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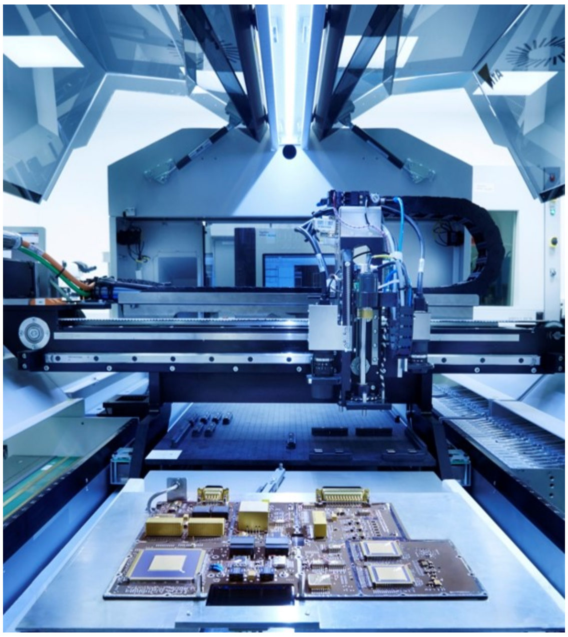

Visualisation of Shop Floor Production Planning in an ETO Environment

A Case Study on How to Visualise Shop Floor Production Plans in an ETO Environment

Master's thesis in Production Engineering

MARIE-MÄDLI KIVIMÄE
HENRIK WIBERG

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2021

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Supervisor: Mattias Svanberg, RUAG Space AB
Supervisor: Jenny Sjöholm, RUAG Space AB
Supervisor: Ninan Theradapuzha Mathew, Industrial and Materials Science
Examiner: Dr. Björn Johansson, Industrial and Materials Science

Master's Thesis 2021
Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

For the past two decades, the space industry has become more competitive, shifting from institutional investors to private ones. The change has lead to an increased focus on economic returns and the customer. To compete in this new market, companies need to become more efficient and shorten their lead times. More systematic planning, execution, and follow up of the production plans can be a way to achieve this. Therefore, this thesis investigates the applicability of a standardised visualisation of short term planning in the production of space components. The project is conducted at RUAG Space AB in Gothenburg, a company producing various electronic products for the space industry. The project intends to develop a conceptual solution, focusing on identifying requirements and potential challenges rather than an actual implementation.

The project used a between-method triangulation approach to establish the concept requirements. The triangulation included a literature review, semi-structured interviews and a survey. Based on the identified requirements, a visual concept was created to guide the development process of the functionalities. The outcome of the project is a conceptual visualisation solution implemented in the Qlik Sense analytics platform. The solution aims to provide decision support and facilitate shop floor autonomy, as it was found vital to cope with uncertainties in Engineer to Order (ETO) environments.

One of the project's major challenges was to create a solution that is both standardised and flexible. The developed concept will be part of the company's Management for Daily Improvement (MDI) boards to support visual management and continuous improvements. Even though the solution has been developed for a case company, the functionalities could be valuable for other companies acting in a similar environment.

Keywords: production planning, visualisation, ETO, decision support system, MDI, digitalisation.

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Marie-Mädli Kivimäe and Henrik Wiberg, Gothenburg, June 2021

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Abbreviations

CIP - Continuous Improvement Process
ETO - Engineer to Order
ERP - Enterprise Resource Planning
ESA - European Space Agency
KPI - Key Performance Indicator
MDI - Management for Daily Improvement
MRP - Manufacturing Resource Planning
PPC - Production Planning and Control
RE - Requirements Engineering
SOP - Standard Operating Procedure
WIP - Work in Progress

1

Introduction

This first chapter will introduce the space industry and the case company, followed by the research questions, the objectives of this study and delimitations.

1.1 Description of the space industry

For a long time, the space industry was characterised by having a high degree of institutional investors and few traditional private and commercial companies [1]. In the European Union, the European Space Agency (ESA), for example, handled most of the civil space-related projects, except for communication satellites. Private companies were then typically assigned contracts based on geopolitical aspects, with a guaranteed profit [1], [2].

However, from around the year 2000, there has been a shift towards what is called New Space. This New Space industry is instead characterised by private customers rather than institutional ones [2]. As a result, the space industry has become more focused on economic returns and the customer, creating a need for shorter lead times in both product development and production [2]. The space industry is hence becoming more competitive, requiring more efficient and flexible production solutions.

1.2 Description of the case company

As a manufacturer and supplier to the aerospace and defence industry, RUAG is one of the companies adapting to the New Space market environment. The headquarter of the company is located in Bern in Switzerland, but they have facilities in 14 countries spread all over the world with a total of around 6300 employees [3].

At their production facility in Gothenburg, the subsidiary RUAG Space AB manufactures various electronics hardware for the space industry. The product portfolio, e.g. includes antennas, microwave products and onboard computers. The products are, in general, Engineered to Order (ETO), resulting in lead times of months or even years. As the products are to be used for space applications, the requirements on both performance and quality are high. Therefore, the production process requires full traceability of components and involves a large amount of inspection and testing.

Aligned with the previously described New Space market environment, RUAG Space sees a need to make their production even more efficient while at the same time retaining the high quality of their products.

1.3 Problem definition

About one and a half year ago, Management for Daily Improvement (MDI) boards were implemented at the Gothenburg site to support the process of continuous improvements and visual management in production. The implemented boards included a production planning part, also called "My planner".

The planning part serves several purposes. One is to provide the shop floor staff with basic planning information, such as when and what to produce. Most of this information is contained in the company's Enterprise Resource Planning (ERP) system, used to create the production plans. Another purpose is to visualise the daily and weekly expectations and progress as part of visual management.

However, several departments did find it difficult to use the implemented production planning part of the MDI boards. One potential reason is that the needs and requirements of the departments vary. As a result, departments are currently either not using this part of the board or have implemented their own customised solutions.

Currently, traditional whiteboards are used, and information is brought to the MDI boards in the form of printed reports or manual writing. However, the company is interested in investigating different digital solutions and any possible benefits and challenges that they could bring.

1.4 Objectives

The overall objective of the master thesis project is to investigate how the production planning part of the MDI boards can be improved and made more standardised.

1.5 Research questions

The master thesis project aims to answer five research questions. The first three questions focus on how to transfer and present information on the MDI boards and are stated as follows:

1. How can the transfer of data between the ERP system and the MDI boards be facilitated?
2. Is it suitable to use a standardised format for the MDI boards?
3. How can the production planning be visualised to provide information about manufacturing orders' status and deviations?

The last two questions are instead meant to investigate digitalisation aspects that the case company is interested in.

4. How can information about short term planning and prioritising be digitally shared with other teams?

5. What benefits could be achieved by digitalising the production planning part of the MDI boards?

1.6 Delimitations

The MDI board consists of several modules that are currently used for visual management at the case company. However, the scope of the project does not include the whole MDI board. The focus of the project is only on the production planning part of the board. Additionally, the deliverables do not include the actual implementation of the proposed concept as a part of working procedures in the company. Rather the aim is to develop a proof of concept, where some of the functionalities are implemented in the software to identify potential challenges.

2

Methods

This chapter presents the methods that were used in this project. Between-method triangulation was used to gain a holistic understanding of important factors to consider. This meant combining information from a literature review, several interviews and a survey. The identified requirements were based on the findings from the triangulation and used for creating a requirements list that guided the concept development process. Brainstorming was used to translate identified requirements into functionalities that were considered while designing the visual concept. The actual implementation of functionalities included several iterations between understanding available data sets, redefining the logic behind the functionalities and collaborating with the stakeholders to evaluate if a correct interpretation of identified requirements has been accomplished. The result of all steps shown in Figure 2.1 is the final concept of production planning visualisation using the Qlik Sense data analytics platform.

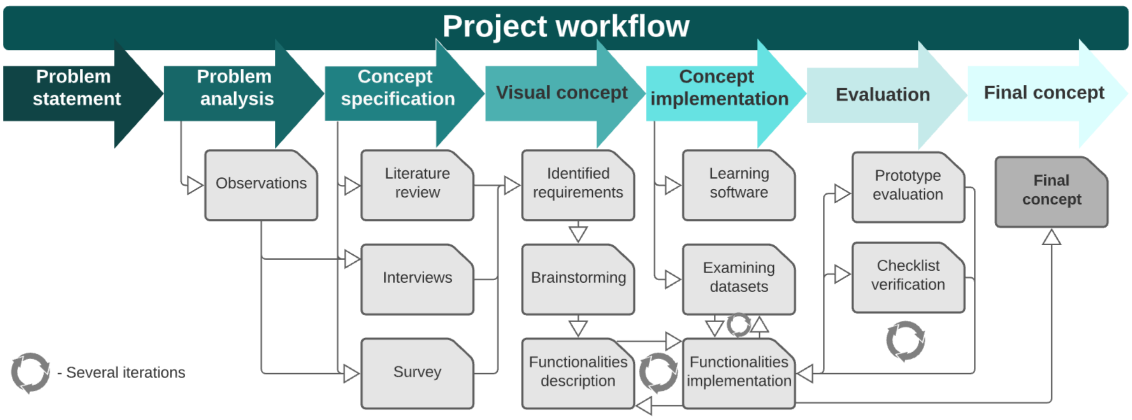

Figure 2.1: Thesis workflow presenting all the steps taken in the concept development process

2.1 Observations

Data collection at the case company began with observations that continued throughout the project. Applied observation techniques presented in Figure 2.2 could be classified as direct and indirect [4]. Guided tours on the shop floor, open interviews with employees and attending morning meetings were part of direct observation methods, where the authors could take notes and ask questions. This approach proved to be invaluable for building the initial understanding of the company, products, production flows, working methods and interactions between roles and departments. In total, four guided tours with a duration of one hour each were arranged with team leaders from different departments during the first week of the project. Additional guided tours and open interviews were scheduled in the following weeks to further grasp the nature of the stated problem and specifications for the concept.

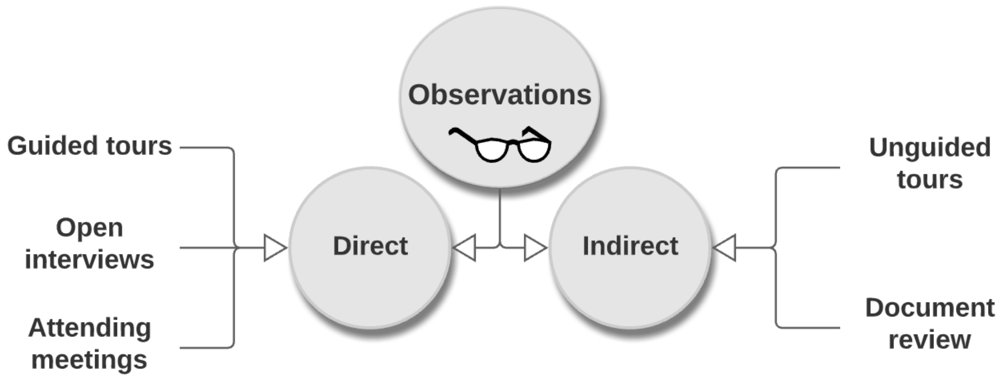

Figure 2.2: Techniques used for observations

As a part of indirect observations, production plans presented on the shop floor were studied individually and compared based on notes. Preparations for each session included scheduling a time slot, structuring key ideas to be answered during the observation and defining the purpose of the observation. A deeper understanding of the design requirements for the MDI board was obtained through document review, where the MDI board Standard Operating Procedure (SOP) was studied carefully.

The acquired knowledge was then used to define the search string for the literature review, design the survey, select the participants, and form the questions for the semi-structured interviews.

2.2 Literature review

A literature review was conducted to lay the foundation for this research project and to map the current development in the field. A structured approach was used to identify what ideas and knowledge have been previously established on the topic in focus. A well-defined approach used for literature review aims to provide impartial analysis by specifying steps taken to reduce bias in each screening stage and enable a reproducible review process [5]. The following sections describe the database and search string used to find relevant articles. Screening in several stages was applied with inclusion and exclusions criteria. Screening in several stages improves the chance of finding articles with the most relevant information for the specific project [6].

2.2.1 Database search

The multidisciplinary reference database Scopus was decided to be used for the literature searches because it includes the major journals found relevant to the research topic. Based on the determined research questions and initial observations at the studied company, various keywords were considered to be used for the search string. The combinations of keywords were used to test search terms and inclusion criteria. This method aligns with the test procedure proposed by [5], where a smaller sample is used to assess the credibility of the search string before carrying out the main literature search. The goal of having a well-defined search string is to facilitate reproducibility. Another aspect to consider is the scope of the search string. An overly detailed search might result in a narrow scope. Therefore, some relevant articles might be excluded. On the other hand, the outcome of a broad scope might be too many articles and a time-consuming screening process. It is hence essential to find a balance between including relevant articles and estimating the time needed for the screening.

