CHALMERS

MAPPING THE CURRENT STATE OF A COMPLEX PRODUCTION SYSTEM

-BY DEVELOPING AND APPLYING A VALUE STREAM FRAMEWORK

Master of Science Thesis in the Supply Chain Management Program

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Gothenburg, Sweden 2017

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Chalmers Reproservice
Gothenburg, Sweden 2017

ABSTRACT

The market of the space industry is on the threshold of a change. Cheaper components and shorter lead-times are required to satisfy the new demands from customers. These requests impose actors on the market to implement changes to their operations. To enable changes, it is fundamental to understand the current state. The purpose of this master's thesis is to determine how a value stream framework can support the current state mapping of the production system at RUAG Space AB - a satellite equipment manufacturer located in Gothenburg, Sweden.

To map the current state of a company that operates a complex manufacturing system in an Engineer-to-Order environment, a traditional Value Stream Mapping could not be performed. Additional inquiries revealed that when the product variation is very high, other methods designed to cope with complex systems could not function either. It was therefore necessary to develop a framework which could meet with this difficulty. Furthermore, since uncertainties permeate the production environment in terms of shifting customer demand and manual manufacturing operations at RUAG Space, a compromise had to be made to select products for mapping which can represent the flows at a general level. This required substantial efforts in understanding the context prior to selecting representative products for mapping.

Once products had been selected through statistical analysis as well as inquiries with key personnel in accordance with the developed value stream framework, the mapping of flows was conducted in a traditional manner. The results of those mappings provide insight in two particularly interesting aspects. It is possible to create a map of the current state of a complex production system. In the case of RUAG Space, this required selection of a representative product to be mapped. The value stream framework enabled this selection through a series of pre-defined steps.

ACKNOWLEDGEMENT

We would like to thank our supervisors from Chalmers, Daniel Nåfors and especially Maja Bärring whom always stood prepared to provide insight and valuable opinions. Your support was a tremendous help during the entire project. We would also like to thank our supervisors at RUAG Space, Ulrika Larsson and especially Camilla Malmer, whom always stepped out of her way to ensure we had what we needed. Special thanks also go to RUAG Space and their employees for their great spirit and willingness to participate in our interviews and provide facility orientation. Finally, we would like to thank Chalmers University of Technology and RUAG Space for providing us the opportunity to perform an interesting master's thesis.

Daniel Henriksen

David Olsson

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1. INTRODUCTION

In the introduction, a background to the research topic is provided along with the purpose and research questions raised in this thesis. Further, the case company is described followed by the delimitations set for the thesis.

1.1 BACKGROUND

The space industry of today is standing on the threshold of a paradigm shift. The digital divide is a current problem, not the least in the sense of internet accessibility – which is only available to approximately 42% of the entire human population (Alltid uppkopplad, 2016). This is about to change. There are currently two consortia racing to exploit this untapped market: OneWeb led by Greg Wyler, and a - currently unnamed - project led by Elon Musk (Tesla, SpaceX) with backing from Google (InsideSpace, 2016). The most problematic issue with OneWeb is that the current costs of producing and launching satellites are too steep. A radical change in production is necessary. The current, low volume manufacturing system must to the largest possible extent change and use components which are offered as stock items on the market. In essence, this means that the production must transcend into high volume (InsideSpace, 2016).

These changes within the space industry require actors to achieve shorter lead-times and lower the cost per part produced. For a company to manage this, it is vital to understand how the internal manufacturing system is working before applying any changes. A way of reaching this enlightenment is to map the current state of the internal processes. There exist various theoretical mapping tools at a company's disposal to utilize in this endeavor, one being Value Stream Mapping (VSM). The basic idea is to select a product family and draw a current state map which is then improved through utilization of various tools to reduce waste and realize a desired future state (Rother and Shook, 2004). However, the traditional model for VSM can only effectively be applied to linear manufacturing systems (Braglia et al., 2006). The method cannot, in a straightforward fashion, account for a complex manufacturing process with flows merging together. Attempts have been made at addressing this complication through VSM-inspired methods (Braglia et al., 2006; Khaswala and Irani, 2001), which also revolve around selecting and mapping a product family. However, when it comes to complex production systems, there is a shortage of research on how to select a product family. This is typical for companies operating in an Engineer to Order (ETO) environment, where the manufacturing usually is characterized by low production volumes, high product complexity and high level of process variation. Further, companies working in this setting usually experience difficulties when trying to implement Lean concepts - such as VSM - due to non-standardized products and non-repetitive processes (Thomassen et al., 2015).

