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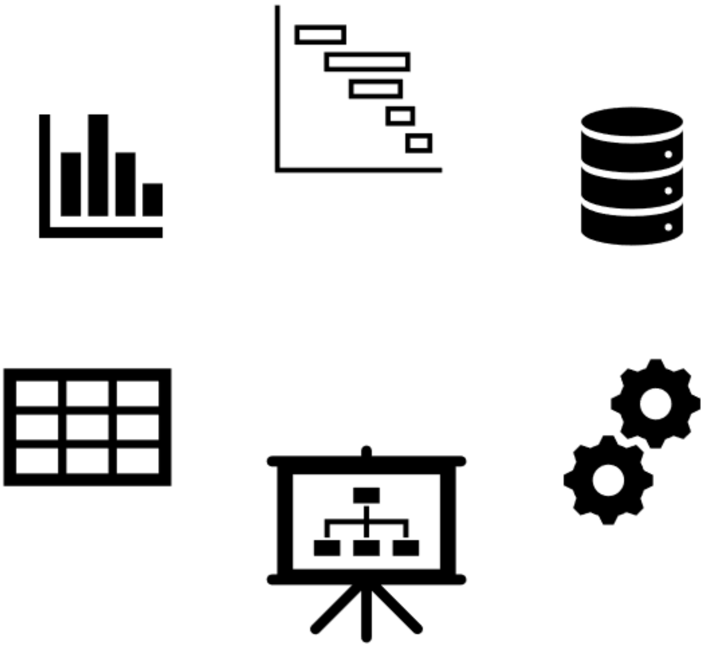

Using data analytics as a decision support platform for effective production planning

An approach to visualize the material shortages to avoid shop order replanning

Master's thesis in Production Engineering

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Gothenburg, Sweden 2020

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Cover: Illustration of data use and analysis in production planning.

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Abstract

Material planning has a huge impact on the performance of Engineer to Order (ETO) companies. Since the ETO companies initiate the product design, raw material procurement and production after the customer places the order, it is difficult to have a forecast of required raw materials, so the procurement of crucial materials and components needed for production is done after the customer places the order. This creates an uncertainty for the materials to arrive in time for the production. If there are material and component delays, then it is difficult to follow the pre-planned production plan. This creates a need to replan the prepared production plan, which creates a ripple effect and disrupts the entire production flow. So, there is a need to have a right system to visualize the material planning flow from the design team in the company to the procurement department to the production planning department, as this will give an overall visual mapping of the material flow and enable better production planning. This visual map can help the production planners to prepare a reliable production plan by considering the late arrival materials and planning the production accordingly in such a way that the production plan does not require replanning due to later arrival of materials. Data analytics softwares can be used for this purpose of mapping and visualizing the material flow.

Keywords: Engineer to order, Production planning, Shop order planning, ERP, Material Planning, Data analytics, RStudio, Tableau

Acknowledgements

This thesis became a reality due to guidance from various individuals. We would like to extend our sincere gratitude to all of them.

First of all, we would like to express our gratitude to our supervisor, *Ninan Mathew*, at Chalmers University of Technology, who encouraged us to pursue this thesis and imparted his knowledge and expertise during this study. He has always been there for us during the entire thesis work and has helped us a lot in progressing the thesis work. We would also like to thank *Björn Johansson*, our examiner at Chalmers University for giving us the opportunity to pursue this thesis work and guiding us throughout the entire thesis work.

We would like to extend our gratitude to *Jenny Sjöholm* , our supervisor at RUAG Space AB. Her consistent mentoring and kind support has been a major factor in delivering a promising result. Also, her open mindedness and contributions during many interactions has helped us to chisel our thesis.

Finally, we would like to express our gratitude to the production planners, project managers, purchasers, component engineers and production managers at RUAG Space AB for their constant support and skillful guidance during our thesis work.

Naveen Kumarr Kandasamy & Subbiah Balaji Paramasivan, Gothenburg, 2020

Contents

Abbreviations

ETO - Engineer to Order
CODP - Customer Order Decoupling Point
PL - Part List
MTS - Make to Stock
ATO - Assemble to Order
MTO - Make to Order
ERP - Enterprise Resource Planning
MRP - Material Requirement Planning
MPS - Master Production Schedule
BOM - Bill of Materials
PO - Purchase Order

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Introduction

1.1 About the company

RUAG Space AB is a leading player within the space industry. RUAG in Gothenburg is specialized in designing and producing a wide range of products for the space industry. The products are of high quality, customized and low in volumes. Existing production involves a high amount of manual work and various stages of inspection and testing to qualify the products to meet the customer's specific requirements.

The customer plays a major role in defining the business. Manufacturing will be performed based on customer order. Each order has an engineering design process and based on the design the product structure and Part List (PL) are developed, then the material purchases are made accordingly. The material purchases required to start manufacturing are categorized as electrical, mechanical and chemical components. The electrical components are further classified as active and passive components. Active components are project-specific components and the passive components are standard components commonly used for all projects and these standard components are maintained in the inventory with a safety stock. The chemical components also fall under the standard components. Each category of components has different suppliers and purchase lead times.

1.2 Problem description

The problem mainly identified at RUAG is the constant need to replan the shop orders from planned production date. The major cause for replanning is material shortage, as the project-specific components are procured after the customer places the order and some of the project-specific components are not available as per the planned delivery date in the purchase orders. There is no link between the component arrival date and the actual date when the component is needed at the shop floor for production. So, when a component arrives late it is not known until the shop order is started and then it is realised that the particular component is missing for the shop order, which causes the production planner to replan and re-prioritize the shop orders. This replanning of shop order causes a ripple effect in the production planning.

1.3 Objectives

The major objectives of this thesis work are:

- To analyze the current state project planning in the company.
- To analyze the factors which cause replanning of the production plan.
- To investigate solutions to improve the production planning in the company.
- To use data analytics tools to develop a platform to assist the planning team to efficiently plan the production.

1.4 Scope and delimitation

The focus of this study is to develop a data mapping and visualisation tool to provide an overall visual mapping of missing project-specific components from design to purchase to its actual need date in the shop floor. So, the goal is to provide better transparency of when a purchased project-specific component is needed in the shop floor and provide better support for shop order planning and release.

The study is specifically targeted towards production planning and activities that involve the manufacture of one particular product segment called "X Product". The cost details and quantity of products produced are not included in this study.

The time duration for carrying out this thesis work is six months. Due to time constraint, the implementation of the solution is not done at the company.

1.5 Research questions

1. How to analyze the production planning problems in an Engineer to order company?
2. How to organise and co-ordinate the planning across different upstream activities in an Engineer to order company to develop a reliable production plan?
3. Describe the characteristics of the current state planning environment at RUAG and how do these characteristics affect their planning operations.
4. How does RUAG currently manage the order planning and operations and how does it relate to the problem identified?
5. How can RUAG improve the planning process and discuss approaches to achieve a more stable production planning?

2

Theory

2.1 ETO environment

ETO (Engineer -to -order) is a complex environment where the products are designed and produced as per the customer's specification. ETO companies generally have a low volume and a high variant production and each product is considered as a project, with the customer influencing the design and the material properties of the product [1]. ETO companies are continuously looking for methods to reduce the cost and production lead time [2]. The production processes of an ETO company are influenced by the customer order and it can vary from one order to another [3]. There is also more emphasis on product quality and delivery of products within planned delivery time to avoid fines for lateness [3].

The inverted triangle in figure 2.1 represents the CODP (Customer Order Decoupling Point) [4]. CODP is the point along the value-adding material flow in a company and for an MTS (Make to Stock) company it is at the inventory of the company. This means that a MTS company produces its finished products and then stocks them in its inventory [4]. When the customer places the order, the CODP is triggered and the product is supplied to the customer from the inventory [4]. For an ATO company, the CODP is at the assembly operation of the finished product. This means that the parts of a product are manufactured based on forecast and they are then assembled when the customer places the order [4]. For an MTO company, the CODP is before the production of parts of a product. This means that the design and raw material procurement is done for MTO companies based on forecast, and the production of the parts of a product is initiated after the customer places the order. However for an ETO company, as seen in figure 2.1 below, the CODP is located at the design phase, which means that only after the customer places the order, the design of the product is initiated and thereafter the procurement of required raw materials and component needed for production is done [5].

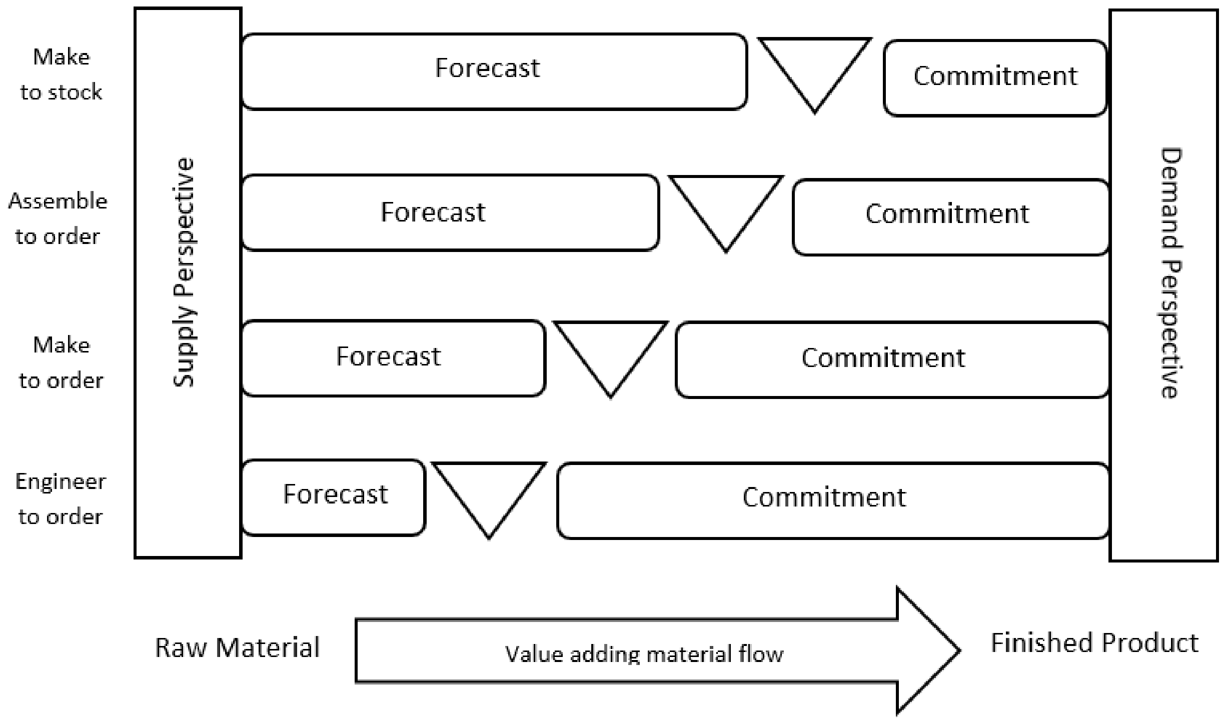

Figure 2.1: Common CODPs

In general, ETO companies have two main flows: Physical material flow and non-physical information flow. The non-physical stage concerns information flow along the design, engineering, procurement, manufacturing and dispatch phases [6]. The physical stage concerns material and component flow in the manufacturing and assembly phases [6]. There must be high inter dependency and coordination between different phases. Any late changes in the product development can have a huge impact on the production and other downstream activities. In order to identify, analyze, visualize and coordinate the changes or delays in information and material flow, there is a need for system-based view for coordination strategies [7]. The system view greatly helps to highlight or find out individual task and each process entity in the planning that may damage or affect other performance [7].