A combination of the article title, abstract and keywords were used for performing the searches. Several alternative keywords were combined for each term to not exclude articles because of missing a specific keyword. The first term used in the search string seeks to limit articles based on activity, which in general for this project is production planning. The following term focuses on the type of solution to be developed. The goal is to provide an overview of solutions developed for visualising production plans and providing decision support. Therefore the keywords used were visual* and decision support. "*"- sign is referred to as a wildcard, which enables to include results that might have multiple spelling variations at the end of the word. The last part of the search string addresses the specific production environment that would be low volume production or ETO. Keywords and terms were combined using Boolean operators such as "OR" and "AND". In addition, a limitation was set based on the language, so that only articles published in English would be included. Source type was narrowed down to "j"-journals and "p"-conference proceedings. However, no restriction was set on the year of publication. The full search string used was:

TITLE-ABS-KEY ("Production scheduling" OR "production planning" OR "manufacturing planning" OR "production planning and control") AND (visual* OR "decision support") AND (hmlv OR "low volume" OR "job shop" OR eto OR mto) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j") OR LIMIT-TO (SRCTYPE, "p"))

This search resulted in a total of 506 articles that could be potentially valuable for this project.

2.2.2 Screening

The steps taken for screening the articles are visualised in Figure 2.3. The initial screening was based on the title and the abstract of the articles. The inclusion criteria in this stage focused on the visualisation of production planning in an environment similar to RUAG Space. This means that there is a high mix of products produced in a low volume. From a concept development perspective, it was also decided to exclude articles with a strong focus on specific algorithms, simulation models, AI, machine learning or deep neural networks. Another exclusion criteria was set to the production environment and the expected results. For example, if a case study was based on a flow shop production or if the solution was developed primarily to improve energy efficiency and reduce energy consumption, it was excluded.

A consultation session with a librarian from Chalmers Library was arranged to discuss which technique would be preferred to effectively reduce individual bias in the screening phases. The systematic review software Rayyan QCRI was recommended by the librarian for conducting screening in literature review [7]. Potentially eligible studies found from Scopus using the search string were therefore exported with citation information (e.g. authors, title, year, DOI), abstract and keywords and uploaded to Rayyan QCRI. The functionalities presented by the software encompass adding keywords, labels, inclusion and exclusion criteria that can be used afterwards for filtering [8]. In addition, users can easily collaborate as the solution is cloud-based. Moreover, blind-mode functionality helps to reduce individual bias as inclusion or exclusion decisions are not affected by the decisions made by the other author [8]. After both authors had made decisions for all articles, contrasting decisions were displayed as conflicts, which were then reviewed collectively by both authors. After this screening phase, full texts of 39 articles were decided to be read.

In the last screening phase, the articles based on their full texts were categorised into groups such as general challenges in production planning, methodology for concept development, cognitive aspects, developed solutions, sustainability aspects, and future perspectives. Those topics are further elaborated under the literature review results.

Backward snowballing refers to a search method where the reference list of the selected articles is reviewed to identify other interesting papers related to the topic [9]. If the reviewed articles presented interesting information from other works, the referenced articles were also included in the review, if found relevant, according to backward snowballing [9].

In total, 27 out of 39 articles were found to be relevant for this thesis project after reading the full texts. 11 additional articles were included through backward snowballing.

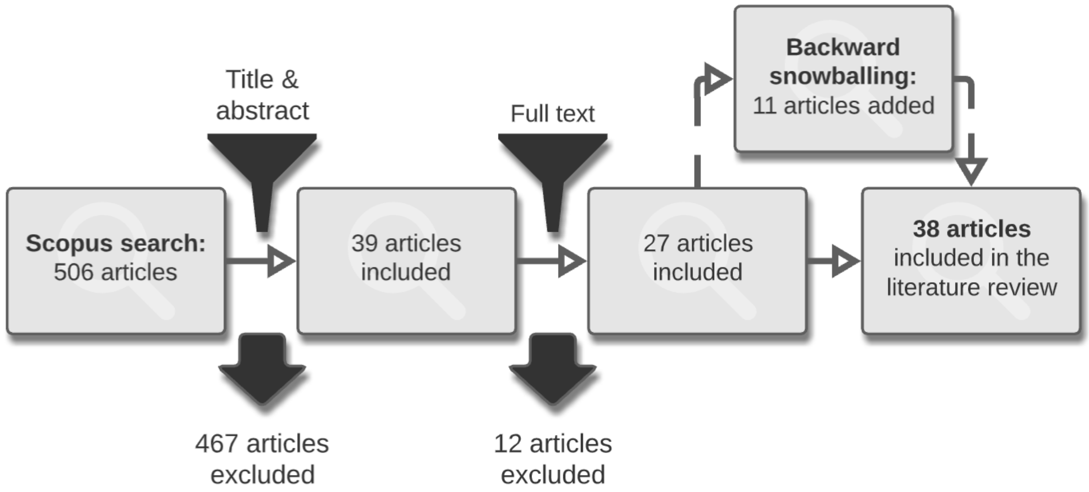

Figure 2.3: Overview of screening phases in the literature review

2.3 Qualitative study

The qualitative study for this project was conducted using semi-structured interviews with team leaders, production planners and production managers working at RUAG Space. The interviews were recorded, transcribed and then analysed using coding.

2.3.1 Semi-structured interviews

A semi-structured interview consists of predetermined questions while allowing the interviewers to elaborate on the topics during the conversation [10]. Additionally, it offers the interviewee the possibility to emphasise the issues they find important [10]. The method selection of semi-structured interviews is useful to explore a diverse range of experiences in-depth [10], which aligns with the purpose of this project. The interviewees were chosen from three organisational levels in each department. The goal was to capture different perspectives on production planning, e.g. how the production plans on MDI boards are used.

In total, nine interviews were conducted, eight in English and one using a combination of English and Swedish. Each interview was followed by a discussion between the authors, and take-ways were collected into a shared file. Interviewees were asked for permission to record the audio of the interviews. The recordings were stored locally on the authors' password-protected computers and will be removed at the latest two weeks after the publication of this thesis. All recordings were transcribed into text, and coding was used to structure the information. Recording and transcribing interviews was found necessary to capture all ideas brought up by the interviewees. Analysing the content of transcripts facilitates pattern recognition and helps to discover themes [11].

2.3.2 Coding

Coding in qualitative research provides a systematic approach to identify and organise information for theory development [12]. The coding process can be divided into different stages.

In the first stage, the transcribed text is analysed, and the main ideas are highlighted [12]. The next step is the axial coding, where identified themes are examined and divided into categories [12]. Findings from the transcribed interviews were compiled into a joint document. The gained knowledge from the interviews was used to understand the challenges in the current situation and to develop a requirements list for the visualisation concept. The interviews will be further summarised in the results chapter and elaborated in the discussion chapter.

2.4 Quantitative study

A quantitative study was conducted to gain a more holistic understanding of the current state and the requirements of the MDI boards. The aim was to get more quantifiable data and sample a broader audience compared to the qualitative interviews. The study consisted of an online survey that was shared with the participants through email.

2.4.1 Participants

As the survey aimed to get a more holistic view of the shop floor status and requirements, it was decided to send it out to all people working with production at the site in Gothenburg. In total, 49 employees were asked to participate in the survey. This included four different types of staff; operators, team leaders, production managers and production planners.

2.4.2 Study design

The survey questions were in English, but participants were also allowed to provide free text answers in either English or Swedish.

The survey was divided into four main sections; introduction, current state, requirements and other. In the introduction section, the participants were asked whether they were currently using the production planning part of the MDI board. If the question was answered no, the succeeding section about the current state would be skipped.

Both the current state and requirements section was constructed similarly to each other to be able to identify gaps. Interval rating scales between one and ten were used for both sections. A low ranking indicated that the information was either missing or unimportant, while a high score corresponded to the information being easily accessible or important. The participants were, for example, first asked how accessible a particular type of information currently was, ranking it between one and ten. In the next section of the survey, they were then to rank the importance of the same information for their daily work, also ranked between one and ten. The information asked to be evaluated was based on findings from the previously held interviews. The complete set of questions can be found in Appendix A.

As the scales are numerical and only provide labels for the extreme values, one and ten, the data can be categorised as interval type data [13]. Parametric methods can be used to evaluate interval type data, given that the data is normally distributed. For small data sets with high variation, it is instead recommended to use non-parametric or descriptive methods [13]. As the number of surveyed staff was relatively low, it was decided to use descriptive statistics to illustrate and compare the median values.

In the last section, the participants were asked if they had any other information or opinions that could be valuable for the project. The answer could then be written in free text.

2.4.3 Anonymity and confidentiality

As anonymity in surveys has shown to facilitate more open and honest answers [13], it was decided to keep the identity of the respondents anonymous. Some of the departments also have few employees, so the survey did not ask about which department the respondent belonged to. The reason being that the persons identity might then be traced back.

There are advanced methods available to keep track of respondents and how many times they reply, while still retaining anonymity [13]. However, as the survey was sent out to a limited amount of people, all employed by the same company, the risks associated with providing unrestricted access to the survey was seen as a minimum.

2.5 Triangulation

The main idea behind triangulation is to combine different methods or sources to increase confidence in the findings [14]. This study used a between-method triangulation approach, meaning that findings from different research methods were combined [14].

The goal of the triangulation was to produce a requirements list for the concept, supported by the literature, survey and interviews. The survey provided general information about what could be important for the stakeholders, while the interviews provided a more in-depth understanding of why certain aspects are important. The literature was then used to compare findings with previously conducted research and developed concepts.

2.6 Requirements engineering

Concept development followed mostly a traditional Requirements Engineering (RE) structure; however, some agile software development methods were applied, for instance, development sprints. The RE process consists of several steps including elicitation, analysis and validation of the requirements that set the foundation for system development [15]. It aims to improve the understanding of the application domain, where the system will be used [15]. The idea behind this is to establish what to build before the actual developing process [15]. The specific steps taken for requirements selection are further described in the following sections.

2.6.1 Requirements elicitation

The first task was to elicit the requirements by consulting the stakeholders and users to find out the requirements and define the system boundaries [15]. Planning, validating and testing the developed concept is based on the requirements. Therefore, it is crucial to involve users to properly understand and align specifications with customers' expectations [16]. Otherwise, it is likely that the development process drifts away from the desired goal [16]. In addition, collaborating with the users during the requirements identification phase supports the establishment of constant feedback loops and acceptance in the implementation phase [17]. Similarly, a lack of user involvement has been found as one of the main reasons why difficulties are faced in the development process [15].

[18] stresses that requirements elicitation methods should be selected according to the characteristics of the stakeholder and situational context; nevertheless, the team members should have good knowledge of the methods. As mentioned in the previous methods sections, a variety of techniques have been used in this project for requirements elicitation. The methods have been chosen accordingly to the authors' knowledge and experience from previous projects.

Observations and open interviews with employees laid the foundation for the initial understanding of the working environment, working methods, processes, and production flows. Furthermore, [18] emphasise that observations can be beneficial as those might reveal aspects that might be part of routine work and therefore forgotten by the user to mention.

The next step was document review, where the MDI board SOP document was studied carefully to further comprehend the visual concept application context, the interaction between different modules and design limitations. Studying the existing system through document review can be used to characterise the requirements for the concept under development [18].

From the requirements abstraction level perspective, two phases are recognised by [18]: problem analysis and product specification. Observations, open interviews, and document review helped to grasp the situation and define boundaries that relate to the problem analysis phase. Using methods like semi-structured interviews and survey focused on the product specification phase by gathering specific information about the desired functionalities and the importance of each feature. In addition, a literature review was used to gather ideas from similar solutions developed before, but potentially valuable for this project. The goal of conducting semi-structured interviews was to identify the themes, explicit requirements, and challenges, while the survey provided quantifiable data that could be used in the analysis state for requirements prioritisation. Setting the priority is essential to establish which features should be implemented first to provide the highest business value [15].

2.6.2 Requirements analysis

The next stage in RE is requirements analysis, where identified requirements should be reviewed and following questions should be answered [15]:

- If the requirement is essential to have?
- If the requirements are conflicting?
- If requirements are fully described?
- If these are feasible to achieve within agreed timeline and budget?

For example, if any contradicting requirements are found, it can be solved by consulting the stakeholders and setting the priority amongst the requirements [15].

2.6.3 Requirements validation

As a final step, requirements validation was carried out to confirm that all planned functionalities have been described to an acceptable level to be implemented [15]. To accomplish that, each requirement was elaborated between the authors to gain a common understanding of every aspect and to structure the workflow. In parallel, the data sets accessible from the Enterprise Resource Planning (ERP) system were examined to connect those with desired functionalities. Combining previous programming experience and the knowledge of available data with desired functionalities, the initial high-level requirements were described more in detail. The requirements also consider implementation aspects in the Qlik Sense analytics platform.

2.7 Visual concept

The aim of a visual concept is to provide a tool for explaining the intended functionality to the end-user to see if the requirements were correctly captured. Moreover, the implementation in the actual software could be shortened with the use of a simplified visual concept as it can be used as a guide in the development cycle [19].

Lucidchart software was used for creating the design layout. Using an online platform enabled the authors to collaborate in the brainstorming process in real-time and keep a log of prototype versions developed in the early stages. In addition, sample templates and shapes provided by the platform made it easier to design a realistic layout for the visualisation concept. The visual concept was used to guide the implementation of the feature in the Qlik Sense data analytics platform.

