pre-study report
- Make a project plan
- Keep contact with supervisors and report on the progress of the project
- Conduct a literature study to further develop the model
- Prepare questions for case studies

4.3 Limitations

Time

The project is carried out during the spring semester at NTNU. The project corresponds to 30 credits, and the delivery deadline is 10 June 2015. Since the project was officially started at 14 January 2015, the timeframe of the project is 21 weeks. The time limit will naturally lead to limitations on how extensive the project is.

Literature

Even if the literature study is comprehensive, the possibility of leaving out some of the relevant literature is significant. The used literature is also limited to what NTNU's library can offer through physical copies and online databases. Several research schools exist within scheduling, and this creates some challenges in the process of choosing literature and extracting its information. Because of these different research schools, conflicting frameworks exist, and one must exercise caution when mixing literature findings from different researchers. Possible differences in terminology must be investigated and taken into account in the literature study.

Case study

The companies being examined through case study does not necessarily represent the full reality. Both type of business and geographical location will certainly make a difference

regarding the findings. It is nevertheless intended that the selected companies should constitute a representative sample. The case study will also be limited in time. If some of the variables are changing over time, the case study will not be able to capture it.

4.4 Main work tasks

This chapter will present the main work tasks that are planned for the project. These are based on the tasks given in the project description (see section 3), but are defined into more detailed subtasks that need to be completed.

1. Elaborate the addressed problem and describe the scope of the project.
 - a. Analyze the problem
 - b. Define the objective and research questions
 - c. Define refinements
 - d. Break the problem into subtasks
 - e. Develop a project plan

2. Conduct a literature study to develop the model further based on theoretical data and prepare the case study (-ies).
 - a. Define search strategy and key words
 - b. Execute a literature search to find the most relevant literature for the project
 - c. Study the obtained literature and extract the most important information
 - d. Describe the result of the literature study in the report
 - e. Use the acquired information to further develop the model
 - f. Prepare questions and/or data sheets for the case studies

3. Conduct the case study (-ies) to obtain relevant empirical data.
 - a. Investigate how the model fits to a real world situation
 - b. Document the observations

4. Refine the model based on observations made in the case study.
 - a. Use the observations to adjust the model
 - b. Develop the finalized model

5. Conclude the project with a final report.
 - a. Use the documented information to write all the necessary chapters in the report
 - b. Make the document well organized and understandable
 - c. Conduct a spell check
 - d. Deliver the report

5 Methodology

This chapter will briefly explain the planned methodology in execution of the master project. Please note that this is a tentative plan that may be changed later in the project as more information is collected.

This master project is a continuation of the project work conducted last year, and some of the observations made in the project work will be used in this master project. New information is however needed in order to build upon those results. The planned methodology for information gathering is through a qualitative literature study and several case studies. The results from last year's project work and background theory from renowned textbooks will be used in the introduction of the thesis, in order to ensure a solid foundation that this project will be based upon. When looking for literature specified towards the actual issue, the majority of information will be gathered through journal articles gathered from online databases such as Engineering Village, ScienceDirect, and Google Scholar.

The methodology for the case studies is not yet decided, but the initial plan is to use either questionnaires or interviews in order to gather the required information from the case companies.

The project will be conducted with the help of project management tools such as Microsoft Project. This program will be used to create an initial Gantt chart and will be used in the process of project follow up, where deviations and changes will be documented. Having a detailed and realistic project plan is important to ensure a steady progress of the project.

6 Project plan

Since this assignment will be performed as a project, project planning and control is an important aspect. This will be of great help during the project execution, and make it easier to evaluate the project progress, since it can be related to the actual plan. The plan is based on plenty of sub-milestones that need to be carried out. These are to some degree based on the work tasks presented in 4.4, but will differ slightly since these sub-milestones are based on the different phases of the project, rather than the different main tasks. An initial project plan with estimated durations, in form of a Gantt chart, is presented in appendix I. A Work Breakdown Structure (WBS) that displays the work packages in the project is also developed and shown in appendix II. Some of the most important milestones are presented in table 1, together with their planned completion dates.

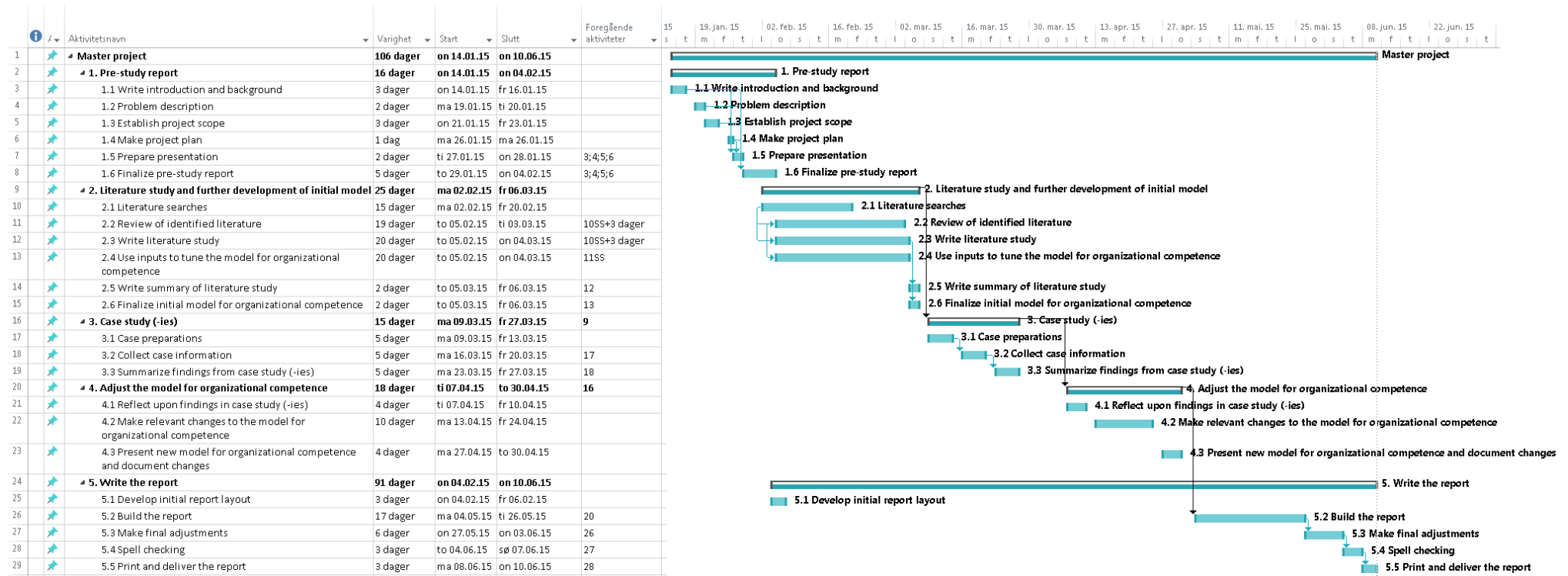
Table 1: Important milestones

Activity	Date
Deliver pre-study report	4 February 2015
Literature study finished	6 March 2015
Refined organizational competence model finished	30 April 2015
Deliver the master thesis	10 June 2015

7 References

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Appendix I: Gantt Chart



Appendix II: Work Breakdown Structure (WBS)