As the orders in an ETO company are customized, there is no standardized product structure to predict demand, which makes it difficult to prepare a forecast plan. The success factor for an ETO company mainly depends on the capability to deliver the order in time [8]. Achieving a shorter lead time and effective synchronization of the design, procurement and production planning activities are key to gain competitiveness in the market. Different decision levels in the organization create a lot of uncertainties for the overall planning horizon [9]. Coordination between decision taken at different stages of planning can be controlled by implementing a collaborative planning system [9].

2.2 Enterprise Resource Planning

Production planning is the main aspect of manufacturing planning and control for achieving the performance goals and meeting the increased competition due to globalisation [10]. In this regard, the Enterprise Resource Planning (ERP) system plays a major role in facilitating the company's business by integrating data from different business processes across the functional and organisational levels [10]. Many companies have implemented ERP system to support their internal process for coordination of various plans and decisions across different stakeholders in the company. ERP can be used to predict and balance the supply and demand with the help of different features integrated into the ERP system such as forecasting and scheduling tools [11]. It plays a major role in handling an entire project from contract signing, design, procurement, production of products and supply chain planning [11]. In the recent years, ERP has become a central platform for all departments in the company for planning, control and execution of all business processes.

Though there are several benefits from the ERP system, there are also many challenges especially in the implementation phase like support from the respective suppliers and so on. Some of these problems are high costs when installing the system, lower flexibility, implementation failure due to poor planning, improper selection of ERP packages, incompatibility with company's business process, inadequate training for end users, high cost for support and training and lack of planning methodology for integrating various departments and management [12]. Due to a dynamic and unstable market, more agility in manufacturing with a high degree of adaptability to diverse conditions and good capability to support key planning process is required [12]. ERP systems are developed and designed to provide business benefits such as data integration and visibility. However, it is argued that ERP systems are ill-equipped for production planning in a complex and an uncertain environment [12].

2.3 Master Production Schedule

Material Requirement Planning (MRP) and Master Production Schedule (MPS) are major aspects of an ERP system in a manufacturing company. MPS provides input to the MRP, like the quantity of raw materials and the delivery dates for finished goods. MRP utilizes lead time data from the MPS along with purchasing and manufacturing lead times stored in ERP to plan the start dates of purchase orders and shop orders [13]. Figure 2.2 below shows the MRP integration model in an ERP system with MPS as front end planning [14]. MPS acts as a front end and initial planning in determining the required parts to manufacture during a period of time and to set customer due dates for delivery. The BOM (Bill of Materials) is a list of materials and components needed for producing a product and this BOM is decided by the design team while designing the product [15]. BOM acts as an input for the MRP and it provides the list of materials needed for production. The release of orders and resources are often executed by MRP logic in the ERP system [15]. The order releases can either be a pull or a push concept. It is noted that the push strategy often produces infeasible production plan due to inaccurate forecasting and unjustified decoupling of final product demand [14]. Pull strategy responds directly to demand changes with all available information of current inventory and resources, whose data are readily available in the ERP system [14].

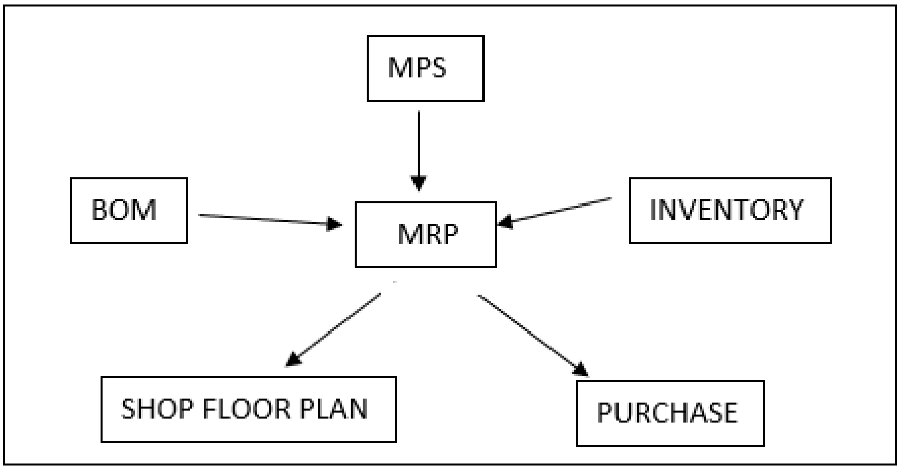

Figure 2.2: MRP integration in ERP system

In ETO companies, engineering and production preparation are done based on each customer order [1]. Generating delivery plans and master production schedule is done at a wider level of planning horizon encompassing different departments from design to procurement to supply chain planning to production planning and after-market service. The master production schedule created at the preliminary stage consists of manufacturing orders and quantities of unspecified product variants. Since the proportion of order-based manufacturing is large, it is not so easy to deduct the planned quantities of different product types for the received orders [14]. The products and its product variants in these cases are unknown, and the information is lacking about the material content and about manufacturing steps which needs to be facilitated along with consideration of resources for capacity planning.

It is important to ensure that the strategic objectives are aligned with operational plans in order to balance supply capabilities with external demand. The typical inputs for MPS are initial plans from different departments, forecast of future events and resource planning. It is important to create setup teams for each customer project and to also include key suppliers and customers in the process [16]. In order to generate a feasible production plan, the MPS should take into account all the materials required, their purchase lead time and processing time in production and all the constraints involved in planning material requirement. Information systems are found to be essentially important to align operations with the planning strategy and this urges the need for the companies to develop tools that can visualize the impacts of decisions from different departments [16].

2.4 Data analytics

Data analytics can be used for mapping required data and visualizing it in required graphical form [17]. Data visualization is using graphical pictures or patterns to represent data. Technological advancements have made it easy to summarize large volumes of data very quickly [17]. Data visualizations are a way to represent the data and explain it as a story, however, it cannot be done without contextual understanding of the data. Furthermore, poorly designed data visualizations can make it difficult to convey the message to the target audience. For effective data visualization, the user should adhere to three important processes. They are data gathering, data representation and data navigation [17]. Data gathering tells how the user should collect and store data. Data representation tells why the user needs the visual forms and state the problems to represent from the collected data [17]. Data navigation tells how the user can make the visualization interactive to navigate the data with its logical connections [17].

ERP system links various department of enterprise and gives a holistic view of what has already happened instead of what is happening in real-time [18]. Combining data analytics with ERP system provides a better guidance for decision making and helps organizations to identify hidden patterns, deriving meaning and finding correlations from unstructured data [18]. Analytics tool can provide deeper insights from the ERP data and can easily create a dashboard analysis for various individual aspects. The data from the past can be compiled to extrapolate trends or patterns to predict future behaviours and probable outcomes [19].

2.4.1 RStudio

RStudio is free and an open source data analytics software where customised R programming code can be developed for data analysis purposes [20]. Developing customized data analytics platform using customized R programming language code provides several possibilities to users to develop their own platform for analysing data as per their needs and requirements [20]. Since it is also free and an open source software, it is an economic way to analyze data. Being an open source software it is also easier to learn, as there are several online modules available to learn the handling of RStudio [20].

2.4.2 Tableau

Tableau is a data analytics software for visually analyzing data. Users can create shareable and interactive dashboards with the connected data in the form of graphs and charts [21]. Tableau can connect to files, relational and big data source to get and process data. It allows data mixing and real time collaboration without forcing users to write custom code [21].

Tableau is used to connect customize data sources and edit data by applying sorting filtering techniques. In its workspace, data can be categorised based on the user's needs and essential charts including line charts, axis charts, scatter plots and maps can be plotted [21]. Tableau is also flexible to write calculations to customize data and to create interactive dashboard for specific data analysis. The workflow for tableau is, connect the data from the data source, analyze the data by building visualization models, and share the analyzes in the form of a dashboard [21].

3
Methodology

The project was done to improve the current state production planning at RUAG by applying scientifically proven concepts and analytical methods adapted to the practical situation of the company. The first part of the thesis involved understanding the current state project planning and determining the problems which affect the production plan. Current state analysis was done by gathering both quantitative data from company's ERP system and qualitative data by conducting interviews with company personnel from different departments. A relevant literature study was conducted to look for similar production planning issues in other ETO companies and to have a scientific backing for the thesis work. Based on the current state analysis different improvement opportunities was found, and finally the most important improvement opportunity was prioritized based on input and recommendations from the company personnel. The other part of the thesis involved looking for solutions to solve the identified problem. Data analytics softwares were used to build a data analytics platform to provide a solution for the identified problem.

3.1 Literature review

A literature study was done based on ETO production. Through literature study it was found that there were several articles analysing the issues in an ETO environment which caused uncertainties in production planning, however, there were not many articles that gave a solution to this problem. Moreover, there was very limited research related to production lead times and operational planning for low volume high variant ETO sector, when compared to extensive literature for MTO sector [22].

Chalmers library, Google Scholar, Science direct, Academia and IEEE Explore was majorly used for searching relevant articles. Maximum priority was given to articles with the latest publication date. As mentioned above, articles were searched for ETO production companies to understand the working and the problems faced by ETO companies. Articles related to how ERP influences the planning of different departments like procurement, production and supply chain were collected and studied. Articles were also studied to understand the material shortage issues in ETO companies. Moreover, articles were studied how data analysis and data visualization could be helpful for analysing different data and drawing relevant conclusions from the analysis.

3.2 Qualitative analysis

To get an understanding of how a project planning was done at RUAG from customer order approval to product dispatch to the customer, qualitative analysis was done by conducting several interviews with various company personnel from different departments in the company. The departments which were interviewed were project management, component engineering, procurement, production planning and production. Moreover, the thesis initially did not have a defined scope and the scope of the thesis work was to be analyzed and defined. To define the scope, it was crucial to understand how current state project planning was done at the company and analyze how planning activities of different departments influenced the production planning. So, two rounds of unstructured interviews were conducted with personnel from the above mentioned departments to understand the organization planning working in the company and how their project planning activities influenced the production planning. These two rounds of interviews were maintained as open as possible to understand the complex planning processes in the company and to get recommendations from the company personnel on how to proceed with the thesis work. After these two rounds of interview, the scope of the thesis work was defined and then multiple rounds of semi-structured interviews were conducted with the component engineering and the production planning departments to determine a solution for the defined problem. According to Flick, having the interviews as open and as diverse as possible could help the interviewer to get more qualitative data and discuss more information from different perspectives [23]. The questions which were asked during the interviews can be seen in Appendix A.