Multiple iterations were done between implementing features in Qlik Sense and revising requested features and the logic behind executing those in the developed concept. The idea of sprints are commonly applied in an agile software development process [20]. This idea was used also in this project, where a group of features were set as a target to be implemented in a period with the length of 1-2 days.

2.8 Concept evaluation

The purpose of evaluation techniques is to guide the development process, provide a systematic feedback loop and assure the alignment with the end-user expectations [21]. The methods used for concept evaluation were selected from a review, where 215 case studies were analysed and reviewed to recommend the most suitable methods for usability evaluation in the software development area [21]. It was decided to conduct the evaluation in two stages with the aim to support the development process from the early phases until the final concept.

The first method used was checklist verification. This means that the functionalities are checked against the specifications [21]. The requirements are based on the findings from the literature review, interviews and survey. Each requirement must be matched with at least one functionality implemented in the concept to be considered fulfilled.

According to [21], prototype evaluation is another suitable method to check the alignment with the end-users expectations. Therefore, in this project, stakeholders were contacted to discuss the expectations for the final concept. Several meetings were organised with the company supervisor to clarify the expectations for the concept and to discuss the functionalities. By doing so, it could be validated that the recognised requirements were interpreted correctly. In addition, as mentioned previously, collaboration with the stakeholders is crucial to gain higher acceptance for the proposed solution. Moreover, in case of difficulties faced in the developments process, stakeholder knowledge and experience in the field could be highly valuable to bring forth unnoticed ideas or alternatives that can be considered for the functionalities implementation. The weekly meetings with the length of 1 hour have been used, for example, to gather feedback to concept layout design, establish automatic data load connection with the ERP system and to discuss the type of data needed for functionalities implementation.

3

Initial observations

The following chapter will present the findings from the initial observations at the case company. This includes general information about the case company, currently used software and the different roles found in production. The end of the chapter provides an introduction to the MDI boards.

3.1 Products and production flows

RUAG Space's facility in Gothenburg specialize in developing and producing various electronic products, mainly for space applications. The main product groups can be seen as:

- **Computers and systems** - On-board computers, power and drive electronics
- **Microwave** - Amplifiers and frequency converters
- **Antennas** - Various antennas to be used in space
- **Built-to-print** - Manufacturing and testing of externally developed electronic products

3.2 Software

There are several different types of software used at RUAG Space to support the production planning function.

- **IFS** is the ERP system used at RUAG Space's site in Gothenburg. The software incorporates data and tools to support planning across different functions, including economy, supply chain and manufacturing.
- **Qlik Sense** is a data analytics platform recently introduced at RUAG Space. The software can be used to create reports to facilitate the analysis and understanding of data to provide insights. The current knowledge and use of the software at RUAG Space is limited.
- **Microsoft Excel** is currently widely used at RUAG Space. It is, among other things, used to create visual overviews of the projects and to generate

the weekly plans to be posted on the MDI boards.

3.3 Role descriptions

Guided tours and interviews with staff provided an overview of the different roles involved in the production process. Below are short descriptions of roles found to be related to the project.

- **Team leaders** are employees who, besides working on everyday testing or assembly operations, are responsible for daily scheduling and problem-solving in their department. They monitor the progress to assure on-time delivery, set the goals and assign operators to work tasks during the morning meetings. Furthermore, they communicate with other departments' team leaders, but also production planners, project managers and production managers.

- **Production planners**, also called object managers at RUAG, are the interface between the projects and production or project managers and team leaders. Their main task is to create production plans in IFS and shop orders for the production. In addition, they estimate operation times, set the priority among the shop orders and follow up the progress. In case of disturbances in the production plan, they are responsible for weekly re-planning.

- **Production managers** work with the production more on a strategic level. They are not so much involved in daily operations; they instead manage production and support functions such as production technicians, planning and procurement on a higher level with a longer time perspective. As an example, they are responsible for planning and organising the alignment of capacity with the planned workload on a 3-4 months perspective.

3.4 MDI board

A performance measurement system is characterised as a collection of multidimensional measures with defined targets used to evaluate organisational performance in the past and to provide data for planning the future performance [22], [23]. Combining visual management tools with performance measures enables the process owners to receive feedback and easily grasp their processes' performance [23]. Therefore, it promotes transparency, shared ownership, discipline, and empowerment of team members [23]. Furthermore, connecting visual management tools with continuous improvement initiatives helps to reveal improvement opportunities and establish a culture striving towards better performance [23].

Gemba walks and MDI boards are two examples of lean methods applied at RUAG Space to support the Continuous Improvement Process (CIP). Roles and activities are divided into three levels. On the first level, the employees working with the products on the shop floor report continuously the results and any constraints they might face [24]. Team leaders are responsible for evaluating the results and supporting the operators in problem-solving. The next level consists of the activities done daily by the team leaders and department managers. Each day, the team leaders communicate results and critical hinders to the department managers, who then analyse problems and initiate CIP activities if needed [24]. The aim is to provide support to the employees so that they can perform their best. The set of activities for continuous routines at the workplace and daily tasks are connected to MDI practices.

The aim of the MDI board is to support the CIP by visualising the processes and making the organization more transparent [24]. The objectives of the MDI boards can be grouped into three levels [24]:

1. Communication channel to fulfill customer's needs and business strategy
2. Problem solving and continuous improvement (learning)
3. Employee empowerment

The objective of the first level is to visualise and analyse key performance indicators (KPI) and align individual goals with organisation targets. The second level aims to facilitate problem-solving by visualising critical areas and non-value adding processes. It emphasises the importance of a proactive attitude towards including the value-creating employee in root cause identification and selecting an appropriate corrective action process. Finally, corrective actions and their results need to be followed. The last level intends to empower employees to become responsible for their own processes and to report issues that hinder them from performing. It also aims to visualise individual results and essential data for effective management [24].

The MDI board used at RUAG Space has two sides: MDI Cell Board 1 and MDI Cell Board 2. The first one provides an overview of the department, while the second focuses on the daily improvement of a single employee or workplace. The modules presented on MDI board 1 include, for instance, a value stream map of the current state and future state, yearly plan and status forms of safety, availability, performance, and quality.

The planning module displayed on MDI board 2 is the focal point for this thesis project. A simplified layout of MDI board 2 can be seen in Figure 3.1, where "My planner" (1), "What hinders me to perform?" (2) and action notes section (3) are visualised. Besides the "My planner" section, board 2 is used to visualise "What hinders me to perform", which is referred to as the "heart" of this board and where occurred disturbances like material shortage, machine failure, quality issues are recorded [24]. In addition, board 2 includes the action notes derived from the root cause analysis process and are used to monitor the problem-solving activities. The "My planner" module, presented in Figure 3.1, is one of the first visualisation drafts created in this project. The middle section is an actual representation of the "What hinders me to perform" module, currently displayed on the MDI boards. A simplified representation of the allocated space for action notes can be seen to the right in the figure.

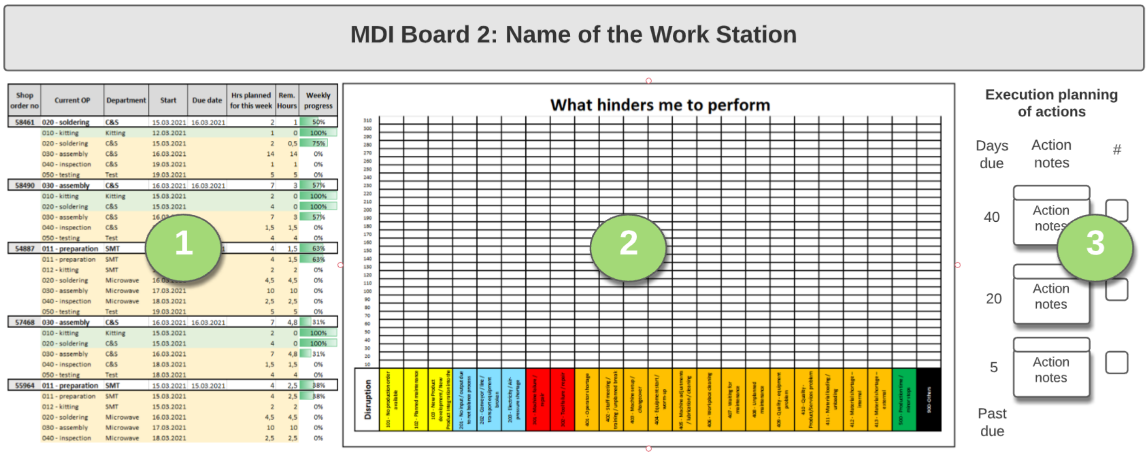

Figure 3.1: Simplified layout of MDI board 2

Both sides of the MDI board are updated once a day during the teams' morning meeting and examined afterwards at the planned Gemba walks. The general idea is to understand at a glance which areas are problematic and need to be improved. In addition, several questions might be asked during the Gemba walks from the team members about the hinders, if the root cause has been identified and if actions have been registered on the action list.

4

Results

The results chapter will present the findings that laid the foundation for the requirements list. The chapter is divided into three main parts, presenting results from the literature review, interviews and survey.

4.1 Literature review

In the following section, the findings from the literature review are presented. The chapter is further divided into smaller thematic subsections according to the main focus areas of the review. The chapter gives an overview of general challenges regarding production planning, but also more specific challenges associated with ETO environments. It also describes the main takeaways from currently available solutions as well as the future outlook in the field of production planning.

4.1.1 Challenges of planning in an ETO environment

In an ETO environment, the products are engineered and customised specifically for each customer, meaning that, e.g. both the routing and bill of material for the product can vary heavily between orders. Therefore, the work of a production planner in an ETO environment is, in general, considered a complex task [25].

Normally, an ERP system is used to facilitate the planning of a company's resources. There are, however, challenges with using an ERP system in an ETO environment. ERP systems generally assume fixed lead times and use deterministic approaches to develop the schedules [26]. This becomes a problem when planning in an ETO environment, as uncertainty is often high [27].

Another challenge is that the majority of the tools available to support production planning today lack information about the current status of the production [28]. The issues associated with this becomes even more apparent when scheduling is done independently by different departments, making it difficult to synchronise planning between succeeding and preceding processes [29]. With this in mind, it is important to facilitate efficient sharing of information between departments and to adapt the level of detail according to the function [30].

A third common challenge can be found in how uncertainties are handled when using

ERP systems in an ETO environment. As ERP systems commonly assume fixed lead times, they lack the functionality to effectively handle a high level of uncertainty, which is found in ETO environments [31]. To cope with this, it is common to use external manual tools to produce the production plans, even though this further undermines the role of the ERP system [31]. As a result, the information in the ERP system becomes outdated, making it difficult to manage the supply chain, leading to longer lead times and increased inventories [32].

A fourth and last challenge is the fact that the Manufacturing Resource Planning (MRP) part of ERP assumes that resource capacity is infinite [31]. As this is not the case in ETO environments, the produced shop floor plans are difficult to adhere to, creating a need for re-planning. Having these infeasible schedules will not only increase the workload for the planners, but it will also decrease the utilisation and increase the cost [33].

4.1.2 General challenges in production planning

It is important to have input data of a high quality to create good production plans. Accurate measurement and reporting of operation times can contribute to higher data quality and hence also more accurate production plans [34]. However, if there is a high level of shop floor autonomy, meaning, e.g. that shop floor staff can prioritize orders themselves, the data quality requirements are lower, as the production plans do not need to be as detailed [34].

Having a high shop floor autonomy, and thus doing much of the planning on a shop floor level, can have other benefits. Producing detailed shop floor plans on a tactical level can, e.g. be problematic, as the tactical level rarely have the same insight and understanding of the shop floor capacity [35].

There are several metrics that can be used to measure the performance of a production schedule, including, e.g. utilisation, tardiness, cost and Work in Progress (WIP) [36]. It can, however, be difficult to evaluate the overall performance, as objectives can be contradictory [37]. It can, e.g. be difficult to achieve both a high resource utilisation and a low WIP, because of uncertainties in the production system.

As there is always a risk of unforeseen production disturbances, a production planning system needs to facilitate easy re-planning [38]. In production systems with a lot of uncertainty, requiring a lot of re-planning, it is, however, common that this type of information is shared in a less formal way, rather than updating the actual plans [30].

When planning and re-planning in uncertain environments, there is also a risk for what is called lead time syndrome. In an attempt to improve due date reliability, planners will add safety lead time and release the orders earlier [25], [39]. This is, however, likely to increase both WIP and lead time, worsening the situation further, creating a downward spiral of re-planning and decreased due date reliability. When re-planning, the workload and stress level of the planner will also increase, decreasing the quality of the plan [37]. Charts and visualisations can, however, help to reduce the risk of lead time bias, given that they are designed to not overwhelm the planner with information [25]. When using human planners, the quality of the schedules will, however, still depend to a large extent on the planner's mental ability [38].