The attempts at mapping complex production systems are inadequate when the targeted system has very high product variation. It is therefore necessary to further investigate this complication. For this study, a value stream framework has been developed with the purpose of, through extensive analysis prior to mapping, provide a solution to this problem. The framework will compensate for the shortcomings of current methods by enabling companies working in complex environments with very high product variation to select a product family to be representative and mapped.

1.2 PURPOSE AND RESEARCH QUESTIONS

The purpose is twofold in the sense that the thesis should first determine a framework to conduct a current state mapping in a complex production environment, and secondly the framework should be applied to map the production at RUAG Space. To fulfill the purpose, the following research questions were posed:

RQ1: How can a value stream framework support the current state mapping of a complex production system?

RQ2: How could a value stream framework aid in selecting representative products for mapping?

1.3 CASE COMPANY

RUAG Space is a key actor within the space industry aiming to become the number one independent supplier of space subsystems and components. RUAG Space is the space division of RUAG Holding AG, a Swiss technology group operating mainly within the aerospace and military industry, employing over 8000 people across several countries. The space division has approximately 1100 employees located to sites in Switzerland, Sweden, Austria, and Finland whereas the sites in Sweden and Finland are part of the subsidiary RUAG Space AB. The company has approximately 415 employees and the headquarters, including the majority of the operations, is located in Gothenburg.

The operations in Gothenburg are divided into three product units; Microwave, Antenna, and Digital Products. The production is characterized by low volumes, high product customization and components of exceedingly high quality, specifically designed to accomplish a low failure rate on component level. The majority of work performed at RUAG Space, including product development, manufacturing and procurement, is project oriented and coupled to customer specific orders. Related to the project oriented manufacturing, various equipment and several fixtures are also project specific which entails that the production system is under constant change i.e. a complex system. The manufacturing processes are largely performed in a manual fashion where different types of assembly and testing are the main constituents. It takes place in a highly-controlled environment, called "*clean rooms"*, where the number of particles per cubic meter air is controlled by advanced ventilation systems and airlocks. To simulate the extreme conditions that the products should withstand, the verification involves extensive environmental testing procedures such as temperature cycling, vibration, and vacuum verifications.

1.4 DELIMITATIONS

The mapping is isolated to RUAG Space AB Gothenburg's current production system - physical production initiation to physical storing of the completed products - and does not include the broader supply chain perspective e.g. customers, suppliers. Further, during the course of this study, VSM is a recurring term. However, a VSM both in a traditional sense as well as versions designed to cope with complex manufacturing systems all includes a phase in which a future state map is designed. This phase does not fall within the direct scope of the study. It is however indirectly influencing the analysis, as a future project (administrated by Chalmers and RUAG Space) will use it as input with the aim of improving the current production systems. Additionally, due to confidentiality no real data can be published, therefore data have been normalized (time to TU, capacity to CU and project names)

2. METHODOLOGY

This section describes the various methods that have been used to gather the data which the research rests upon. At the end, a detailed description of how the practical approach was performed is presented.

2.1 PRIMARY DATA GATHERING

There are several ways in which primary data can be collected and classified. Saunders (2009) describe three separate groups of primary data collection; observations, interviews and questionnaires, while Bryman and Bell (2011) mention the use of focus groups.

Observations involve a systematic approach of how to observe, analyze, record, describe and interpret the behavior and actions of other people. There are essentially two types of observations; participant observations which relate to qualitative gathering of actions, and structured observations which include the gathering of quantitative data such as the frequency by which activities occur (Saunders, 2009). In this study, observations of people were performed at different phases. Initially, observations were made through several guided tours of each product units' manufacturing system. This was crucial to establish a fundamental understanding and begin grasping the complex environment. Once a product had been selected and the mapping of the flow commenced, observations were made at each of the included workcenters to increase the understanding and collect qualitative data to support the quantitative data. In this way, a general understanding could be established as well as the collection of process data parameters.