The project management team was interviewed to understand how initial project planning was done by converting the customer order to a project. Further information collected from project managers were how they plan a project from start to finish and how much they influence other downstream activities in setting internal deadlines for various departments.

The component engineering team decided the components needed for a project and they were crucial for fixing the component list and the product structure. Information collected from them were how they create the purchase order requisition for various components and how prioritization was done for the purchase of components with varying purchase lead times.

The procurement team was interviewed to understand how they convert the purchase order requisitions created by component engineering team into purchase orders. They were also interviewed to understand how they set the purchase lead times, how they liaised with the suppliers and how they dealt with late component arrivals.

The production planning team planned the shop orders based on the customer delivery date. They were interviewed to understand how the shop order planning was done from shop order requisition creation to shop order release. More information was collected from them to analyze the factors which cause replanning of shop orders. They were crucial for this thesis work and this thesis work was done to provide support to the production planning team, so several interviews were conducted with the various personnel from the production planning team to understand their current way of planning.

Production managers were interviewed to learn how the work of the production planning team influenced the work on the shop floor. They were interviewed to analyze if any delay in production activities on the shop floor caused replanning of shop orders. Several inputs were collected from them regarding time study of different production activities, management of shop floor workers and how they reported the progress of production work to the production planning team.

3.3 Quantitative analysis

Quantitative analysis was done based on the defined scope and qualitative analysis highly influenced what kind of quantitative data had to be retrieved from the company personnel and analyzed. The company's ERP system was extensively analyzed for collecting data needed for the thesis work. Multiple workshops were conducted with different departments to see how they handled the ERP system and what kind of quantitative data they dealt with while handling a project. The project manager maintained the MPS for the selected product variant and it was used as a benchmark for planning the production activities of different projects. This MPS was obtained as an excel file from the project manager for analysis. Data which influenced the production planning and material planning at the company were collected from the component engineering team, procurement team and production planning team. These data were collected as excel files extracted from the company's ERP system. The relevant data were collected for a selected time frame and also for one particular X Product project.

The collected data was stored in a common online folder in Box, so that it was easily accessible by the project members. Using the collected data, excel was used to analyze the number of late delivered components and the number of components delivered on time. Moreover, for mapping and visualizing relevant data extracted from the ERP system, data analytics tools was used for building a pre-defined and an user friendly data analysis platform. This pre-defined platform could also be used for upcoming projects as well.

3.4 Data analytics

Data analytics is used in several diverse fields for analysing data and it can also be used in production planning for decision making. It was used to assist the planners in production planning. An overall visual map of the project-specific components was needed from its component planning phase to its procurement to its actual need date in the shop floor. So, data analytics software was used for this data mapping and visualization purpose. Relevant data required was obtained from the company's ERP system as excel files as mentioned in Section 3.3. The relevant mutual data present in the selected excel files were mapped and then visualized as a graph. This graph provided the required output in a graphical way, which could be very useful for the production planners to prioritize and release the shop orders accordingly.

RStuido is a free and open source software. R programming code was developed and run on RStudio. This was done to develop a customised code for analysing data from multiple excel data files retrieved from the company's ERP system. Developing code in RStudio gave the flexibility to map the data and visualize the output based on the company's needs. Moreover, developing the code could also help in creating a customised data analytics platform based on the user's needs.

Tableau is a data analytics software which is also used for mapping the data from different excel files and visualising the output in the form of graphs. Tableau has built-in data analysis tools and there is no need to develop a code from scratch for data analysis as compared to RStudio. Tableau also has better built-in user friendly interface and better visualisation features compared to RStudio. Even though Tableau was a paid software, it was used for analysis in the thesis work as Tableau provided free access for Chalmers University students.

4
Current state analysis

4.1 Organization structure

The departments involved from project creation to planning the production of the project are project management, design and component engineering, procurement and production planning. The project manager initiates the project creation in the company's ERP system. When the project is created, the design team first starts to work on the project by creating the product structure and the initial list of components needed for the project.

Then the component engineering team further develops the component list and selects the particular variant of the each component, and thereby developing the Part List (PL). Then the project specific components with the longest purchase lead times are sorted out and then procured based on the component's lead time. The component with the longest lead time is ordered first for procurement and this ordering and procuring process is handled by the procurement team.

The project-specific components are procured and then stored in the inventory after inspection. The standard components in the PL are available in the inventory with a safety stock. These standard components are reserved by the production planning team and taken from the inventory when needed. The production planning team plans the production schedule in the company's ERP system. This schedule is followed by the production team on the shop floor. The production managers are responsible for managing the employees on the shop floor and keeping up with the production schedule. The project is generally completed prior to the customer promised deliver date to have a buffer time for quality testing and dispatching.

4.2 Order management process

To get the thorough understanding of the operational process and planning at RUAG, a swim lane diagram is developed to map the internal order flow. This diagram shows how customer order flows through the organization and it shows corresponding activities involved in processing a customer order. The structure of the order flow is shown in figure 4.1.

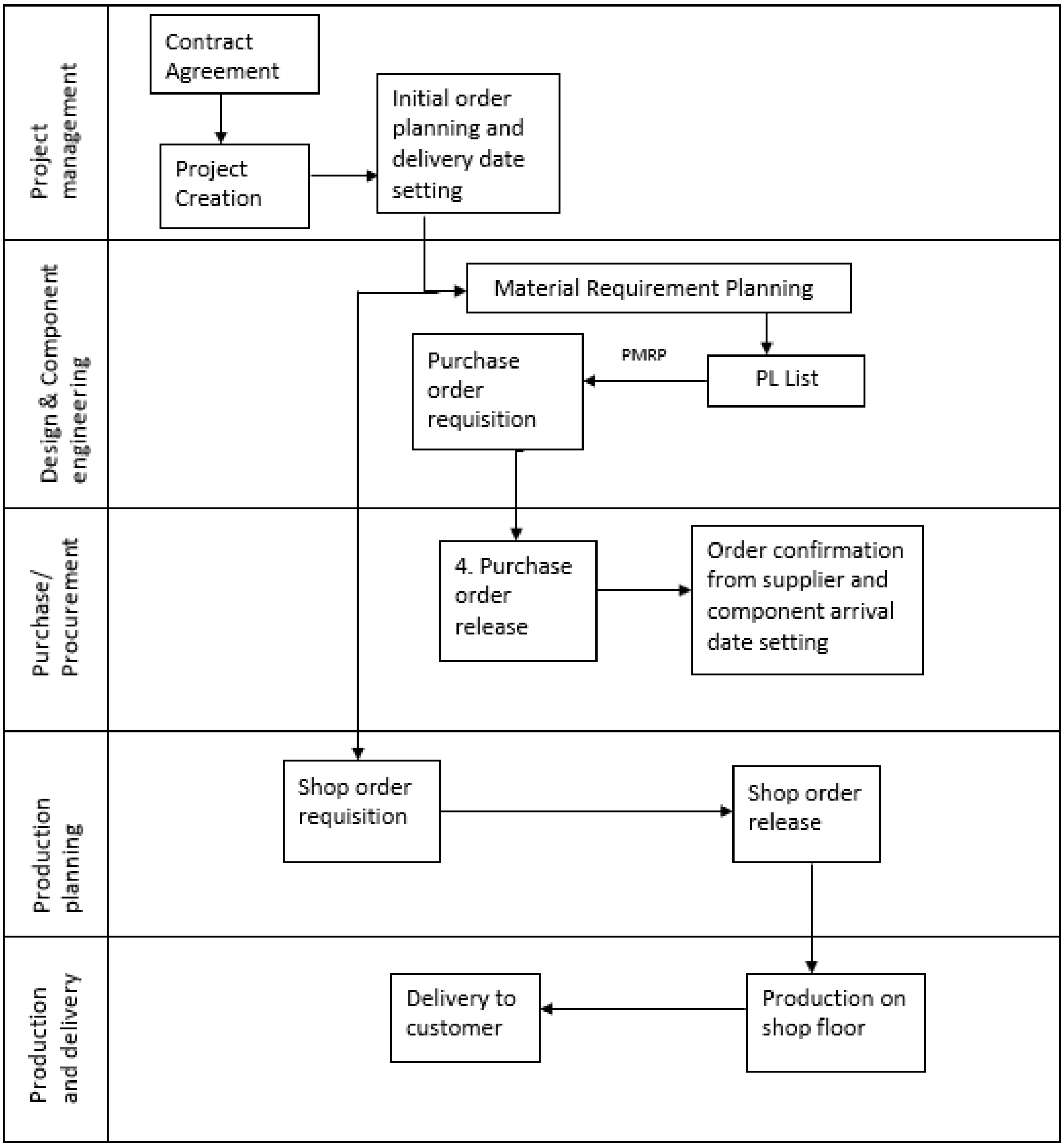

Figure 4.1: Customer order flow process

4.2.1 Project management

When the company receives a order, the project manager initiates the conversion of the order into a project in the company's ERP system and the project setup team sets up the project in the ERP system. The project manager is also responsible for maintaining the MPS for the selected product variant. A product has a multi-level hierarchical product structure as shown in the figure 4.2. The MPS consists of the planned production start date and the customer delivery date of running product X based on the product structure level. Based on this customer delivery date, backward scheduling is done by ERP to determine the production starting date of X product based on their product structure level. The time needed for production of different levels of X product is fixed based on the history of production time needed to produce earlier X product. So, when a new project arrives the project manager enters the production planning data for the project in the MPS. This MPS is used for overall tracking of a project's production progress and also used by the production planners as a benchmark for their planning purpose.

4.2.2 Design and component engineering team

When the project is set up in the company's ERP system, the design team then designs the product structure. However, for X product a fixed product structure is followed as shown in the figure 4.2 below. The design team then decides the components needed for the project in the ERP system. Each component fixed by the design team is mapped to a serial number called "Design Part Number" in the ERP system.

Next, the component engineering team starts the planning process. The component engineering team decides the variant of each component fixed by the design team, and thereby map the Design Part Number of the component to its Variant Number. When this mapping of all the components from the Design Part Number to the Variant Number is done, the Part List (PL) is created. The PL consists of all the details of all the components needed for the particular project. However, the PL is revised repeatedly until all the right components are selected for the project. This PL consists of different types of components: mechanical components, passive electrical components, active (project specific) electrical components and chemicals as well.

When the PL list is created purchase order requisitions are created for all the components on the PL list. The project specific components are sorted as per their purchase lead time and the component engineering team raises purchase orders for the components with the longest purchase lead time. After raising purchase orders for the longest purchase lead time components, purchase orders are then raised for other components which are needed to be procured. The purchase order requisitions created for the standard components are handled by the production planning team who maintain the inventory of standard components. Based on the inventory availability and the project needs for the standard components, the production planning personal makes an informed decision if the purchase order requisitions of the standard components should be converted to purchase order or not.