4.1.3 Reasons why add-ons are developed

Several case-specific production planning and control solutions that visualise the status and provide decision support have been developed for ETO companies. To start with, previously studied cases address various weaknesses of ERP systems, explaining why customised add-ons are developed. One of the reasons identified by [40], is that the decision support is based on simplified mathematical problem definitions without comprehensive inclusion of constraints and uncertainties, for example, deviations in estimated times. From another perspective, characteristics of a production environment, like frequent design changes, complex product specifications and skilled workforce, make computer-centred methods that generate schedules automatically less suitable [41]. Other drawbacks often related to ERP systems are the difficulty to access or not easily customisable to specific needs [30]. However, the most common aim for using external tools for visualisation is to improve the user-friendliness of existing systems [30], [36]. Therefore, flexible add-on tools are seen as advantageous to fulfil particular needs for information visualisation and to modify production scheduling plans [30].

Making the system more intuitive can increase the user-friendliness [42]. The case study by [43] indicates that there is a tendency of using add-ons like customised excel sheets to access updated data in the desired format. On the other hand, a common shortcoming of those customised production planning solutions that are based on Excel sheets or visualised as Gantt-Charts is that they lack the possibility to directly interact in case of deviations from the production schedule, e.g., maintenance work or priority changes [42].

4.1.4 Solutions

[36], [44] and [41] introduced an interactive computer graphics approach, where scheduled jobs are displayed as a Gantt chart. The solution developed by [36] used a built-in algorithm to generate a schedule. However, to overcome the previously mentioned challenge regarding direct interaction, the user can easily modify the schedule using "drag and drop" manipulation [36]. In addition, the proposed solution has "split" and "join" functionality [36]. The first one allows the user to divide the operations into several parts, while the "join" option gives the possibility to merge sequential orders into one [36]. Thereby, the guidelines followed through the design of the interface included the possibility to revise the schedule and provide enough information for decision support in a dynamic environment, while at the same time not overwhelming the user [36].

Another web-based visualisation system proposed by [41] is meant to assist the decision-making process in production planning for a shipbuilding company. The potential of integrating a tabletop system for multi-user scenario in production planning and scheduling was explored by [42].

A different approach is illustrated with a case study by [45] where the Production Planning and Control (PPC) process in a low volume high mix ETO company is improved by implementing lean management techniques. The proposed technique can be summarised with the following steps. The first step in the planning process starts with estimating project lead times by grading the complexity in design, production and assembly [45]. Computed times based on historical data and required delivery dates are used as an input for the initial plan [45]. After that, managers from different departments meet to revise the plan during the morning meetings and discuss the current status, problems faced and upcoming orders [45]. Plans are displayed using a visual tool, which is a prominent theme in lean shop floor management [45]. Perceived benefits from working this way included faster information sharing and solving problems using a holistic approach, where all projects could be considered in the decision making process [45]. The outcome was an integrated plan, which supports informed decision making, more efficient priority setting and earlier identification of potential conflicts [45]. Therefore, for instance, if a mismatch between planned and required capacity is noticed, adjustments could be made daily, which leads to proactive behaviour in activity planning [45].

Unravelling the reasons behind the deviations between estimated and actual times is important to enhance the company's performance. An order progress diagram was proposed by [46] that outlines the deviations of an individual order from the average order progress pattern. This, in turn, gives insights about the progress and possibility to trace back to a stage where the orders have been delayed, therefore providing a starting point for improving the delivery reliability [46].

4.1.5 Interface

Designing a visualisation concept places various demands on the user interface. Besides having a supporting software system to solve scheduling problems, it is essential to present adequate information for the user in a way that is intuitively understandable [44]. Previously developed solutions have considered the interface that is monitoring operations, presenting information from a dynamic environment, and providing guidance in a critical situation, while maintaining flexibility in interaction between the user and the system [44]. In addition, allowing easy manipulation for the user to apply its own decisions and suggestions [44].

Additionally, the interface could visualise the deviations from the initially planned scenario and allow a comparison option for "what-if" situations based on different scheduling policies [44]. Therefore, the decision-maker would have the possibility to evaluate several alternatives and associated consequences [44]. An interesting observation from the concept introduced by [42] is the indication of conflicts that helps the user to avoid constructing inconsistent states, like moving a process that has already started or moving a process to a machine that is missing some required functionalities. Human-machine cooperation for production planning and scheduling was studied by [47]. The experiments with the designed human-machine interface model, where the disturbances accompanying the decisions were displayed, showed that the scheduling performance improved [47].

4.1.6 Real-time monitoring

[48] mention that involving humans in information sharing hinders fast information sharing. Moreover, [40] point out the dilemma between appropriate and timely decisions, which may be caused by a collaborative decision-making mode. Humans are proficient in information gathering, communication, negotiation and filling in the missing information for rescheduling [40]. [49] acknowledge the efficiency of humans in adapting to changes and making decision based on emerged constraints. However, humans have a limited cognitive ability and might not have access to relevant information kept by co-workers [50]. Likewise, according to [48] lack of relevant information prevents an optimised order release and might lead to a higher risk of errors. On the other hand, [48] bring up the issue of receiving too much interference and irrelevant information, which makes it difficult to focus on problematic areas. Computers provide complementary support in processing large data sets [47], [51], [52]. Therefore, with the aim to successfully design and implement production scheduling system for decision support, the findings from the studies [40], [53], [54], [55] indicate the need to combine the human, technological, and organisational aspects. [47] supports that human-machine cooperation is necessary for decision-making in production scheduling.

According to [32], production planning complexity in an ETO environment could be reduced by using regular, near real-time feedback of the production status together with systematic re-planning. In addition, they assume that current trend towards industry 4.0 and digitalisation paves the way to more accurate real-time data collection and enables constant monitoring of the status [32]. Data sharing and monitoring systems are vital to be able to act on changes and reflect on the scheduled plan [41].

Commonly used centralised production planning and control often have a shortcoming in the feedback loop between involved stakeholders [32]. To avoid this common drawback the plans need to be frequently updated and information shared with actors within the value chain [32]. Failing to do so could result in obsolete information for decision making and high levels of non-value adding work, like unnecessary transportation of products or waiting [32]. Therefore, it is crucial to consider how often the status of current state should be updated. Two types of frequency cycles have been defined by [32], namely soft or near real-time and hard real-time updates. Receiving updates in every minute to daily interval is classified as soft real-time [32]. If the status is updated more often, e.g. seconds to minutes, it can be seen as hard real-time update [32]. Furthermore, [32] exemplifies a near real-time solution to be used in a construction company.

Another contradicting aspect to consider is the manual effort needed to capture the data to provide real-time status updates compared with the value of reducing the complexity in production planning and providing support in decision making [32].

4.1.7 Trigger points

To reach just-in-time manufacturing in an ETO company, [32] emphasise the significance of defining the ideal trigger point for re-planning. How the trigger point is defined depend, among other things, on the type of products and production [32]. As an example, [32] illustrated that more frequent trigger points and shorter planning interval would achieve a higher planning accuracy. On the other hand, long planning intervals and deviations due to unpredictable circumstances can led to remarkably low planning accuracy [32]. As an example, a system designed by [56] provides feedback after each operation is completed, enabling the managers to be more informed of the current status. Furthermore, [56] decided to use daily interval for production planning, because weekly plan might not provide sufficient control.

[48] discuss that the event-driven production planning and control system could reduce the reaction time and time spent gathering information. Seen results included improved adaptability in case of changes and decreased the scheduling losses by increasing the utilisation [48].

4.1.8 Re-planning due to high degree of uncertainty

Deviations from plans and schedules may require reactive control actions. [40] looks more into typical challenges faced in production scheduling and the implementation of advanced scheduling. The challenges arise as a result of typical characteristics of sociotechnical environments [40]. It is common in complex manufacturing environments to lack the ability to easily adapt the production plans in case of unforeseen events [40].

[57] identified some of the common root causes for systematic deviations between the proposed production plan and actual. Those include:

- Lack of staff or machine capacity shortage
- Variations in work processes and plans
- Incorrect target times
- Sequencing
- Changes in delivery dates

Frequent and less formal re-scheduling is a common response to uncertainty and variability existing in ETO manufacturing environments [30]. Another reason why completely automated production scheduling tools might be unsuccessful in assisting in the day to day shop floor plan execution is that re-scheduling is seen as a social activity and human exercise [30], [58].

Therefore, the focus of the study by [40] was to propose a framework for rescheduling decision-making. This includes guidelines of when the disturbances should be handled by the shop floor personnel and when it should be escalated to higher level decision makers [40].

Nevertheless, the degree of autonomy was found to be critical to maintain the performance and flexibility [56]. Therefore, it is important to consider it when developing a web-based decision support system to cope with uncertainty like late changes in customer request [56].

4.1.9 Future outlook on production planning

When studying how the future of production planning could be like, there appear to be two major discussion areas: sustainability aspects and digitalisation.

In order to produce accurate and feasible plans it is important to have high quality input data to the ERP system [34]. A contribution towards this can be seen in the new IoT technology, as it can facilitate real time information sharing, supporting both vertical and horizontal integration [59]. From a planning perspective, increased digitalisation is thought to provide improved effectiveness and flexibility [59]. The biggest gain can be achieved when integrating data from several systems, such as data about maintenance, quality and scheduling [59].

There are however challenges with increased digitalisation, as it will require more decentralised systems to communicate and collaborate [60]. Some of the more practical challenges will be how to process diverse and large amount of data in real time [59].

The other identified focus area was sustainability. Many companies today have an outspoken plan to be more eco-efficient, but this is rarely considered when creating the production plans [61].

Even though sustainability is generally considered to include environment, economy and social aspects, mainly environmental ones are currently considered [62]. The reason behind this is thought to be that environmental aspects are easy to measure, e.g. CO_2 or waste water emissions [62]. For social aspects, metrics measuring the amount of sick leave could be used. Economic aspects can instead be represented by metrics measuring set-up times and productivity [62].

4.2 Survey

In this section, the findings from the survey will be presented in more detail.

4.2.1 General information about the survey

The digital survey was sent out to 49 members of staff working in production at the site in Gothenburg. The survey was available for one week, with a reminder being sent out after 3 days. In total, 11 persons replied to the survey, corresponding to a response rate of around 22%.

4.2.2 Currently available information on the boards

Table 4.1 presents the min, max, mean and median of the rated current availability of different types of information. As seen in the table, the availability of information varies heavily between the respondents, all varying between at least one and eight. Studying the median, the most common type of information currently available in the planning part of the board appears to be the operations included in each shop order, which operations to be done each week and the person assigned to an operation.

Table 4.1: Currently available information, sorted from left to right according to median

	Operations included in each shop order?	**Operations to be done each week?**	**The person assigned to an operation?**	**Estimated duration of operations?**	**Due dates for shop orders?**	**Status on today's work?**	**The need to re-plan operations?**	**Capacity?**	**How to prioritize orders?**	**Operations to be done each day?**	**Status on specific shop order?**	**Planned start date for operations?**
Median	7,5	5,5	5,0	4,5	3,5	3,0	2,5	2,0	1,5	1,5	1,5	1,5
Mean	6,1	5,4	5,0	5,1	4,0	4,4	4,1	4,1	3,5	3,1	3,0	2,6
Min	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Max	10,0	10,0	10,0	10,0	8,0	9,0	10,0	10,0	9,0	9,0	8,0	8,0

4.2.3 Required information

Table 4.2 illustrates the min, max, mean and median of the rated importance of different types of information. As the table is sorted from left to right according to the median, aspects to the left in the table was ranked as high importance, while aspects to the right ranked low. The columns grouped to the left scored a median of 5,5 or higher. As 5,5 is the theoretical center of the scale, a value larger than 5,5 indicates that the aspect is somewhat important.

Table 4.2: Importance of required information, sorted from left to right according to median

	Due dates for shop orders?	**How to prioritize orders?**	**Status on specific shop order?**	**The need to re-plan operations?**	**Operations to be done each week?**	**Capacity?**	**Planned start date for operations?**	**Operations included in each shop order?**	**Estimated duration of operations?**	**Status on today's work?**	**The person assigned to an operation?**	**Operations to be done each day?**
	Median ≥ 5,5							**Median < 5,5**				
Median	9,0	8,0	8,0	8,0	7,0	7,0	7,0	5,0	5,0	5,0	5,0	4,0
Mean	7,9	7,7	7,0	6,5	6,4	6,1	6,2	4,7	4,9	5,1	5,0	4,0
Min	2,0	4,0	2,0	3,0	2,0	1,0	2,0	2,0	1,0	1,0	2,0	1,0
Max	10,0	10,0	10,0	10,0	9,0	10,0	8,0	10,0	9,0	9,0	8,0	8,0

A further enhanced visualisation of the survey responses can be seen in Figure 4.1. The figure illustrates the distribution of the survey responses, colour coded according to the median value. The two most important ranked types of information, according to median, was how to prioritize shop orders and the due dates of the shop orders. Also the status of a specific shop order and the need to re-plan ranked high.

4.2.4 Comparison between current state and requirements

In order to easier identify potential gaps between the currently available information and the required one, the radar plot in Figure 4.2 was constructed. As can be seen in the figure, some of the largest gaps are related to information about dates, status and how to prioritize shop orders. Also information about the available capacity and need to re-plan seem to be missing in the current solution.