An interview is a powerful tool in collecting useful and valid information to support research. Lantz (1993) define an interview as the interplay between two persons with different roles with one asking the questions and one answering. It is the communication which occur between the two that is object for analysis. There are several important demands which need to be fulfilled in relation to interviews; the method must yield reliable results (reliability demand), the results must be valid (validity demand), and it should be possible to critically examine the conclusions. Interviews can be designed differently regarding form and content. What determines the data received from an interview can be connected to its structure. Saunders (2009) mention three different types of interview structures with varying degree of flexibility during the occasion: structured-, unstructured-, and semi-structured interviews. Structured interviews are performed in a controlled environment with a list of questions which are predetermined and accompanied by responses which are limited in their options. On the opposite end are the unstructured interviews. These revolve around the researcher presenting a theme for the respondents, who are then encouraged to explore their own thoughts on the subject. The researcher does not provide leading questions in this setting. Finally, the semi-structured interview is a combination of the two previously mentioned methods. The researcher poses questions to the interviewees who are allowed flexibility and to reason around their answers. In this thesis, interviews were utilized as a primary tool for information gathering and are recurring throughout all phases of the project. Initially, a series of semi-structured interviews were performed with key personnel for each of the three product units - Antenna, Microwave and Digital, see Table 1 and Appendix A. The respondents were selected based on the criteria that they needed to be well versed in the manufacturing system for their respective units to provide the information required to create a context. The acquired data was complemented by studies of internal documents found on the company's intranet. The data gathered was used to create an initial, basic picture of the company's organization and processes.

Table 1 Interviewees, initial data gathering session

Interviewee	Product Unit	Title	Date
Niklas Hendtman	Antenna	Object Manager	6/2-2017
Mats Wahlström	Microwave	Assisting Manager	8/2-2017
Magnus Årebro	Digital	Production Engineer	8/2-2017
Ulrika Larsson	Microwave	Manager	10/2-2017
Stefan Persson	Microwave	Operator	10/2-2017
Bengt Mattsson	Digital	Manager	14/2-2017
Joakim Anjeby	RUAG Space	Operations Development Manager	14/2-2017
Lars-Göran Green	RUAG Space	Project Manager	27/2-2017

The third method to collect data mentioned by Saunders (2009), is sampling and questionnaires. It consists of a series of questions that the receivers should answer and return to the researchers. The main advantage of this method is that the researchers can collect opinions and perceptions from several, or large, groups of people in a standardized way. This will enable comparisons to be utilized as a foundation for analysis. For this study, the sampling of perceptions and opinions were not considered crucial and are therefore not included as a method for data collection.

According to Bryman and Bell (2011), another way of gathering qualitative data is through focus groups. Unlike traditional interviews which transpire between an interviewee and interviewer, a focus group is another method of interviewing which involve more than one respondent. The method is usually conducted in qualitative research, and the environment is fairly unstructured allowing for the participants to provide individual views and perceptions. It is also possible to voice issues to a topic which participants find important. The number of individuals that should participate in a focus group is a contested subject, and has ranged from as low as three up to ten. However, in a group of ten it becomes difficult to manage the discussion. Furthermore, the moderator should only pose general questions to guide the focus group session. The participants should be selected according to interest in the topic, and can represent a specific occupational or organizational role (Bryman and Bell, 2011). In this study, focus groups were used to make decisions that required a high level of company-specific knowledge. The focus groups were formed to include key personnel from each product unit. The focus groups were tasked, through an unstructured interview format, to discuss what product best represent the general flow for that particular product unit. To create an appropriate format for the topic, a presentation of the progress and ultimate goals was held for each focus group to make the participants aware of the session’s intentions.

2.2 SECONDARY DATA GATHERING

According to Saunders (2009), secondary data includes data that were initially collected for some other purpose. This includes data collected by organizations to support and measure their performance, governmental statistics, or journal publications. Further, it includes both qualitative and quantitative data which could consist of raw unprocessed data or compiled data that has been previously analyzed to some extent. Three main sub-groups of secondary data are described by Saunders (2009), see Table 2.

Table 2 Three groups of secondary data (Saunders, 2009)

Type of data	Definition
Documentary secondary data	Include internal company documentation such as correspondence, minutes of meeting, shareholder information, organizational charts etc. It could also include external and public material such as video recordings or media publications. As for the overall secondary data, it can be used to extract quantitative or qualitative data, but also to triangulate findings based on primary data.
Survey based secondary data	Data that have been collected using some sort of survey based strategy, such as a questionnaire. The data have afterward been compiled, or in any other way analyzed, based on the initial purpose of the survey. The category includes data aggregated to a macro level such as governmental investigations and indexes, academic findings, and data extracted from organizational databases.
Multiple source secondary data	Data where one or several sets of sources of data have been combined. It can either be based solely on documentary data, survey data, or a hybrid of both. By combining several sources of data, it is possible to extend the data gathering to cover longer periods of time and thus increase the quality of the research.