Multiple revisions of the PL list will be carried out based on changes in the design and specification of the component. Once all the revisions are finished, it is transferred to the product structure and it is finally frozen. Ideally there won't be any changes in product structure after this stage. Final PL list can be extracted from the ERP system based on the product structure.

4.2.3 Procurement phase

The procurement team receives the purchase orders raised for the project needs. The purchase lead time of each component is entered and maintained in the ERP system by the procurement team based on the component's purchase lead time history.

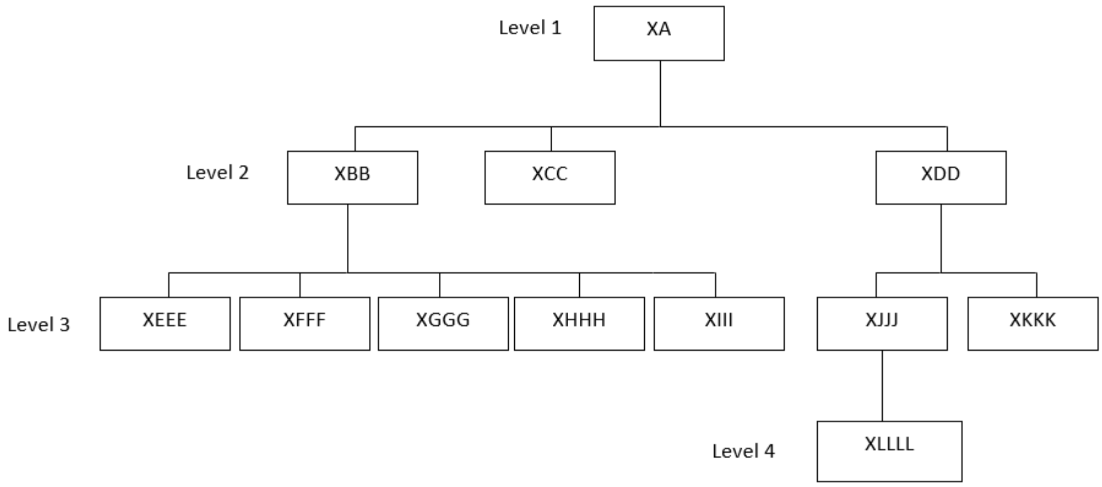

Figure 4.2: Overview of X Product structure

The procurement team works on the procurement of components by getting the quotation of the components from the suppliers. After receiving the quotation, the procurement personnel gets the financial approval from the project manager for procuring the components. When the project manager gives the approval, the procurement personnel starts the procuring process by placing the order for the intended components.

The procurement personnel constantly liaises with the suppliers regarding the status of order delivery and updates the delivery status in the ERP system. The procurement team is responsible for updating the status in the ERP system if the component has arrived at RUAG. The procurement of project specific components is done in such a way that they arrive before the starting date of the first level of production. So, it is crucial that they are procured at the right time. If there is a delay in the component delivery, then the procurement personnel is updated of the delay by the supplier and the delivery status is updated in the ERP accordingly.

4.2.3.1 Delivery monitoring

Delivery monitoring is done to ensure that the deliveries are delivered on the promised delivery date. Delayed deliveries result in disruptions in production and too early deliveries cause unnecessary tied-up capital and require unnecessary storage space. So, monitoring helps in increasing the probability that the delivery takes place on agreed time and to avoid shortage situations. Setting the dates for the components to reach the facility is a crucial deciding factor and the components' wanted delivery date in the purchase order is set based on historical data of each component's purchase lead time. Since the company is following a procurement policy of procuring components just before the starting date of the first level of production, it is crucial to set a precise purchase lead time for the components based on the components' historic purchase lead time so that there is no deviation from the company's wanted date and the supplier's actual delivery date.

4.2.4 Production planning phase

The different operations which are connected to the production of X product must also be defined and connected to their respective work centres and labour class in the ERP system. Each operation is given a setup time, buffer time and machining time which collectively affects the scheduling of the operations. Shop orders requisitions are built based on the assemblies and their sub-assemblies in the product structure and the required components and operations involved for manufacturing that particular sub-assembly. For planning the shop orders the capacity available in machines and number of shop floor employees at the shop floor are also considered.

The ERP system computes the proposed start date of shop orders at a requisition level to manufacture the net required quantity of final products. The system follows backward scheduling to set the proposed start date for the shop order requisitions and this backward scheduling is done based on the customer delivery due date. Before releasing the shop order requisitions, a material check is done by the production planner on all shop order requisitions to ensure that the components are all available for starting the shop order. After reviewing this the production planner releases the shop order requisitions which has no material shortage and converts them into shop orders. At this stage, the shop orders are ready to be worked on in the shop floor to manufacture the X product. This shop order releasing activity is done before the production starts and when a component or components are missing for a shop order then it creates a difficulty in planning and releasing the shop orders as per the pre-planned schedule. Then there is a need to replan the shop orders based on the available material which causes a ripple effect in the shop order planning. This replanning is also done at later stages of shop order planning and not in earlier stages which makes it even more difficult to replan at the last moment.

4.3 Misalignment of component planning and production planning

After discussion with various company personnel from different departments like component engineering, procurement, project management, production planning, and an analysis of the planning process in the company it is found that the component planning and production planning are not properly coordinated. The component team plans the purchase of the project-specific components in such a way that the long purchase lead time components are ordered first and the other components are ordered in such a way that they arrive in the inventory just in time before the planned production start date, but this component purchase is not done in reference with the shop order requisition start dates. So, there is no link between the component arrival date and the actual date when the component is needed at the shop floor for production. So, when a component arrives late it is not known until the production planning team releases the shop order requisition and then it is realised that the particular component is missing for the shop order, which causes the production planning team to replan and re-prioritize the shop orders. There is a lack of overall visual mapping of components from purchase to its actual need date in the shop floor as per the product hierarchical structure.

It is challenging to maintain the production balance between orders and the availability of limited resources. The resources here are mainly materials and components needed for assembly and manufacturing operations, and sometimes human operators, equipment and machines. The accuracy in setting the planned production start date plays a major role and is a deciding factor for production planning. The planned production start date is set by following backward scheduling from the customer order delivery date and the component purchases for each sub-assemblies and top assemblies should have arrived in the facility before the planned production start date of shop orders.

4.3.1 Lead time uncertainty

As unique and project-specific components are used, the supplier's supply lead time is usually long. Decisions on the component's required date and the quantity is of great importance to RUAG, so that the order can be placed and the components are in-house before the planned production date.

Since the suppliers do not always meet the agreed delivery dates, a delay in component arrival affects the flow of the shop order plan. Sometimes there are also lack of accurate update of the supplier's delivery history.

The procurement team maintains the promised delivery date in the ERP system as the date confirmed by suppliers. However, based on analysis in the ERP system it has been noted that the confirmed delivery dates have not been met by the suppliers on several occasions.

5
Results and Discussion

5.1 Data analytics software

The aim of using data analytics softwares is to link the project specific components from the PL list to their purchase order lines and to the component's actual need date in the shop floor. This data mapping is done separately for each product structure in X product. This mapped data is then visualized in a scatter plot to show an overall visual mapping of the component flow from the planning to procurement to its actual need date in the shop floor as per the product structure.

5.1.1 Results from RStudio

5.1.1.1 RStudio input

In this section, the input given for RStudio will be discussed. Relevant data is extracted from the ERP system as excel files for data analysis. A X product project is chosen for analysis and X product has a fixed product structure as shown in figure 4.2. PL list for every sub-assemblies in the product structure is extracted from the ERP system. In this case, a level four sub-assembly of the product structure known as XLLLL is chosen for analysis and the PL list for XLLLL sub-assembly is given as a input. In this XLLLL sub-assembly PL list, the column containing the information about the component's Variant number is chosen for analysis. The XLLLL sub-assembly PL list can be seen in the Appendix B.

The purchase order lines for the selected project is extracted from the company's ERP system. The majority of the purchase order lines includes project-specific components as the project specific components are procured after receiving the customer order and they have no safety stock. So, the majority of the components procured for a project are project specific components. The purchase order lines data is extracted from the ERP system as excel file and the data column analyzed is the one which has the components' serial number data called Part number and the components' planned receipt date. The purchase order lines excel file can be seen in the Appendix C.

The other excel file extracted from the ERP system is the shop order requisition file which consists of list of all the shop orders for the project. Every product structure has its own list of shop order requisitions and every requisition has a proposed start date. The earliest start date is noted down from the list of shop order requisition for the selected product structure. An image highlighting the list of shop order requisitions for the selected project can be seen in Appendix D.

To work in RStudio, a customized R programming code must be developed for data analysis. RShiny feature in RStudio is used to develop the code and an interactive customised data analytics platform for analysing and visualizing the data. The data model for RStudio representing the input and output for RStudio is presented in figure 5.1.

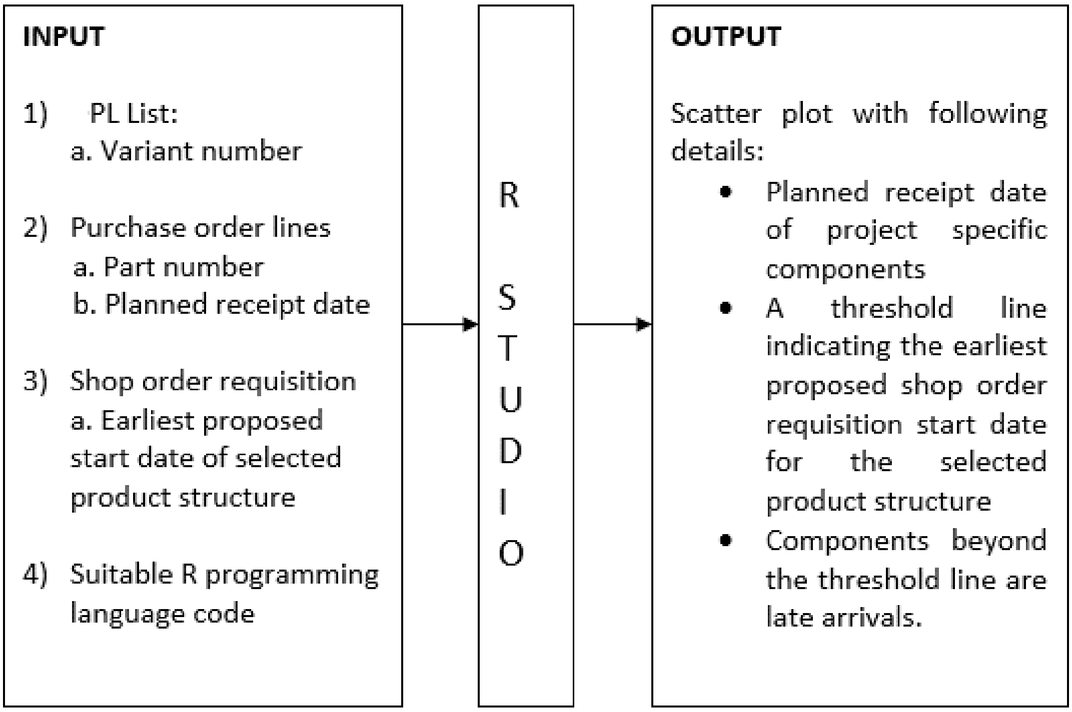

Figure 5.1: Data model for RStudio

5.1.1.2 Working with RShiny feature in RStudio

RShiny feature in RStudio is used for developing the R programming code. RShiny provides provision to develop a customized data analytics platform with a back end for customizing the front end of the customized data analytics platform. The code is developed and executed in the upper left hand corner of the RStudio window as seen in Appendix E. The code developed for can be seen in Appendix F. After the R programming code is developed in RShiny feature in RStudio, the code is run. When the code is run, a front end platform appears for giving the relevant input as seen in figure 5.2 below. The PL list and purchase order lines excel files can be uploaded. The earliest proposed start date of the shop order requisition can be entered in the date input provision.