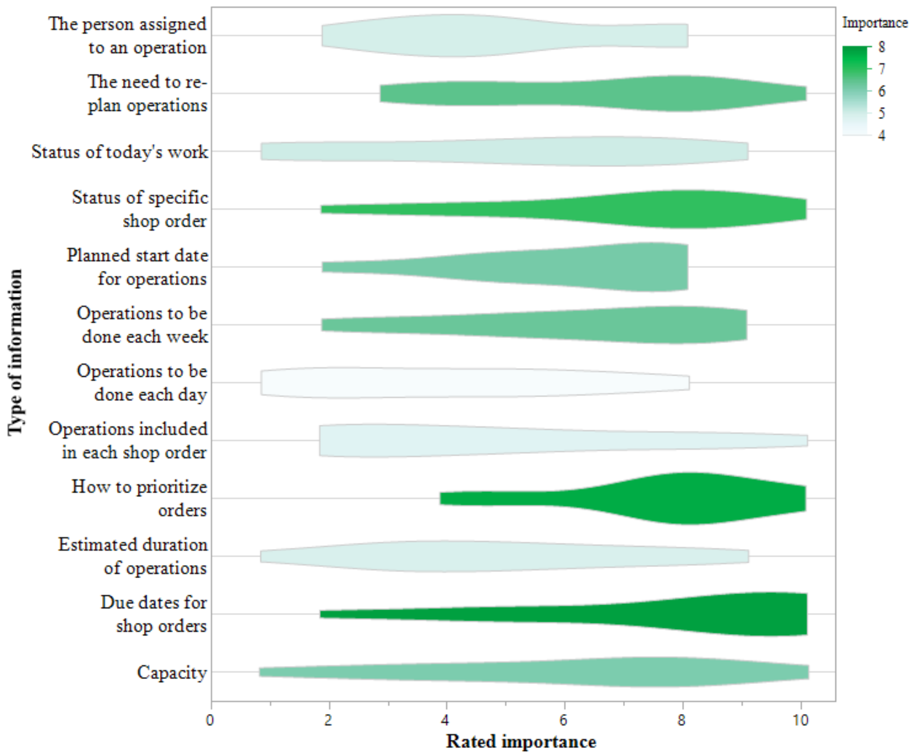

Figure 4.1: Violin plot illustrating the distribution of survey responses regarding requirements

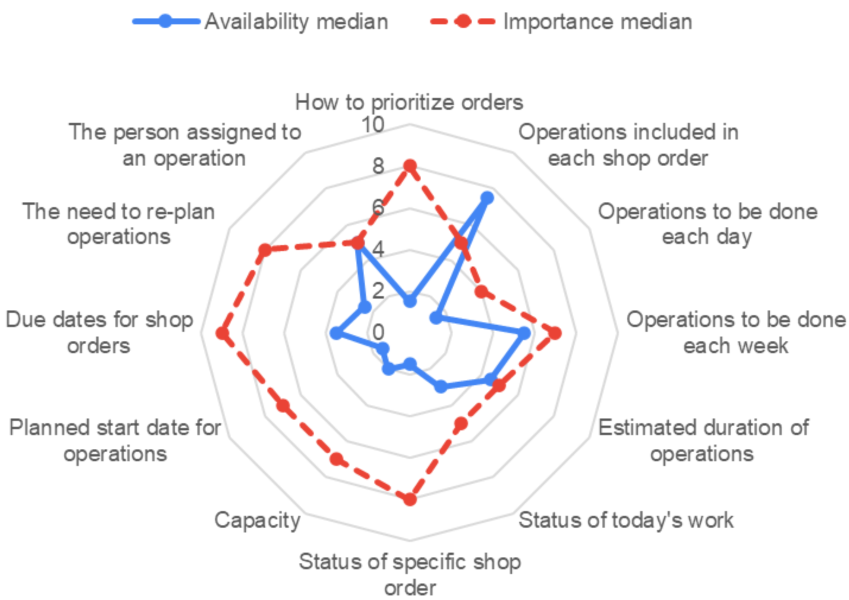

Figure 4.2: Radar plot illustrating the relationship between the median rated availability and importance

4.3 Interviews

Nine semi-structured interviews were conducted for the qualitative study, covering six different departments. The results are summarised in Appendix B and explained further in the following section. The main ideas of the interviews were to understand:

- The current use of MDI boards
- How different plans are made?
- What information is needed?
- What kind of challenges one might face when making the plans?
- What would be the requirements for the new solution?

Interviews were conducted with team leaders, production planners and production managers. For more information about the different roles, see section 3.3.

4.3.1 Current use of MDI boards

The implementation of MDI boards in the Gothenburg facility started around November 2019. Since then, each department has worked on a customised solution that would suit their needs and align with their operations. Currently, three departments out of six use MDI boards for displaying the weekly plan and two departments follow a global plan instead of planning on the MDI board. One department does not visualise all types of shop orders on the MDI board.

4.3.2 Additional flow boards

The internal flow boards are used to present the status of ongoing projects in four departments. The interviews made it clear that the internal flow boards can be seen as complementary to MDI boards. However, their importance is relatively high as it gives a bigger picture of the current WIP status.

Three different kinds of solutions could be encountered on the shop floor when using those additional boards. To start with, internal boards show typical operations that are needed to assemble a variety of products. Some departments use simple magnets that have project related details. In addition, particular colour magnets are used that represent the current state of the shop order. The status can vary from for example "operation started", "paused"/"on hold", "finished" etc. In one department, magnets called "smart tags" are used on internal flow boards that hold the same information as previously mentioned magnets, but additionally have information about the due date. A box in the upper corner shows how many days are left until, or already passed from the due date. As a disadvantage, internal flow boards are updated manually, and the information is presented only on the location of the boards. Two departments are not using additional flow boards.

4.3.3 How are the plans made?

From the interviews, it emerged that in some cases, production planners are responsible for making the weekly plans, and then the team leaders have the freedom to assign people daily. Estimated times for operations, together with planned capacity, are used for creating the weekly plans. In departments where a global plan is followed as a guideline, detailed weekly or daily plans are not used. Instead, the priority is set daily, considering the whole project context and due dates. A common aspect in all departments is that specific operations or projects are divided during the morning meetings based on the competencies and available time. A significant difference in one department is that operators are assigned to entire projects rather than dividing the operations individually. Delivery dates were mentioned as the most important information needed to make plans and set priority. Other aspects such as precise project requirements and estimated workload are valuable to team leaders for more accurate planning.

4.3.4 Required information

Essential information for creating the plans is gathered from several sources. In one department, the weekly plans combine orders from various flows. In this case, production planners from different departments have weekly meetings to set the priority between the orders. Thereafter, the incoming shop orders with delivery dates are forwarded to the team leader responsible for this department. After that, the team leader manually generates the visual plans presenting one and two-week perspective. A shorter period is more detailed, showing specific operations together with estimated times. At the same time, a two-week plan gives more of a general overview and an estimation of the resource usage in the following weeks. As mentioned previously, in some departments, a global plan determines the long term outlook for production planning, and then production planners and team leaders break it down into weekly and daily plans. Further, daily dialogues with project managers are used to discuss the project requirements and other specifics.

4.3.5 Information sharing

Morning meetings and escalation meetings play an important role in information sharing. Discussions on a department level are done during the morning meetings, where usually the team leader, together with operators, divide the operations or projects. In some departments, priority between different operations and projects could be set based on a global plan and revised daily. The global plan is updated every week. In other departments, production planners gather information about delivery dates and the latest updates from the project managers. Afterwards, this information is brought to the morning meetings and considered when making more detailed daily plans. It was mentioned in the interviews, however, that resource attainability and available competencies can interfere with executing the ideal plan. Any faced problems can be dealt with during those meetings, for example, by preparing an action note or raising the issue to a higher level. Managers encourage employees to solve the problems locally, if possible. For example, the idea behind the

"What hinders me to perform?" section on the MDI board is providing an overview of the most critical areas. Thereby the effort can be focused on tackling the issues that prevent employees from performing their best. Escalation meetings are planned to occur every day, half an hour after the morning meetings. These present a formal way for the departments to share information and find solutions for raised issues or occurred disturbances. Besides those formal meetings, additional informal communication is used to cope with deviations, e.g., rework or rescheduling decision during the day.

4.3.6 Challenges in production planning

ETO production environment is characterised as containing a lot of uncertainty. This has been mentioned as one of the main challenges by the interviewees. Accurate planning might be affected by, for example, inconsistency in work procedures caused either by not standardised operations or different experience levels of operators. Making plans was mentioned to be challenging also because of floating delivery dates and varying workload.

4.3.7 Estimated times and deviations

One aspect that came into sight was that estimated operation times are perceived as quite accurate in some departments. In contrast, in other departments, the difference between planned and actual times can be significant. In all departments, estimations are based on experience and previous projects. However, it was mentioned that departments performing better in this aspect might have more similarities between previously assembled projects. Therefore the value of historical data is higher.

4.3.8 Rescheduling and following actions

Related to the previously mentioned topic, a high tendency for frequent rescheduling can be found in departments where deviations in planned times occur often. However, there might be other reasons behind rescheduling, like a lack of materials, shortage in resources, rework or rush orders. Despite fluctuations in operation times or in-coming rush orders, the weekly plans are not updated to visualise the changes affecting the short-term period. Rescheduling is done daily through informal communication between concerned parties and seen more as a social practice. Otherwise, adjustments in plans are made simultaneously with weekly updates. One explanation behind this might be that the current system does not support convenient rescheduling or visualise accompanying conflicts when modifying the plans, as mentioned by one interviewee.

4.3.9 Capacity consideration

Another challenging topic raised by the interviewees is capacity consideration. In one department, some adjustments are made based on future workload expectations. Steps taken include, for example, hiring consultants to balance the planned workload with available capacity. However, the capacity in other departments is more or less fixed. In the event where required and available capacity differ, some balancing options are used. Those include, for example, working overtime, loaning personnel from other departments or levelling out the workload between weeks and months.

4.3.10 Status of work orders

All interviewees mentioned that once the operation is finished, the shop order status is also updated by closing the operation in IFS. A shortcoming with this system is related to long operations, spanning, e.g. several days, as updates can only be seen whenever the operation is completed. Therefore, information about the current status becomes obsolete after some time has passed, and an overview of progress is missing. For a new concept, the preferred update frequency varies from half an hour to daily updates. This mostly depends on how the information from the updates is to be used. Another determining factor is also the average length of operations. For instance, in departments where some collaboration is needed or several operators work on the same product, the current status could be updated every half an hour to an hour. From another perspective, if the operation times are long or the information is used to make corrections to plans during the morning meetings, daily updates would work sufficiently. The interviewees also mentioned that some kind of progress bar or count down functionality would be valuable to visualise the progress of long operations.

5 Concept development

This chapter gives an overview of steps taken in designing the visualisation concept and implementation in Qlik Sense. Selected requirements and features for the concept are further elaborated under the functions section. The outcome was the initial visual concept that was thereupon presented and discussed with the stakeholder to check if the interpretation of requirements was aligned with expectations.

5.1 Requirements list

Based on findings from the survey, interviews and literature review, the concept requirements presented in Table 5.1 could be identified. Table 5.1 is divided into three sections, where the first section displays the requirements from the survey, followed by the requirements from the interviews and the literature review.

Analysing the requirements from the survey results, it was decided that the requirements with a median of 5,5 or higher (see Table 4.2) are essential to have in the proposed concept. Thus seven requirements were selected from the survey to be followed in the development process.

The analysis of interviews provided a good overview of visualisation themes and challenges to focus on in the current state. In addition, several suggestions of “like to have” requirements were made during the interviews. Moreover, different solutions already being used on the shop floor were considered as inspiration. In total, based on the analysis, the authors identified 14 requirements that could be considered in the development process. Even though all recognised requirements are listed in Table 5.1, some of them were found to be more critical and mentioned several times during the interviews. For instance, almost all interviewees emphasised the importance of seeing ahead or behind status.

The conducted literature review presented some beneficial functionalities implemented in previously developed solutions and highlighted best practices to overcome common challenges that could be considered for the future concept.

Collecting the requirements from all methods and answering the questions for requirements analysis was a starting point for the visual concept.