When all the required input is given a scatter plot and a table will be generated. The scatter plot's X-axis is the component number and the Y-axis is the component's planned receipt date. All the components mutually present in the PL list and the purchase order lines are mapped in the X-axis, their corresponding planned receipt

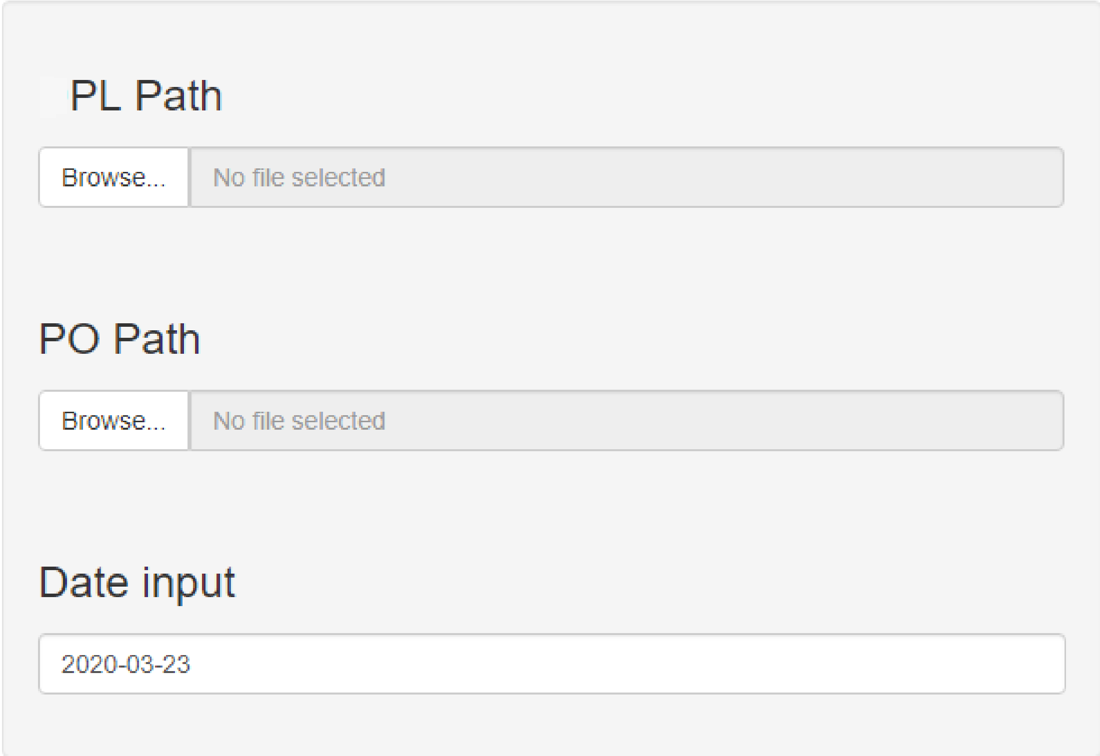

Figure 5.2: Front end of the customized data analytics platform

date is marked as a point in the scatter plot. A threshold line is generated based in the Y-axis, which indicates the earliest proposed start date of the shop order requisitions of the selected product structure. The components with planned receipt date longer than the earliest proposed start date are mapped above the threshold line and the components above the threshold line are late arrival components. So, this gives an overall visual mapping of components from the PL list to the purchase order to the components' actual need date on the shop floor for all the components present in a product structure. The scatter plot generated can be seen in figure 5.3 below.

There is also a small table below the scatter plot as seen in figure 5.3, which shows the list of components arriving late and their planned receipt date.

5.1.2 Results from Tableau

5.1.2.1 Tableau input

This section describes the preparation of data for importing it to the tableau. Tableau gives the option to connect to an excel file, a text file, an access file, or a statistical file located in the computer or the option to connect to online data or web data connector server. The excel, text, access, and statistical files will be local databases, while the online data connection will allow connecting to an online database. The overview of input and output of the tool is given in the figure 5.4

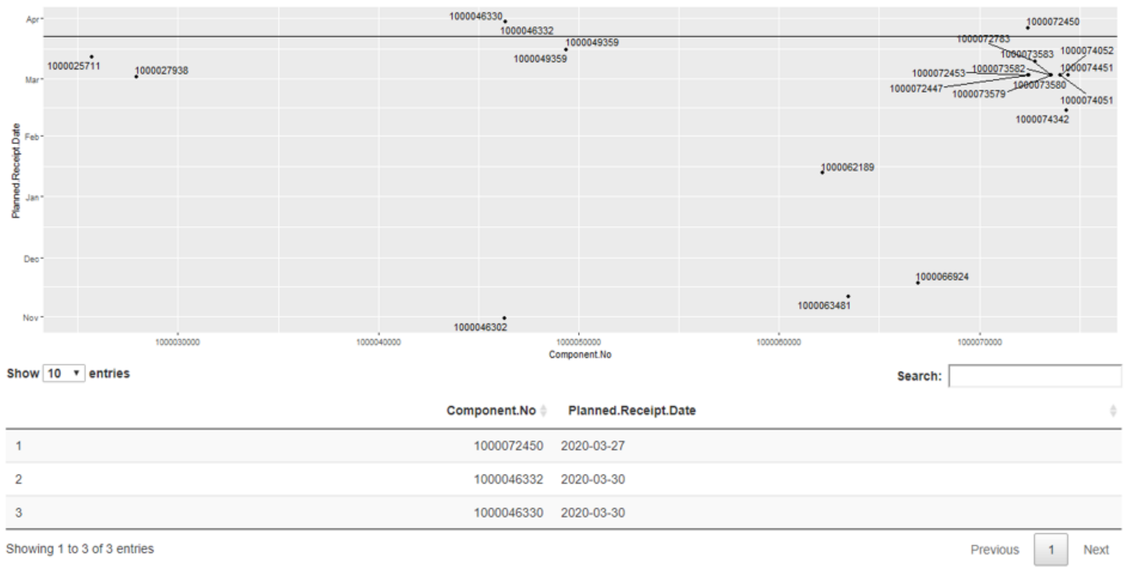

Figure 5.3: Scatter Plot

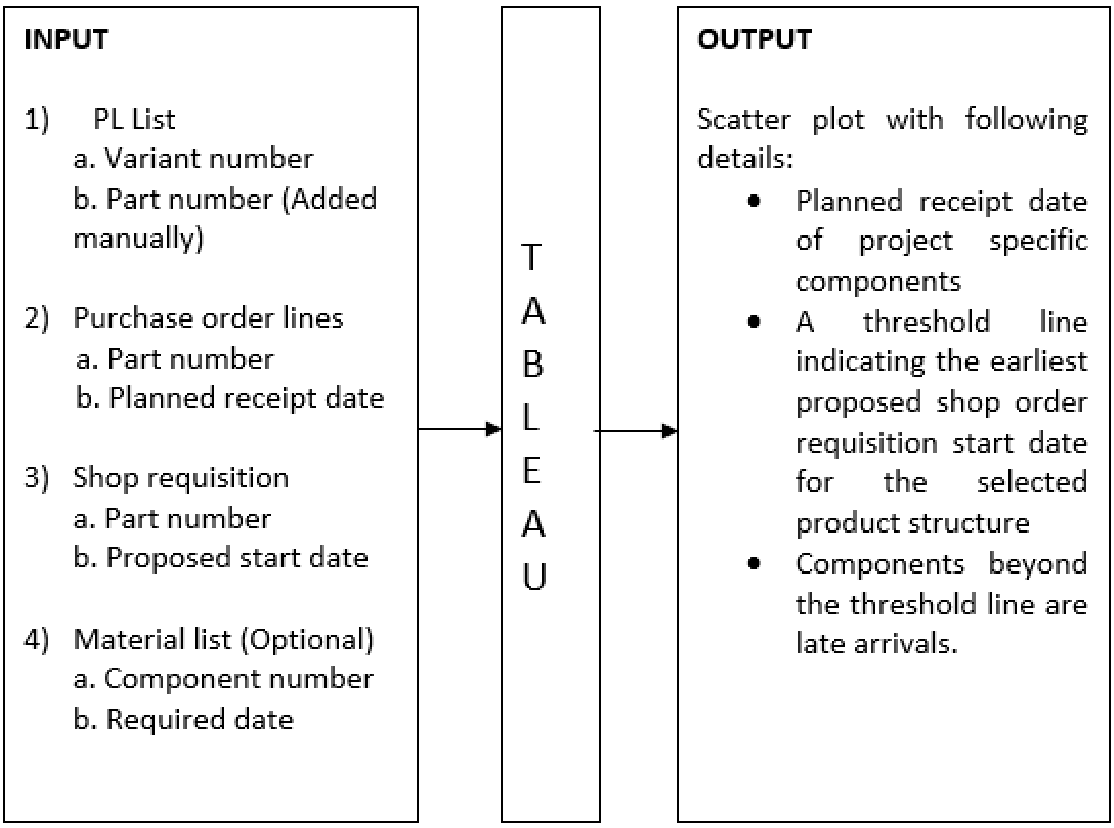

Figure 5.4: Data model for Tableau

Excel file extracted from ERP system is imported to tableau. Tableau will import every sheet that is present in the Excel workbook and each sheet will appear under Sheets tab at the bottom of the worksheet. The excel files of PL list, PO lines and shop requisition list are now imported into Tableau.

The first step is to choose the attributes from different excel files to analyze and to visualize the relationship between them. As shown in figure 5.4, variant number and part number are chosen from PL file, the part number and planned receipt date is chosen from PO lines, and from shop order requisition file, proposed start date and part number is selected.

To merge different data tables, join and union functions are used to access data from all the intended data sets to map the required data and to visualize the relationship between them. As shown in figure 5.5, the second step is to use inner join between the excel sheet of PL, PO lines, and shop order requisitions list to map and display the common records present in all the above mentioned excel files. The material list file is considered as an optional file used to visualize the required need date of every individual component number at the shop order level.