Table 5.1: Combined requirements list

	Requirement
Survey	
Req S_1.	Information about due dates for shop orders
Req S_2.	Information about how to prioritise orders
Req S_3.	Status of shop orders (ahead or behind)
Req S_4.	Information about the need to replan orders
Req S_5.	Information about operations to be done each week
Req S_6.	Information about planned start date for operations
Req S_7.	Information about the available capacity
Interviews	
Req I_1.	Information about the due dates, to facilitate prioritisation
Req I_2.	A solution supporting easy rescheduling
Req I_3.	Visualise potential scheduling conflicts
Req I_4.	Visualisation of remaining manufacturing hours on specific shop order.
Req I_5.	Possibility to split long operation times.
Req I_6.	Visualise potential deviations, such as operations taking longer time than expected or a lack of material.
Req I_7.	A progress bar to visualise estimated progress on long operations.
Req I_8.	Visualise the difference between planned capacity and workload
Req I_9.	Visualise the booking of shared resources.
Req I_10.	Provide an easy and intuitive overview to support daily decision making.
Req I_11.	Support the teams in their daily planning and problem solving.
Req I_12.	The detailed planning should be done on shop floor level, as the operators have different skills and competencies.
Req I_13.	Update interval for the visualisation: - 0,5 - 1 hour for shop floor staff - Daily for production planners and managers
Req I_14.	A digital solution is prefered to: - Provide easy access to the information - Reduce the amount of manual labour involved in updating the boards - Make it easier to change the format of the visualisation
Literature review	
Req L_1.	Support shop floor autonmy to facilitate a high level of flexibility
Req L_2.	The visualisation should not include too much information as it risks overwhelming the user.
Req L_3.	A flexible and, to some degree, customisable visualisation
Req L_4.	Information about deviations from planned (estimated) operation times. Precondition for continuous improvements
Req L_5.	Plans should be updated according to well-defined rules.
Req L_6.	A digital solution - Facilitates both horizontal and vertical integration, leading to easier collaboration between departments. - Improved flexibility and effectiveness

5.2 Visual concept

As mentioned in the previous section, the identified requirements were implemented first in a visual concept, see Figure 5.1. This way of working could be compared with developing the first prototype, where most of the wanted features are represented in a simple format. An intuitive user interface was mentioned as one of the most critical aspects to consider for successful acceptance of the proposed solution. Therefore, the presented visual concept is used to receive feedback from the stakeholder before moving on to the next development phase as changes are easy to make.

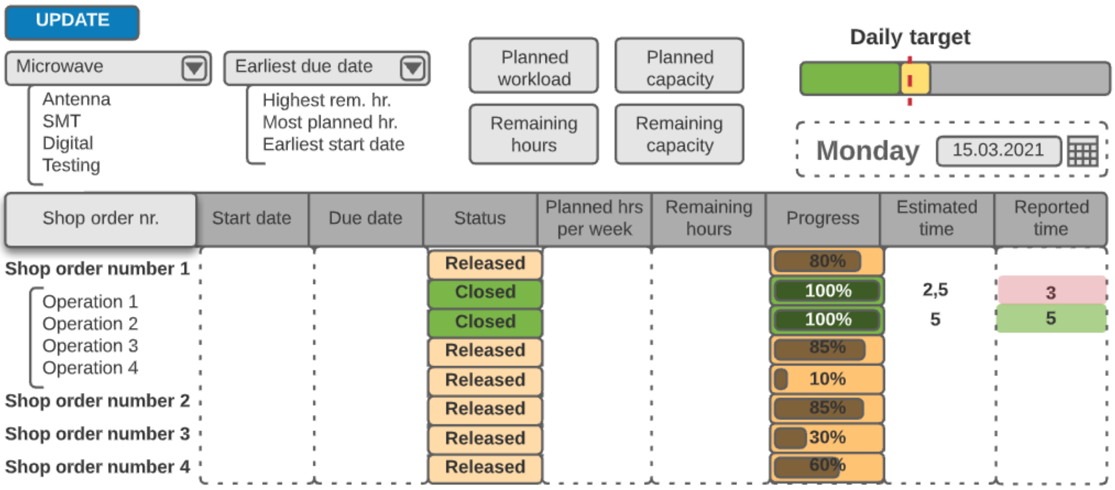

Figure 5.1: The developed visual concept

5.3 Functionalities

The implemented functionalities in the proposed solution are shortly described below.

- **Shop orders:** The findings from the survey and interviews indicated that end-users would have varying demands on the presented shop orders level of details. On one hand, some departments would like to see the operations included in each shop order, while for other departments, this information appears to be unnecessary. Therefore, to avoid overwhelming the user with the information and at the same time fulfil both expectations, the solution displays only shop orders in the default mode, but gives the user the possibility to expand the shop orders to display included operations. The intention of the concept is to display a weekly plan for production. Inclusion criteria for shop orders and operations in the proposed solution were defined as: the start date for the operation included in the shop order is in the current week or the previous week, but status is not closed. The user can see the planned start and due date for each operation. In addition, status is visualised using colour coding, which should simplify grasping the information and understanding of the current state with just a quick view. As it can be seen in Figure 5.1, if the operation status is closed, the status is coloured green. If all operations belonging to one shop order are closed, then the status of the shop order would be coloured green. Otherwise, a yellow colour indicates that at least one operation belonging to this shop order is not finished.

- **Planned hours per week** on a shop order level sums up planned hours for all operations scheduled for this week. In case of long operations extending over more than one week, the estimated operation time is divided by the number of workdays and then equally assigned for each day.

- **Remaining hours** shows the remaining time according to the calculation of estimated time minus reported time.

- **Progress bar:** Seeing the ahead or behind status was mentioned the most times during the interviews. The user has two options to see the current progress either on shop order level or weekly progress. On a shop order and operation level the progress is calculated based on the estimated operation time and remaining hours. Once the operation is finished, the corresponding progress bar is coloured green, otherwise the released operations are displayed with a yellow progress bar and percentage. Weekly target on the other hand is calculated summing up all planned hours for the week. In addition, the progress bar has a red line, which shows the daily target and is updated once per day. Operations planned for this week, but already finished add up to the green share of the bar. If the operation is released and the remaining hours are less than the total estimated time for this operation, the work task is handled as started and visualised by the yellow part of the progress bar (see Figure 5.1).

- **Prioritisation** was identified as an important requirement for the solution to provide decision support. Four options on how to sort the shop orders have been implemented in the proposed solution. The user can either choose the earliest start date for the operation, the earliest due date for the shop order, the most planned hours for this week or the highest remaining hours for the shop order.

- **Department selection** drop-down menu provides the user with intuitive functionality to limit the displayed shop orders according to the specified department. All work centres are grouped together under five categories, corresponding to the main production units (see Figure 5.1).

- **Planned workload and capacity** indicates if the planned workload is higher or lower than the available capacity. Hence, for example, if the planned workload is higher than the available capacity, either the planned workload should be reduced, levelled out, or the available capacity needs to be increased. The mismatch will be shown with contrasting colours. The goal is to indicate the need for re-planning and could be seen as the trigger.

- **Deviations from estimated times** highlight operations where a difference between the estimated and actual time could be noticed. Once an operation is reported as finished, the digits are coloured red if the time exceeds 20% of the expected time. If the deviation is below 20%, the digits are instead coloured green. Continuously monitoring actual operation times and adjusting estimated times could, in the long term, improve the planning accuracy, as the findings from the literature review demonstrate.

- **Today's date** displays the selected date. Moreover, the user has the freedom to choose the date acting as a variable that determines which week's plan is visualised.
- **Update frequency:** In the developed solution, the information could be updated by clicking the "Update" button, which triggers the loading of the data from IFS. Additionally, if needed, automatic cycles could be defined in the script that updates information after a specified time.

5.4 Implementation in Qlik Sense

During the initial company observations, it was found that RUAG Space had recently started using the data analytics platform called Qlik Sense. The concept implementation phase of this thesis project was therefore seen as a good opportunity to explore and evaluate the applicability of the Qlik Sense platform in RUAG Space's production environment. The concept implementation was therefore conducted using Qlik Sense.

In this section, the actual implementation using the Qlik Sense platform will be described in more detail.

5.4.1 Transferring data from IFS to Qlik Sense

There are two ways of loading data to the Qlik Sense application. The first option is to upload a file, for example a Microsoft Excel spreadsheet or a Comma-Separated Values file. The other alternative is to connect directly to a database, for example the database used by IFS. It was decided to use the later alternative to facilitate easy transfer of data, minimising the need of manual labor.

Studying the available data in IFS, and considering the proposed functionalities described in Chapter 5.3, it was found that data from five different tables were needed. The first table contains data about the shop orders, including for example the name of the project and when the order is planned to start and finish. The second table incorporates data about each specific operation, such as the estimated time, the type of labor needed and whether the operation is finished or not. The third table includes historical data about each operation, for example the actual time it took to finish the operation. The forth table only includes the number and name of each department. Finally, the fifth table includes information about the available capacity for a certain type of labor and date.

A more detailed description of each table and the extracted content can be seen in Appendix C. The names of the tables and variables have been changed for the purpose of this report.

To load the data from the five tables into Qlik Sense, a data load script was written. The script was written using a combination of Structured Query Language and Qlik Sense specific syntax. The script also included functions to format the data, for example by converting the dates to a common format and applying the same naming convention for the variables.

To reduce the amount of data being loaded into the platform, only operations with a planned start date in the past two weeks or the coming week are loaded.

5.4.2 Visualisation in Qlik Sense

Once the data had been loaded to the platform, the next step was to work with the visualisation, realising the previously developed visual concept illustrated in Figure 5.1.

The implemented concept is built up using standard visualisation elements found in Qlik Sense. The main table containing the shop order and operations information is for example created with a pivot table element, while the progress bar is a bar graph type element. The proposed concept, implemented in Qlik Sense, can be seen in Figure 5.2.

There is a possibility to create custom visualisation elements, using JavaScript, but this was considered to be outside of the scope of this thesis project.

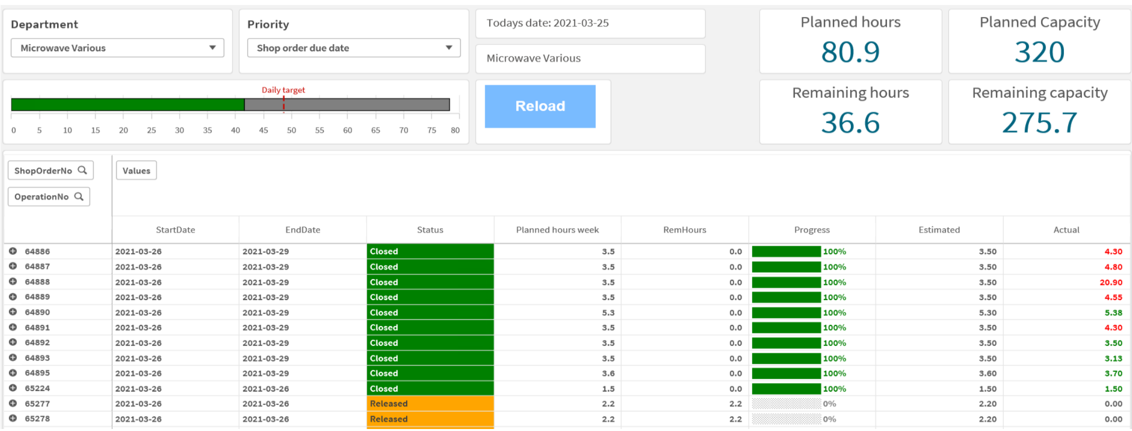

Figure 5.2: Illustration of the concept implemented in Qlik Sense

5.5 Evaluation

Concept evaluation started with checklist verification. In the Table 5.2, each identified requirement from the survey, interviews and literature review (see Table 5.1) is matched with described functionality.

Table 5.2: Identified requirements matched with implemented functionalities

Functionality	Matched requirement
Shop orders	S_1, S_5, S_6, I_1, I_12, L_1, L_2
Planned hours per week	I_5
Remaining hours	I_4
Progress bar	S_3, I_7
Prioritisation	S_2, I_1, I_10, I_11
Department selection	L_2, L_3
Planned workload and capacity	S_4, S_7, I_2, I_3, I_8, I_10
Deviation from estimated times	I_6, L_4
Today's date	L_2, L_3
Update frequency	I_13, L_5

The proposed solution fulfils all requirements found important from the survey. Identified requirements I_14 and L_6 about digital solution could be classified as general specification for the type of solution. Using Qlik Sense software to visualise production plans accomplishes that as information could be accessible to all roles regardless of the department.

On the other hand, the recognised issue with resource booking (see Requirement I_9 in Table 5.1) could not be solved with the proposed solution. As one of the possible options, the authors would recommend adding this option to IFS by setting a capacity limit for each shared resource.

Other requirements not specifically connected to any functionality are I_12 and L_1 (see Table 5.1), which state that detailed planning should be done on the shop floor to facilitate high level of flexibility. This has been considered when establishing the level of detail for the plans. Shop orders displayed in the solution show recommended start date for the operations, however, the autonomy to divide operations between employees and freedom to decide the exact sequence remains on the shop floor. In other words, operators are not assigned to the work tasks.

Overall, all requirements found from the studies completed in this research project, have been considered when developing the concept. Nevertheless, collaboration with the stakeholders during the prototype evaluation stage has proven to be crucial to confirm the correct interpretation of each requirement.

6
Discussion

In this chapter, the answers to the research questions, the developed concept, the used methods and sustainability aspects are discussed.

6.1 Research question 1

RQ1 - How can the transfer of data between the ERP system and the MDI boards be facilitated?

Both the interviews and observations showed that there is currently a mismatch between the actual production environment and the information contained in the ERP system at RUAG Space. Some information in the ERP system is not kept up to date, but are instead included in external spreadsheets. As found during the literature review, a potential reason behind this could be the high level of uncertainty involved in typical ETO environments. Another reason might be that IFS is not presenting relevant information in a desired format.