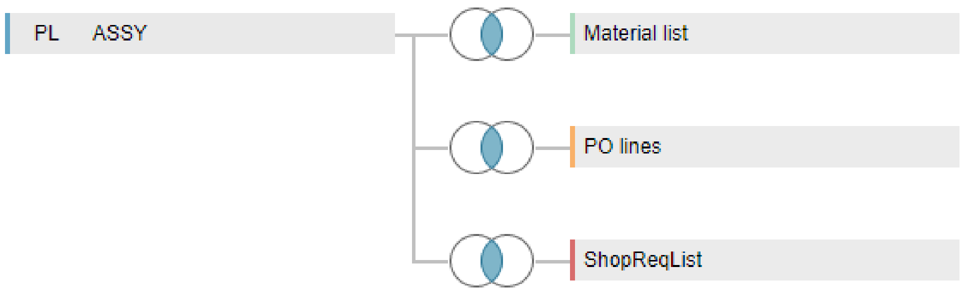

Figure 5.5: Data mapping platform

5.1.2.2 Output from Tableau

In the first stage, the project-specific components are mapped and extracted from the PL lines and purchase order lines. The graph is plotted to visualize the components with its planned receipt date as represented by the dots in the scatter plot. Every product structure has own list of shop order requisitions and in the second stage, the proposed start date of shop order requisitions aligned with the chosen product structure is connected to the PL and PO lines with its mutual columns. The graph now shows a scatter plot and the dots represent the list of project specific components present in the product structure and their respective purchase order planned receipt date. The line formed in the scatter plot is generated based on the proposed start date of shop order requisition and this line acts as a threshold line. The points above the threshold line are the late arriving components for the respective product structure. In other words, the shop order requisition needs to be replanned based on the late component arrival date or followup should be done with suppliers to ensure that the late arrival components can be brought within the time of the start of its respective shop order.

Figure 5.6 shows the different sections from tableau desktop screen for XDD sub-

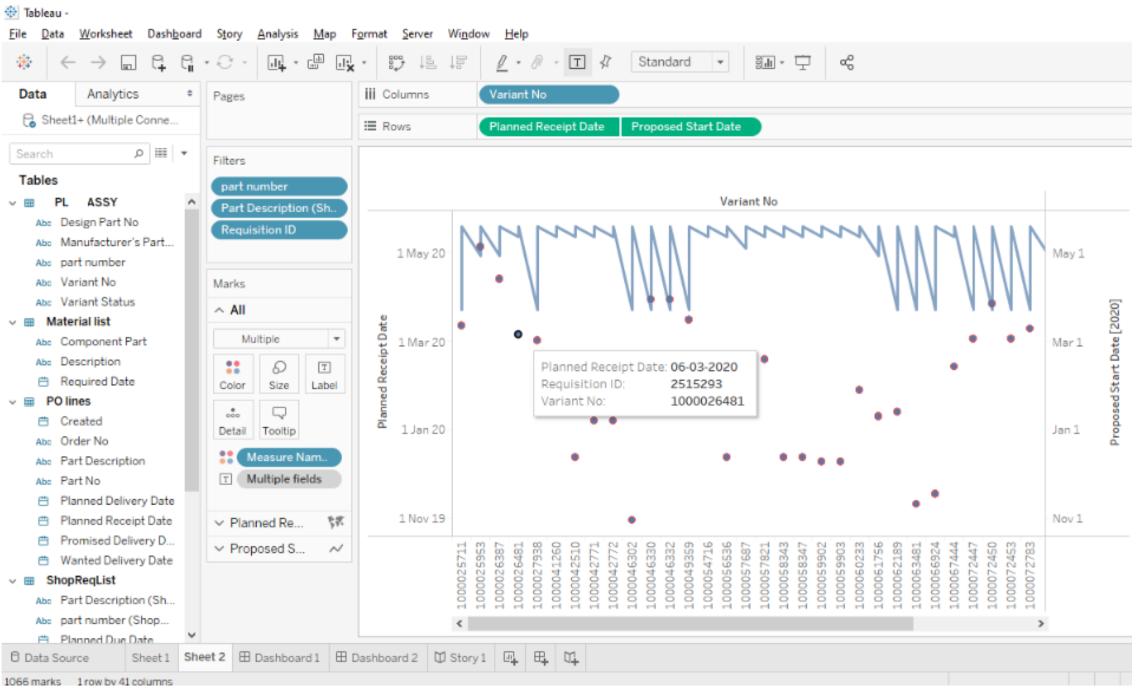

Figure 5.6: Overview of Tableau screen for XDD sub-assembly

assembly and its sub-assemblies. Columns on the top indicate the X-axis showing the component number / variant number. Rows indicate Y-axis showing planned receipt date of PO lines and proposed start date from shop order requisition list as their dual axis. The points in the graph show the component number aligned based on planned receipt date and proposed start date. Using the mark feature on the left side, the columns from the tables can be selected and dragged to show the required details such as variant number from PL list table, planned receipt date from PO lines list, requisition ID and proposed start date from shop order requisitions list table. At the right side of the screen, there is an option to switch and to navigate between different product structure.

The detailed examination and illustration of missing components for XLLLL sub-assembly is shown in figure 5.7. The scatter plot here shows the points above the threshold line indicates the missing component for the shop order requisition or in other words, they are late arrival components. The variant number (1000046330) in the graph has a planned receipt date of 30-03-2020 as its arrival date to the company facility, but the shop order requisition (Requisition id: 2508948) for that same variant number 1000046330 has a proposed start date 23-03-2020 as planned by ERP system's backward scheduling. This illustrates that the component 1000046330 will be a late arrival for the shop order requisition 2508948 and when this shop order is started as per the proposed start date, then this particular component will be missing for this shop order.

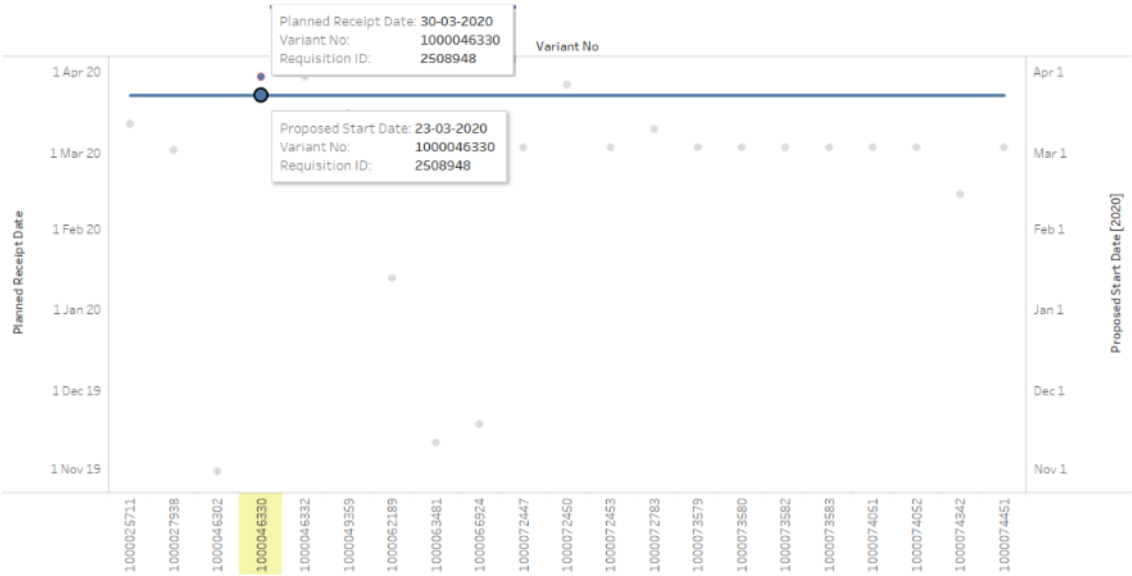

Figure 5.7: Graphical view of Tableau screen for XLLLL sub-assembly

5.2 Positioning of data analytics software in the planning process

This section describes how the data analytics software will fit in the planning process at RUAG. The figure 5.8 below show the overall order planning process at RUAG and at what planning phase the data analytics software/tool can be used for better planning and prioritizing of shop orders.

The data analytics software identifies the bottleneck materials and gives an early stage visualization of late arrival components. Based on this the production planning team can plan and prioritize the shop order release in such a way that there is no need for replanning at the last moment. This enables the production planning team to have a reliable production planning schedule. It is also useful for providing an overall mapping and visualization of all the project specific components for a specific product structure from the PL list to purchase order lines to its actual need date on the shop floor. It can also be used by the procurement team to visualize the components which arrive late as per the respective shop order requisition start date. They can then prioritize to do a follow up of late arrival components with the components suppliers and try to bring the components into the company as early as possible so that they are available as per the proposed shop order start date. If those late arrival components cannot be accelerated and brought within time, the shop orders associated with that component identified through visualization should not be released and the shop order planning should be done accordingly to have an effective shop order plan which does not need a later replan.

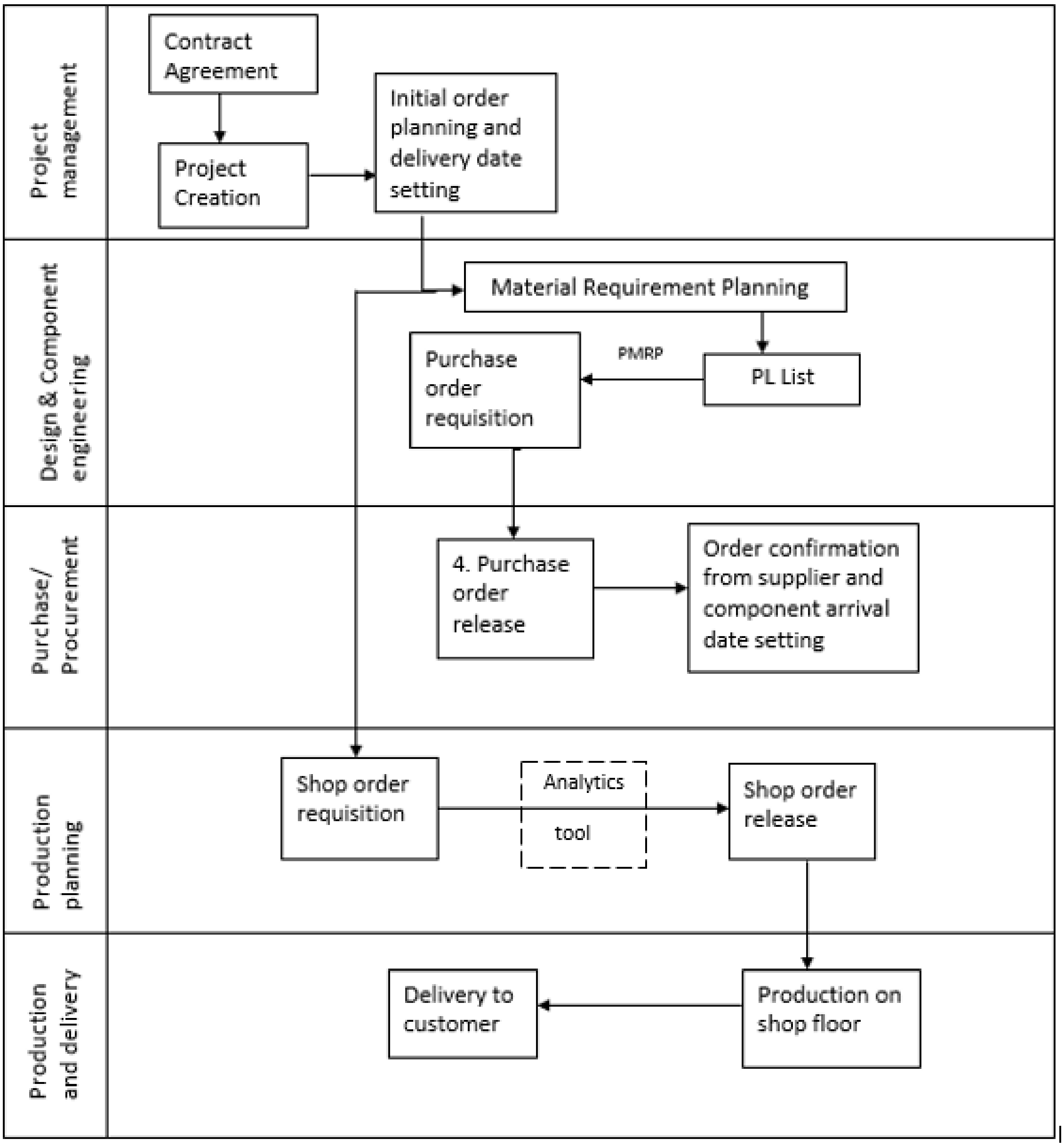

Figure 5.8: Positioning of data analytics software in the planning process

6
Conclusion and Recommendations

This report is concluded with the reflections on the thesis work and how they answer the framed research questions. This chapter starts with the answers to the research questions which were formulated in the problem description and ends with recommendations for the company for further development.

6.1 Answering research questions

1. How to analyze the production planning problems in an Engineer to order company?

   ETO is a complex planning environment where a project planning and production is done based on the customer order. So, it is difficult to have a forecast for production and have a streamlined production flow as the projects in the company are defined by customers and are highly customer oriented. So, in an ETO company, not only the production planning department and the downstream activities should be analyzed for identifying the problems, all the other upstream activities above the production planning like project management, finance, design, purchase and sales department must also be analyzed to see how they influence the production planning.

2. How to organise and coordinate the planning across different upstream activities in an Engineer to order company to develop a reliable production plan?

   The upstream activities to a production planning department include the project management, finance, design and purchase department. A common interactive platform should be developed in such a way that all the activities of different departments which affect the production planning are coordinated and if there is any issue which could affect the production planning then it should be alerted as early as possible so that the issue can be mitigated by solving it or by early replanning of the production plan in such a way that it does not need replanning in the last moment.

3. Describe the characteristics of the current state planning environment at RUAG and how do these characteristics affect their planning operations.

   RUAG operational environment is characterized by high dependency on its suppliers and the procured project specific components often have long purchase lead times. There are uncertainties in both demand and supply due to unpredictable forecasting which has a direct impact on the company's operations. Since, the company follows an ETO approach, minimum inventory is maintained for selected components, and each project is customer specific. The challenges include long component purchase lead time, complex product structure and planning and prioritizing the shop orders.

4. How does RUAG currently manage the order planning and operations and how does it relate to the problem identified?

   RUAG uses material requirement planning MRP embedded in their ERP system to process the customer order and to create demands for the material requirements. The ERP system has several shortcomings regarding the overall visibility of material availability constraints and misalignment in the component planning and production planning as discussed in section 4.3. Because of the company's characteristics and high dependency on just in time purchase of project specific components, the above-mentioned issues have a huge impact on company's operational performance. This results in an unreliable production plan which requires rescheduling and replanning of shop orders.

5. How can RUAG improve the planning process and discuss the approaches to achieve a more stable production planning?

   To improve the current planning system at RUAG, the production planning team can use the data analytics software as mentioned in section 5 to assist them in planning the shop orders. To improve the planning stability and to reduce the rescheduling, the data analytics softwares can be used to map the project specific components from PL list to purchase orders to its actual need date on the shop floor. The results from the data analysis give an early stage visualization of bottleneck and late arrival components in a single window. This provides alignment between component and production planning. Therefore, it is suggested that the component engineering, procurement and the production planning team can collaboratively use this decision support data analytics platform for more effective production planning.

6.2 Recommendations to the company

- Implement the data analytical platform for better planning of shop orders. Including it in the planning process will make sure that all the released shop orders will have no component shortage, which can help in achieving a more stable production plan. If the company plans to implement the solution, then the production planning team must learn how to effectively handle the data analytics softwares and adapt to the changes.

- It is recommended to explore the possibilities of linking the data analytics software with the company's ERP system to have a real-time visualization rather than extracting data from the ERP system as excel files and uploading those files in the data analytics software.

- RStudio is a free and open source software. It also has its own server called RServer, which can be connected with the company's server so that all the personnel in the company who need this data analytics platform for their analysis can use it. It can be done with no investment. However, in the case of Tableau, it is a paid software and the company should pay an annual fee to use the software for commercial purposes.
- The ERP system at RUAG contains large amount of data which can be used for revising and setting the safety stock for components. Factors on deciding the safety stock of standard components can be supported by evaluating supplier performance from the past. Long lead items can be segregated and their safety stock can be re-calculated to avoid any component shortage.
- This solution can also be potentially scaled to other product segments which are produced at RUAG's Gothenburg production facility.

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A

Questionnaire

Interview with the Project managers and Component planning team

1. Does RUAG has a Master Production Schedule for X and Y products manual assembly operations?
2. What is the planning horizon for the MPS?
3. Who creates and verifies the MPS with the capacity constraints? Is that the task of planners (object managers)?
4. How the lead times for each customer order is fixed from MPS point of view? Are the lead times fixed based on experience from historical orders? Do you feel the lead times fixed are compatible with the available capacity of the shop floor?
5. What information the operators (assembly workers) has while doing their operation? Do they have information about the whole production plan for that particular order or they just see the information about their particular station?
6. How is the planning done for long lead items? How are other components other than long lead items procured? Are they procured so that they are available in the inventory as per the production starting date mentioned in the global plan?
7. Is there a large variation between the planned time for manual assembly operation prepared by planners and the actual time logged by operators in the system?
8. If you want to track or identify the status of a shop order/customer order, contract or component that is required by a particular customer? Is it possible to check that in the ERP system?
9. How often does the planners, project managers and production managers (manual assembly operations), assembly operators meet in a week for X product assembly operations to discuss the current status of production (shop orders) or problems with the scheduling or planning of shop orders.

Interview with the Procurement and Production planning teams

1. What are the current major issues that leads to delays or Replanning?
2. Before creating or starting the shop orders every time based on suggestions from shop order requisitions, is there an actual checking of the available machine capacity or resource capacity?
3. What is the current process used for checking resource capacity to make sure that we have enough capacity to release the shop orders from the system?

4. We would like to know about how the shop orders for X product manual assembly operations are released. Are the shop orders released from Top assembly level or sub assembly level? Is the top assembly manual operations and sub assembly manual operations included in a single shop order?
5. How is the order sequencing done in the shop floor? Do the production team exactly follow the plan created by planners?
6. Is there a Gantt chart that is prepared as a part of detailed capacity planning (shop floor planning)?
7. Is the Gantt chart available in ERP or the ERP system is anyway used to build the Gantt chart as part of scheduling the sequence of orders in the shop floor? If ERP is not used, what other tools are used to build the Gantt chart?
8. What is the common order dispatching rule in the shop floor?
9. After performing an operation, how the operator will update the information like whether the operation is completed, delayed, stopped due to other issues etc. Is it possible to see that information in the ERP system?
10. If an operation is delayed or stopped, is the reasons for that notified in the ERP system or are these issues captured and acted upon or used as a basis of doing the planning in the future?
11. How they will check the workload on resources if they introduce a new shop order (rush orders)? Is this usually a discussion between the planners and the production managers that will solve the constraints?
12. Currently we have a Production planning board in the shop floor. Is it satisfied with current planning boards? If no, what is the problem with the current planning boards?
    - Is it the amount of details visualized not enough to track the status?
    - Is the details visualized not easy for the operators to understand?
    - Is the operators not trained in using the boards?
    - Is there problems with the proper updating of planning boards in the shop floor?
    - Is the plan provided in the planning boards does not exactly coordinate with the plan in the ERP system?
13. What is the difference between planned receipt date, promised delivery date, planned delivery date maintained in the ERP system?
14. If you want to track or identify the status of a customer-order, contract or component that is required by a particular customer? Is it possible to check that in the ERP system?

B

XLLLL sub-assembly Part List

	A	B	C	D	H	I	J	K	L	M	N	O
1	Change Co	Change Code Description	Design Part No	Design Par	Quantity	Net Quant	Attrition	Spare Kit	Adjust	Total Quar	Variant No	Variant Re
2	A	New Part	1000031887	R01	1		0	0		1	1000031888	R01
3	A	New Part	1000000332	R01	2		0	0		2	1000006160	R01
4	A	New Part	1000000334	R01	1		0	0		1	1000006168	R01
5	A	New Part	1000000356	R01	1		0	0		1	1000006256	R01
6	A	New Part	1000000367	R01	1		0	0		1	1000006300	R01
7	A	New Part	1000000373	R01	2		0	0		2	1000006324	R01
8	A	New Part	1000000340	R01	7		0	0		7	1000006192	R01
9	A	New Part	1000000342	R01	2		0	0		2	1000006200	R01
10	A	New Part	1000000346	R01	2		0	0		2	1000006216	R01
11	A	New Part	1000034411	R01	1		0	0		1	1000034413	R01
12	A	New Part	1000000352	R01	4		0	0		4	1000006240	R01
13	A	New Part	1000000354	R01	3		0	0		3	1000006248	R01
14	A	New Part	1000000366	R01	3		0	0		3	1000006296	R01
15	A	New Part	1000000369	R01	3		0	0		3	1000006308	R01
16	A	New Part	1000000372	R01	4		0	0		4	1000006320	R01
17	A	New Part	1000000339	R01	3		0	0		3	1000006188	R01
18	A	New Part	1000000331	R01	37		0	0		37	1000006156	R01
19	A	New Part	1000044897	R01	5		0	0		5	1000066924	R01
20	A	New Part	1000031625	R01	3		0	0		3	1000049359	R01
21	A	New Part	1000062157	R01	4		0	0		4	1000063481	R01
22	A	New Part	1000000822	R01	1		0	0		1	1000025711	R01
23	A	New Part	1000001398	R01	1		0	0		1	1000025755	R01
24	A	New Part	1000001402	R01	3		0	0		3	1000074051	R01
25	A	New Part	1000001403	R01	1		0	0		1	1000025760	R01
26	A	New Part	1000001405	R01	1		0	0		1	1000074052	R01
27	A	New Part	1000001406	R01	2		0	0		2	1000025763	R01