To better connect the ERP system with the information presented on the shop floor, an easy way of transferring information is required. Findings from both the literature review and interviews highlighted that a digital solution is preferred. A digital solution also aligns with the identified requirement on how often the information on the board should be updated. To manually update the information on the board that often, for example, by printing reports, would be labour-intensive and time-consuming.

The literature review did, however, also show that a digital solution requires up to date data of high quality. To support this, RUAG Space could consider implementing formal trigger points for rescheduling, and thus assuring that the information is up to date. The high level of shop floor autonomy at RUAG Space could also be seen as advantageous, reducing the need for highly detailed data.

However, looking more into the future, it might not be enough to only visualise data from the ERP system. As findings from the literature review showed, solutions are being developed that will allow the user to, for example, manipulate the production plan by drag and drop functionality. However, this would require two-way communication between the ERP system and the visualisation, compared to the one-way communication used today.

6.2 Research question 2

RQ2 - Is it suitable to use a standardised format for the MDI boards?

The observations, survey and interviews all showed that the current production planning part of the MDI boards differ a lot between the departments. This includes both how the boards are used and the type of information presented on them. The reason behind this appears to be that the departments have different needs, even though some requirements seemed more common. In general, information supporting shop floor autonomy and local decision making were highlighted as important in both the survey and the interviews. The idea of having a high shop floor autonomy was also supported by the literature review, where it was shown to be important in production environments with a high degree of uncertainty.

It is challenging to create a standardised solution when there are diverse requirements. As pointed out in the literature review, too much available information risks overwhelming the user. To balance the two aspects, the visualisation can be made flexible, for example, by providing the option to show only specific features found relevant. With this in mind, one of the main challenges of the concept development has been to create a standardised but yet flexible solution.

Whether it is suitable or not to use a standardised format depends largely on how much the requirements differ between the departments. Also, the total amount of specific requirements is a limiting factor, as a standardised solution can only be made flexible to a certain degree.

For the case company, the departments can still be regarded as relatively similar, even though the requirements differ. All the departments, for example, act in an uncertain ETO environment, produce electronics and use the same ERP system and IT infrastructure. With this in mind, a standardised but, to some degree, flexible solution can be seen as the preferred one for the case company. To gain acceptance for the standardised solution, it is also recommended to include the shop floor staff in the future development and implementation of the concept.

6.3 Research question 3

RQ3 - How can the production planning be visualised to provide information about manufacturing orders' status and deviations?

The maturity level of using the MDI board and visualising production plans at the company today differs between the departments. From the interviews and survey, it became clear that one reason behind this is varying information needs and the historical way of working. Some departments use weekly plans to schedule operations each day, while others follow a global plan that indicates which shop orders to prioritise daily.

The main recognised drawback in the current production planning environment is that status updates on the boards are not digitally shared, and a standardised solution is missing. In other words, although IFS is used to report operation times, it is not directly connected to the displayed visualisations of the production plans. In all cases, information is transferred from IFS to different external tools, such as Microsoft Excel, to create the visualisations. Therefore, the information on the displayed plans is updated whenever the new spreadsheet is printed. In some cases, colour-coding by hand is used on the shop floor to highlight that an operation is finished. However, the regular activity of keeping the plans updated can be seen as non-value adding, labour-intensive and with limited options for replanning. Hence, plans are not renewed for daily re-planning or rush orders. Another observed disadvantage is that deviations from the ideal plans could easily make the presented information and plans obsolete.

The main focus for this thesis project has been the identification of requirements of a standardised production planning visualisation concept. As mentioned before, the requirements vary a lot, supported by the findings from the survey and interviews. It can depend on, for instance, the length of the operations or if the operator is responsible for a single operation or the whole project. Hence, some departments would like to receive updates about the status of each operation every half an hour, while other departments find this type of information redundant and would rather like to see only shop orders with a daily update frequency. In addition, the conducted survey revealed that there is a gap between some of the currently available information and the required one. On the other hand, the proposed concept should not display too much information since it can overwhelm the user, as found from the literature review.

Therefore, prioritisation was used to distinguish between significant requirements and "like to have" functionalities. To cover all the important requirements, but still provide a standardised solution, the proposed concept has functionalities like sort, prioritise, limit and expand. The user has the possibility to use a drop-down menu to choose a specific department. Furthermore, in the default mode, the plans display only shop orders, while those could be expanded if needed to see the underlying operations. Decision making is supported with the priority drop-down menu, where the user can choose in which sequence the shop orders should be presented. For instance, the shop orders with the earliest due date could be shown on the top. The limit functionality determines the shop orders belonging to the exact week. The proposed solution includes operations with a start date in the selected week or the week before, but with the status "not closed".

The literature review highlighted the importance of visualising deviations since it is a precondition for continuous improvements. This was mentioned as essential information also from the interviews because it could improve the estimations for operation times and therefore facilitate more accurate planning.

As mentioned by the end-users, seeing the "ahead" or "behind" status appeared to be the most important type of information that is currently missing. Progress bar functionality has been implemented in the proposed concept to fulfil this requirement. The user can either see the weekly progress based on the estimated workload and the reported time or progress on shop order-level according to the planned workload for the selected week. The status of operations is visualised with colour-coding. Additionally, the progress in percentage is displayed on operation level and shop order level. However, one aspect to consider is that for long operations, the continuous estimated progress can only be seen if the count down option in IFS is enabled or time is reported during the ongoing progress.

Another aspect to consider is that the estimated times are often based on experience and could vary a lot, as mentioned in the interviews. The weekly progress and progress on the operation level is based on the estimated times. Therefore, one might not be able to make accurate progress estimations using the available data. If the actual time differs a lot, the progress bars displayed in the concept could be misleading. For example, with an estimated operation time of 10 hours and 9 reported hours, one would expect the remaining time to be one hour, but in reality, this could differ because of uncertainties. To cope with this drawback, the estimated times could be adjusted if deviations occur or are to be expected. This would then trigger the change in planned workload and available capacity. The mismatch would then be highlighted with colours in the proposed concept, showing either the need to adjust the capacity or the possibility to plan more operations for this week.

6.4 Research question 4

RQ4 - How can information about short term planning and prioritising be digitally shared with other teams?

Customised production planning solutions are used on the shop floor for short term planning. The main formal routines for information sharing applied in the company are morning meetings and escalation meetings. In the first one, the teams, together with team leaders, divide the operations, discuss occurred issues and make the daily plan. Additionally, production planners can provide insights about which orders to prioritise. After that, team leaders bring the most critical information to the escalation meeting to discuss together with production managers.

One department uses weekly plans, where single operations and the workload is divided into specific days. This way of visualising provides a detailed overview of short term planning and prioritisation. However, in case of disturbances and deviations, the plan becomes obsolete and updating the visualisations on the board is time-consuming and difficult. Another downside of the customised solutions currently in use is that information is not shared digitally and can only be accessed on the shop floor in the location of the board. Currently, a high tendency for informal information sharing could be observed. Especially decisions about rush orders and daily re-planning are mainly shared verbally and not visualised on the production planning part of the board.

The findings from the literature review point out that this kind of information sharing supports autonomy and provides flexibility. On the other hand, it can also hinder information sharing as information held by different persons might be difficult to access. Furthermore, humans' cognitive ability sets a specific limit to the amount of information to be handled. In addition, it was mentioned in the literature review that receiving too much or irrelevant information might hamper focusing on problematic areas. Therefore, complementary decision support could be received from visualising essential information and sharing it digitally with all involved stakeholders.

The developed digital concept has the option to navigate between different departments and look at their short term plans. Thus information about short term planning could be easily shared within the company. Additionally, the intention of a standardised format is that the presented information and status should be effortlessly observable. In other words, the user does not need to spend time to understand how the information is presented while switching between departments.

A possible downside with the proposed solution is that even though the prioritisation functionality can support the decision-making process, the solution does not provide information about which orders are prioritised. In addition, the production planner's possibility to prioritise orders is limited. This might affect the production planners to make their own prioritisation in the proposed solution. For example, if the priority needs to be changed based on the latest knowledge from the communication with the customer or considering the critical booking of resources.

Therefore, as a recommendation for future improvement, production planners could have the flexible option to specify which orders need to be prioritised, and this information could then be presented in the digital solution.

6.5 Research question 5

RQ5 - What benefits could be achieved by digitalising the production planning part of the MDI boards?

As previously mentioned, both the interviews and the literature review highlighted that a digital solution is preferred. The main reason, based on the interviews, is that it could reduce the amount of manual work spent on updating the boards. This is especially true for the type of data that is currently read from the ERP system by an operator and then written by hand on the board. This type of data is hence readily available and easy to include in a digital solution.

The literature review revealed other aspects of a digitalised solution. One of the main benefits being that it facilitates easier sharing of information, creating a more informed company. For RUAG Space, this, for example, means that production planners, production managers and project managers can easily access the same information as the shop floor staff.

The interviewees also pointed out that it might be easier to make changes to a digital visualisation compared to a manual solution. An underlying reason for this could be that the digital solution would fetch data directly from the ERP system, so a change in the ERP system would be directly reflected in the visualisation. There is hence also a benefit in fetching data from one common source, the ERP system, rather than storing information locally in, e.g. spreadsheets.

A digital solution can also be seen as an introduction to more advanced solutions. As pointed out in the literature review, there are visualisation solutions available that support re-planning by drag and drop, available directly on the shop floor. The introduction of different IoT solutions is also likely to contribute to a more informed system that can provide even better decision support to staff.

Looking more at the potential challenges of a digital solution, the literature review pointed out the need for high-quality data. To achieve this, it is recommended to adopt a structured way of reporting and updating data in the ERP system. This includes formal trigger points for rescheduling and agreed on work methods for reporting status updates.

6.6 The developed concept

From the checklist evaluation, one can see that the developed conceptual solution does fulfil all the specified requirements. However, not all of the conceptual functionalities have been implemented in Qlik Sense. The main reason for this is the rather steep learning curve for Qlik Sense, as it takes time to build up the skill set needed to implement all features. It is then again important to remember that the goal of this project was not to implement a solution, but to develop it.

The Qlik Sense implementation uses mainly standard visualisation elements built into the software. Even though these basic elements are generally easy to use, they are not easily adapted to specific needs. The white space seen above the pivot table in Figure 5.2, can, e.g. not be removed or reduced in size, as it is part of a standard element. To implement a more customised visualisation, there is a need to write the code in JavaScript.

A potential drawback of the conceptual solution is that the progress bar is based on both actual and estimated times. The only way of knowing if an operation is actually finished is to monitor when the status of the operation changes to "Closed". When an operation is started but not reported finished, estimated times are instead used. This means that for a started operation, estimated to take two hours, the estimated progress will be 50% after one hour. If not understood correctly, this can be somewhat misleading, as the actual progress might be more or less than stated in the visualisation. To improve this, more frequent status updates would be needed, for example, by splitting long operations into smaller ones. Overall, the data quality could be improved by introducing a more standardised way of updating and reporting operations to the ERP system.

Another limitation might be found in the fact that the thesis project only proposes one conceptual solution instead of several. There are, of course, more than one way to visualise the information. With this in mind, there is always a risk of both the solution and the evaluation of it being biased by the author's opinions and experiences. It might therefore be beneficial to implement the final solution in different stages. As a first stage, the solution could be tried out in one department, with feedback loops to further evaluate and improve the solution.

As the solution is developed at a case company, parts of the solution might be case-specific. For example, the specific solution needs to support continuous improvements by illustrating deviations between estimated and actual operation times. But for a company using the visualisation mainly as a planning tool rather than a lean tool, this might be redundant information. However, the exact information included in each pivot table column can easily be customised to fit company-specific needs. Other parts of the solution, such as the progress bar, the prioritisation functionality and capacity illustrations, can be seen as more generally applicable features.

6.7 Methods

Based on the author's previous experience, triangulation was decided to be used in this research project, where knowledge from literature review, interviews and survey was combined to define the requirements for the visualisation concept. The literature review used a structured approach to map previously developed solutions in the area of focus. It was done by defining a specific search string and reducing the number of articles in described screening stages. However, in hindsight, the used inclusion and exclusion criteria might have been broad, which reduces the reproducibility. Another thing to consider is that the literature search focused more on actual visualisation concepts rather than general theory. Therefore, some relevant articles might have been left out of the scope.

The intention with semi-structured interviews was to achieve a broad perspective on how production planning is done today. Another purpose was to have a deeper discussion of the requirements and why some requirements might be more important than others. Using semi-structured questions fulfilled those objectives and enabled the creation of a comparison of needs summarised in a table format. This step was crucial for considering standardising the concept for all departments. Nevertheless, more interviews could have been conducted to cover more opinions, which could have been spread over time. This could contribute to a higher acceptance rate for the solution. On the other hand, the chosen method of analysing interviews is time-consuming. Therefore, there would have been a risk of not finishing the project on time, considering the appointed time for this thesis work.

The main recognised drawback with interviews was the language selection, which was necessary so that both authors would be included in the discussion. However, some valuable insights might not have been captured because of the communication barrier.