Figure B.1: PL for XLLLL sub-assembly

C

Purchase order lines

	A	B	D	E	F	G	H	I	K
1	Part No	Order No	Status	PO Status	Planned Delivery Date	Planned Receipt Date	Promised Delivery Date	Wanted Delivery Date	Quantity
2	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
3	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
4	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
5	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
6	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
7	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
8	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
9	1000027247-6410	55874	Closed	Received	2019-12-11	2019-12-11	2019-12-11	2019-12-11	1
10	1000053338	60060	Closed	Received	2019-12-13	2020-01-13	2019-12-13	2020-01-22	23
11	1000062189	60060	Closed	Received	2019-12-13	2020-01-13	2019-12-13	2020-01-22	24
12		60060	Confirmed	Received	2019-12-13	2019-12-13	2019-12-13	2019-12-06	1
13		60060	Confirmed	Received	2019-12-13	2019-12-13	2019-12-13	2019-12-06	1
14		60060	Confirmed	Received	2019-12-13	2019-12-13	2019-12-13	2019-12-06	1
15	1000066924	59599	Closed	Closed	2019-10-18	2019-11-18	2020-01-30	2020-01-30	104
16	1000046332	59600	Closed	Closed	2020-02-28	2020-03-30	2020-03-03	2020-03-03	109
17	1000046335	59600	Closed	Closed	2020-02-28	2020-03-30	2020-03-03	2020-03-03	69
18	1000046330	59600	Closed	Closed	2020-02-28	2020-03-30	2020-03-03	2020-03-03	69
19	1000046334	59600	Closed	Closed	2020-02-28	2020-03-30	2020-03-03	2020-03-03	29
20	1000028047	59725	Closed	Closed	2020-02-04	2020-03-04	2020-01-20	2020-01-20	100
21	1000033518-6410	55874	Closed	Received	2019-09-23	2019-09-23	2019-09-23	2019-09-23	1

Figure C.1: Purchase order lines excel file for a project extracted from the ERP system

D
Shop order requisitions excel file

100817	2515276	1000074388	1	2020-05-21	2020-06-04	Material FM	ShopOrderCreated	2	R02	1	PCS	PMRP
100817	2515277	1000074388	1	2020-05-21	2020-06-04	Material FM	ShopOrderCreated	2	R02	1	PCS	PMRP
100817	2515293	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2515294	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2515295	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2515296	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2515297	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2508925	1000074568	7	2020-05-05	2020-05-20	Material FM	ShopOrderCreated	3	R02	1	PCS	PMRP
100817	2508946	1000073791	9	2020-04-29	2020-05-20	Material FM	ShopOrderCreated	4	R01	1	PCS	PMRP
100817	2508947	1000074527	19	2020-04-15	2020-05-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2508948	1000074396	19	2020-03-23	2020-04-28	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2520364	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2520365	1000074390	1	2020-05-12	2020-06-04	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2520366	1000074390	1	2020-05-19	2020-06-11	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2520367	1000074390	1	2020-05-19	2020-06-11	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2520368	1000074390	1	2020-05-19	2020-06-11	Material FM	ShopOrderCreated	1	R01	1	PCS	PMRP
100817	2506997	1000072213	4	2020-05-13	2020-05-20	Material FM	ShopOrderCreated	6	R01	1	PCS	PMRP
100817	2506998	1000072213	4	2020-05-13	2020-05-20	Material FM	ShopOrderCreated	6	R01	1	PCS	PMRP
100817	2506999	1000072213	4	2020-05-13	2020-05-20	Material FM	ShopOrderCreated	6	R01	1	PCS	PMRP
100817	2507000	1000072213	4	2020-05-13	2020-05-20	Material FM	ShopOrderCreated	6	R01	1	PCS	PMRP
100817	2507001	1000072213	3	2020-05-20	2020-05-28	Material FM	ShopOrderCreated	6	R01	1	PCS	PMRP
100817	2507002	1000046770	4	2020-05-12	2020-05-20	Material FM	ShopOrderCreated	42	R03	33	PCS	PMRP
100817	2507003	1000046770	4	2020-05-12	2020-05-20	Material FM	ShopOrderCreated	42	R03	33	PCS	PMRP
100817	2507004	1000046770	4	2020-05-12	2020-05-20	Material FM	ShopOrderCreated	42	R03	33	PCS	PMRP
100817	2507005	1000046770	4	2020-05-12	2020-05-20	Material FM	ShopOrderCreated	42	R03	33	PCS	PMRP
100817	2507006	1000046770	3	2020-05-20	2020-05-28	Material FM	ShopOrderCreated	42	R03	33	PCS	PMRP
100817	2507007	1000053919	9	2020-05-05	2020-05-20	Material FM	ShopOrderCreated	9	R02	9	PCS	PMRP
100817	2507008	1000073604	9	2020-04-29	2020-05-20	Material FM	ShopOrderCreated	2	R01	1	PCS	PMRP

Figure D.1: List of shop order requisitions

E

RStudio Workspace

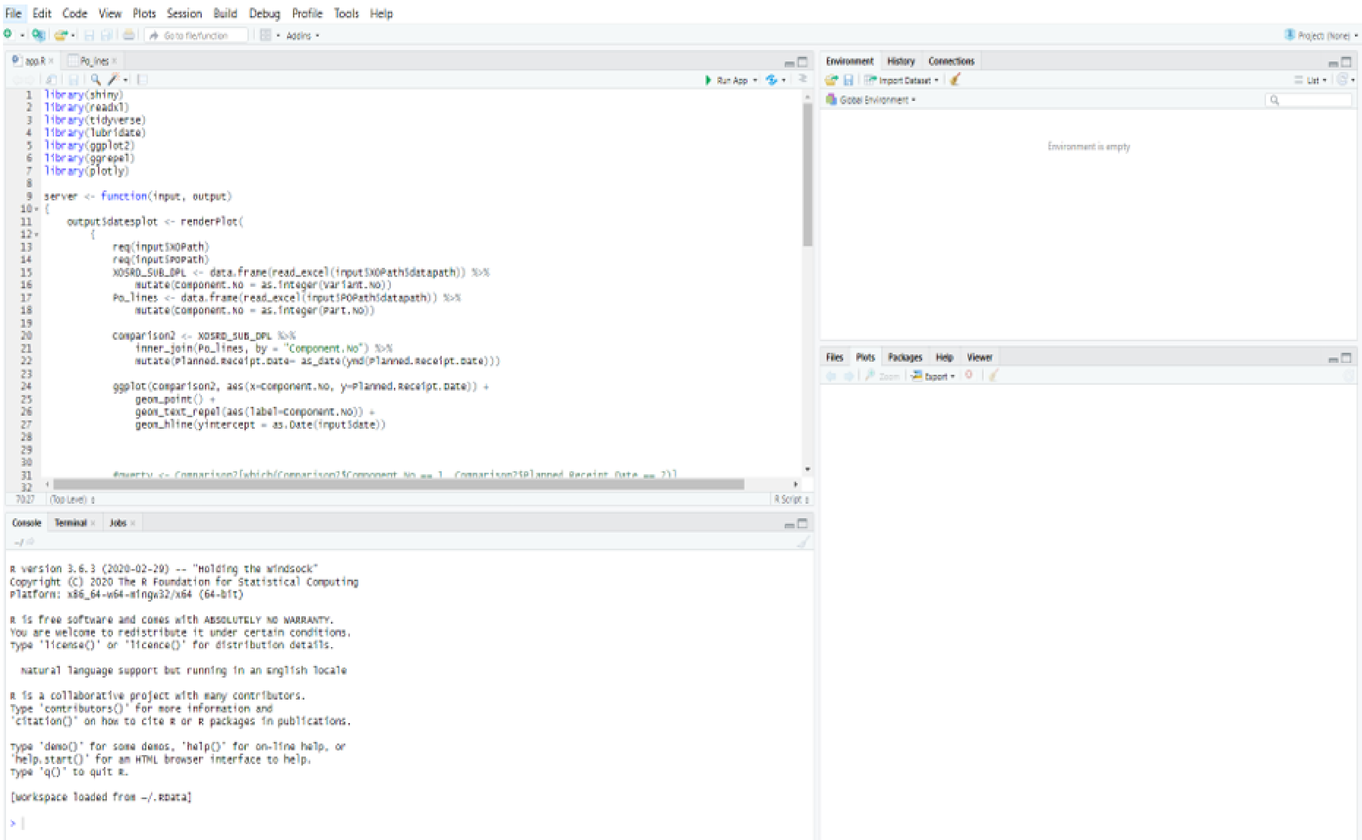

Figure E.1: RStudio workspace- Upper left hand corner is the R programming language code execution area

F
RStudio code

```
library(shiny)
library(readxl)
library(tidyverse)
library(lubridate)
library(ggplot2)
library(ggrepel)
library(plotly)

server <- function(input, output)
{
    output$datesplot <- renderPlot(
        {
            req(input$XOPath)
            req(input$POPath)
            XLLLL_PL <- data.frame(read_excel(input$XOPath$datapath)) %>%
                mutate(Component.No = as.integer(Variant.No))
            Po_lines <- data.frame(read_excel(input$POPath$datapath)) %>%
                mutate(Component.No = as.integer(Part.No))

            Comparison2 <- XLLLL_PL %>%
                inner_join(Po_lines, by = "Component.No") %>%
                mutate(Planned.Receipt.Date= as_date(ymd(Planned.Receipt.Date)))

            ggplot(Comparison2, aes(x=Component.No, y=Planned.Receipt.Date)) +
                geom_point() +
                geom_text_repel(aes(label=Component.No)) +
                geom_hline(yintercept = as.Date(input$date))

        })
    output$Table <- DT::renderDataTable(
        {
            req(input$XOPath)
            req(input$POPath)
            XLLLL_PL <- data.frame(read_excel(input$XOPath$datapath)) %>%
                mutate(Component.No = as.integer(Variant.No))
            Po_lines <- data.frame(read_excel(input$POPath$datapath)) %>%
                mutate(Component.No = as.integer(Part.No))

            Comparison2 <- XOSRD_SUB_DPL %>%
                inner_join(Po_lines, by = "Component.No") %>%
                mutate(Planned.Receipt.Date= as_date(ymd(Planned.Receipt.Date)))

            Comparison2 %>% select(Component.No, Planned.Receipt.Date) %>% filter(Planned.Receipt.Date>= input$date)
        }
    )
}

ui <- fluidPage(
    {
        sidebarLayout(
            sidebarPanel(fileInput("XOPath", label = h3("DPL Path")),
                         fileInput("POPath", label = h3("PO Path")),
                         dateInput("date", label = h3("Date input"), value = "2020-03-23")),

            mainPanel(plotOutput("datesplot"),
                      DT::dataTableOutput("Table")),
        )

    })

shinyApp(ui, server)
```