Regarding the survey, one potential risk can be seen in the fact that respondents might interpret the scales differently. The data from the scales do, however, indicate the general trend. Another risk can be seen in the relatively low response rate to the survey. Only around 22% answered the survey. It is also difficult to know if all departments were represented in the responses as this type of information was not collected to keep the survey respondents anonymous. Combined, this means that it is difficult to draw specific conclusions based on the data. An aspect scoring higher than another does not necessarily mean that it is more important than the other. Because of this, the features were not ranked among themselves but instead grouped into two groups; more important and less important.

Specifications for the visualisation concept were based on the conducted studies. One might, however, question the selection of requirements as those can be biased. This was taken into account and tried to avoid by applying several methods to gather information.

The concept evaluation was carried out in several iterations. The first primary method used was checklist verification, where identified requirements were matched with implemented functionalities. If several concepts were rated, one could add weights to each requirement to differentiate between more and less critical requirements. In other words, an evaluation matrix could have been used. However, as an outcome for this project, one concept is proposed instead of several solutions that could be evaluated. The correct interpretation of each requirement and alignment with expectations was checked in multiple sessions with the project leader. The following recommended evaluation step would be using a focus group to assess the concept in a broader context.

6.8 Sustainability

Even though sustainability aspects in production planning have not been the focus of this thesis project, the literature review highlighted it as an essential and growing area of research.

The ambition of the developed visualisation concept is to contribute to improved productivity and resource utilisation. Both of these aspects can improve environmental and economic sustainability. Any potential impact on social sustainability is more difficult to foresee. However, more intuitive visualisations providing decision support could reduce the staff's cognitive workload. The available cognitive capacity could then instead be directed towards continuous improvement activities. To study how sustainability metrics can be incorporated into the visualisation concept to evaluate production plans can be seen as a future thesis topic.

6.9 Ethical considerations

Throughout the thesis project, different ethical aspects have been discussed and considered. The main considerations have been regarding the selection of research methods.

For the interviews, the chosen interviewees were asked for permission to record the conversations, which were thereafter transcribed. This step was found vital as it helped to include all ideas and opinions. Otherwise, takeaways from the interviews could have been biased as authors could have anchored on the information they found more relevant. The chosen method also gave the possibility to go back to transcribed texts to check facts. However, stored data security needs to be considered. To comply with this, the transcribed texts were stored only on the authors' password-protected computers and will be deleted after the completion of this project.

The interviews were also summarized in a table, where the identity of the interviewed staff is not disclosed in detail.

When designing the survey, the primary ethical consideration was instead regarding the anonymity of the respondents. Even though gathering information about the respondents' role and department could have provided valuable information, it could not be motivated from an ethical perspective. The main reason was to avoid that information and opinions could be traced back to a specific employee.

7

Conclusion

The thesis project resulted in a conceptual solution for visualising short-term production planning data on a shop floor level. The case company's production environment is characterised by a high level of uncertainty combined with varying needs between departments. High shop floor autonomy and flexibility were found to be key to cope with an uncertain environment. A digital solution was also preferred to reduce the need for manual work and facilitate information sharing within the company. The main challenge of the project has been to develop a standardised and flexible solution, as these can be seen as opposing terms.

The literature review revealed that customised visualisation solutions are commonly used in ETO production environments to display relevant information from the ERP system in a desired format. Highlighting deviations from the production plans was found necessary to facilitate continuous improvements as the solution is to be part of the case company's MDI boards. Even though the developed visual concept is specific for the case company, it is believed that the proposed functionalities can still be valuable for other companies acting in a similar production environment.

As a continuation of the implementation phase, it is recommended first to introduce the visualisation in one department, followed by a focus group evaluation. Drag-and-drop functionality requiring two-way communication could be further investigated to provide direct interaction with the production plans. A production environment with a high level of autonomy was found to be a prerequisite for less detailed plans. However, as the developed solution is digital, successful implementation depends on the case company's ability to adopt a more standardised work method for keeping the data up to date.

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A

Survey questions

MDI-board survey

Thank you for taking the time to answer this survey. The survey is part of our thesis project aimed at improving and standardizing the production planning part of the MDI-boards. Your answers will provide us with quantifiable data that will be used both when developing and evaluating new concepts. Your responses to this survey will be kept confidential and anonymous. You can write answers in either English or Swedish.

*Required

1. At your department, do you currently use the MDI-board for production planning? *

Mark only one oval.

- ◯ Yes *Skip to question 3*
- ◯ No *Skip to question 17*

2. At your department, do you currently have any separate solution (apart from the MDI-board) to visualize the production process and planning? This could e.g. be boards illustrating the internal production flow.

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Other: ______________________

Current state

This section includes questions to get an overview of the current usage and available information on the MDI-boards.

3. About how long is the production planning horizon on your board? (E.g. how many days/weeks/months into the future can you see planned work?)

____

4. How often is the production plan on the MDI-board updated?

Mark only one oval.

- Daily
- Weekly
- Monthly
- Other: ______________________

Ranking of currently available information

Please rank how well the following information is currently presented on the production planning part of the MDI-board?

When answering the following questions, 10 indicates information that is readily available, while 1 indicates a total lack of information.
Note: Only include information found on the MDI-board, not any separate boards that you might have.

5. How to prioritize orders?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Not at all											Very well

6. Operations included in each shop order?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10

7. Operations to be done each day?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10

8. Operations to be done each week?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

9. Estimated duration of operations?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

10. Status (ahead or behind) on today's work?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

11. Status (ahead or behind) on specific shop order?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

12. Capacity (e.g. number of staff and machines that are available)

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

13. Planned start date for operations?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

14. Due dates for shop orders

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

15. The need to re-plan operations? (e.g. missing material, lack of capacity, quality issues, etc.)

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

16. The person assigned to an operation?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

Skip to question 17

Requirements

This section includes questions to provide us with information about how important different types of information is for you in your daily work.

17. How long planning horizon would you prefer to see on the MDI-board? (day/weeks/months?)

Requirements

What type of production planning information would you need to support your daily work?
Rank the importance from 1-10, where 1 indicates low importance and 10 indicates information of very high importance.

18. How to prioritize orders?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Low importance	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	High importance

19. Operations included in each shop order?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

20. Operations to be done each day?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

21. Operations to be done each week?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

22. Estimated duration of operations?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

23. Status (ahead or behind) on today's work?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

24. Status (ahead or behind) on specific shop order?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

25. Capacity? (e.g. number of staff and machines that are available)

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

26. Planned start date for operations?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭

27. Due dates for shop orders?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

28. The need to re-plan operations? (e.g. missing material, lack of capacity, quality issues, etc.)

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

29. The person assigned to an operation?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

30. Are there any other information that could help you in your daily work?

Additional information

31. Here you can write if you have any additional information that you believe could be of value for us.

B

Interview summary

Table B.1: Summary of interviews

	Department A	**Department B**
MDI boards usage	MDI board is used for displaying weekly plan	Global plan is followed instead of planning on the MDI board
Additional flow boards	Internal flow boards for WIP	None
Making production plans	Weekly plans are made by production planner and those are followed for daily planning	Global plan is used as a guideline for weekly planning. Good mix of large and small projects.
Important information	Ahead or behind, if behind, then what is the reason?	Delivery dates for projects from the global plan
Challenges	Due to uncertainties, planning is not so accurate and that is one of the main challenges. Capacity calculation is another. Delivery dates are floating, which makes planning difficult, shop order status is changed only when reported as finished.	Varying workload, while capacity remains constant
Status of work orders	Once the operation is closed, it becomes visible in the IFS.	Operations are reported in IFS, however, seeing the status of each operation on MDI board would be unnecessary
Operation times estimation	Based on previous projects and experience	Historic data from previous projects together with experience provide a good estimation

	Department A	**Department B**
Shop orders prioritization	Priority is set by the combination of delivery dates and available resources, but difficult to set	Based on the global plan, priority is set on weekly or daily basis
Capacity consideration	Upcoming week's capacity is estimated on Friday and workload is assigned accordingly, additional capacity can be added using over hours or loaning personnel from other departments	Fixed capacity, levelling out is used to cope with varying workload
Sharing information	Information is shared during the morning meetings and escalation meetings. Informal communication with production planners, project managers and production managers, but also with other departments	Informal communication with project managers and other involved parts, additional documents are used
Work division	Team leaders are responsible for daily planning. Specific operations are divided during the morning meetings depending on the competencies/skill-sets and available time	Projects are divided together in the morning meetings
Rescheduling	Rescheduling is common, mainly because deviations in delivery dates or estimated times (hard to estimate times due to uncertainty, but also differences between the way how operators work). Rework or quality problems.	Not so common currently, but reasons behind rescheduling might include lack of outside resources
Actions following rescheduling	Plans are updated on a weekly basis, besides that there is informal communication. Rush orders are not added to the plan.	In case of rescheduling, plans are updated on weekly basis
Update frequency	Daily to react on the raised issues	Daily updates would be good, because adjustments could be made in the morning meetings

	Department C	Department D
MDI boards usage	MDI boards are used to visualize the weekly plan. In addition, a two week perspective is presented.	Global plan is followed instead of planning on the MDI board
Additional flow boards	None	Internal flow boards for WIP
Making production plans	Visual plans are made manually based on information received from several sources	Global plan is used as a guideline for daily planning
Important information	Longer timeline perspective to plan resources and machine setups; accurate date for material delivery and estimation of operation times	Delivery dates for projects from global plan
Challenges	Deviations from estimated operation times; material shortages	Limited skillsets for some operations and shortage of operators
Status of work orders	Shop order status is updated in IFS after closing the operation, informing production planner via email	Shop order status is updated in IFS after closing the operation. Internal flow board gives a bigger picture of current WIP status
Operation times estimation	Estimated times are not correct, a template is used by production planner to come up with a estimation.	Estimations are mostly accurate, small deviations might occur due to inter-operator variablity
Shop orders prioritization	Priority for different orders is decided between production planners	Based on delivery date displayed on the global plan that is used to set daily priority
Capacity consideration	Capacity is considered according to the number of employees and their working hours	Capacity is considered in 3-4 month perspective and number of employees is adjusted accordingly
Sharing information	Escalation meetings are used to share information with other departments	Informal communication between project managers, production manager, production planner and team leader plays an important role in every day planning

	Department C	**Department D**
Work division	Operations are divided together in the morning meetings	Operations are divided in the morning meetings based on competencies and priority
Rescheduling	Rescheduling is common, mostly because deviations in estimated times, but can also be because of missing material or machine park service	Not common, long-term plans are used as guidelines for daily planning
Actions following rescheduling	Rescheduling is done through informal communication, changes are not visible in weekly plans as those are not updated	Rescheduling is more of an informal communication
Update frequency	Updates should be in every half an hour. For long operations, progress bar showing current status would be valueable.	Updates could be in every half an hour/hour or daily, depending who is going to use the information

	Department E	**Department F**
MDI boards usage	MDI board is not used	MDI board is used for displaying weekly plan
Additional flow boards	Yes, internal flow board to present current status	Yes, internal flow board to present current status
Making production plans	Weekly plans are made by production planner and those are followed for daily planning	Weekly plans are made by production planner and those are followed for daily planning
Important information	Project requirements are discussed with project managers	Delivery dates and estimated workload for a week
Challenges	Resource usage is not well considered in upcoming weeks/-months perspective; ahead or behind status is visible	Long operation times and overview is missing either they are behind or ahead; inconsistency in work procedures
Status of work orders	Current status is presented on internal flow board, once the operation is closed the status is also reported in IFS	Current status is presented on internal flow board, once the operation is closed the status is also reported in IFS
Operation times estimation	Operation times are estimated by experience and quite accurate	Operation times are estimated by experience and quite accurate
Shop orders prioritization	Project managers can help with setting the priority	Priority is set by the production planner
Capacity consideration	Not good system for capacity consideration, capacity is fixed	Capacity is fixed, but additional capacity options include overtime and planning operations in advance
Sharing information	Internal flow board, status updates in IFS and informal communication with project leaders and production planners	Escalation meetings, daily informal communication between team leader, production planner and project managers
Work division	Based on the competencies	Based on competencies, assigned by the team leader in the morning meetings
Rescheduling	Plans are updated on a daily basis, rescheduling is done if rework is needed or deviations occur	Rescheduling is done often, mostly if something happens with a unit, but also if there are not enough resources

	Department E	**Department F**
Actions following rescheduling	No action, informal communication	Information sharing with project manager and production planner
Update frequency	Not more often than once in half a day	Once a day would be enough

C

Overview of used data tables

- Shop order data
  - Shop order number
  - Shop order earliest start date
  - Shop order due date
  - Quantity to produce
  - Project name
- Operations data
  - Shop order number
  - Operation number
  - Operation name
  - Estimated labor time per product
  - Reported labor time
  - Planned start date and time
  - Planned finish date and time
  - Status of the operation
  - Department number
- Operation statistics data
  - Shop order number
  - Operation number
  - Estimated time to perform operation
  - Actual time taken to perform operation

  - Planned start date and time for operation
  - Actual start date and time for operation
  - Planned finish date and time for operation
  - Actual finish date and time for operation
- Department data
  - Department number
  - Department name
- Capacity data
  - Type of labor
  - Date
  - Planned available capacity for given date

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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