In this study, secondary data were gathered in profound quantities as it was crucial to statistically analyze manufactured products. This was performed to determine which products should be selected for thorough analysis. Thus, quantitative data for each of RUAG Space's projects between the year 2013-2017 in the past were gathered through the company's internal Enterprise Resource Planning (ERP) system. The data which were extracted from the ERP system were imported into an Excel-sheet where each row represent an individual manufacturing order (MO), providing information of particular interest e.g item number, project and start and finish date.

In conjunction to the mentioned data gathering methods, a literature study was performed in a continuous manner. This was necessary to examine relevant field theory and gain inspiration to the development of the framework. In this thesis, this was mainly achieved through analyzing traditional mapping approaches as well as earlier attempts at mapping similar, complex environments. Chalmers Summon Database and previous course literature were used to retrieve theoretical information. Most commonly used information came from articles and was complemented by books. Particular keywords include "VSM, Complex Manufacturing, Data Classification, Current State Mapping". Much like the existing theories which try to incorporate the VSM methodology to a complex system, it was deemed necessary to emphasize the actions performed prior to the current state mapping.

2.3 HOW THE STUDY WAS PERFORMED

This section describes how the master's thesis has been performed to answer both research questions so that the trustworthiness in the achieved results may be judged. The first part consists of a brief description, and is followed by separate sub-parts to explain the complexity in detail.

The research project was organized into seven project steps, displayed in Figure 1. This overview serves to display the components of each phase performed throughout the study.

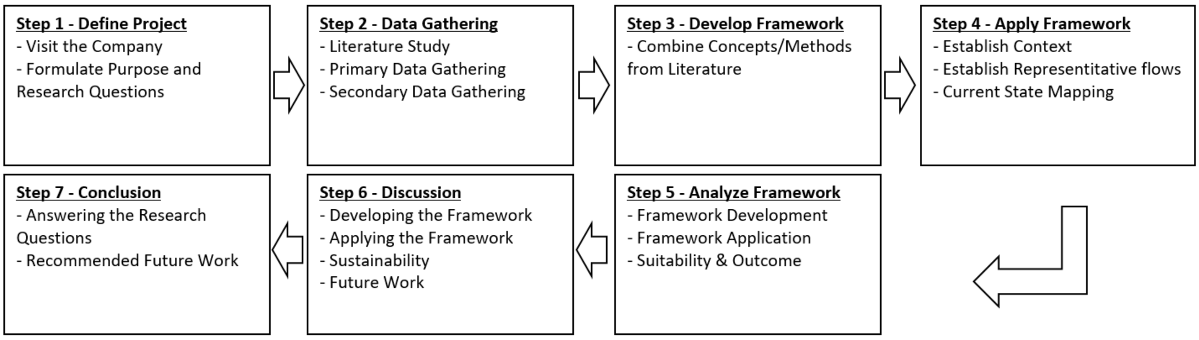

Figure 1 Project overview

2.3.1 Step 1 - Define Project

The first step was performed, through conversations with the company and other stakeholders, to establish the frames for the thesis. This included defining the scope of the project, initial research questions, delimitations.

2.3.2 Step 2 - Data gathering

Initially, a literature study combined with semi-structured interviews were performed to determine what options exist in terms of performing a mapping of a production system in an industry. Several mapping techniques were analyzed, both aimed at linear production systems and dynamic, complex systems. Following this was an exploration of how a framework could be developed and applied to describe the context of RUAG Space.

2.3.3 Step 3 - Develop Framework

After the initial data gathering, an appropriate framework had to be developed to meet the challenges of a company working with a complex production system of very variation. As the qualitative data revealed, RUAG Space has an ETO production system characterized by variation where no manufacturing order is exactly like the other. Performing a mapping in such environment would require the mapping of every single flow as no product is the same.

The framework was developed by gaining inspiration and combining elements from several methods published in academic journals and articles. This was complemented with additional aspects deemed necessary to handle the complexity.

2.3.4 Step 4 - Apply the framework

The framework was applied to the production system at RUAG Space in a sequence of three phases.

Establish Context (Framework Step 1)

The first step in establishing the context was to generate a basic visualization of the production to further increase the context and understanding. This entailed performing a process mapping to provide a visualization of the production system and the overall processes involved. The maps act as visual representations of the gathered empirical data. The purpose of it is to act as both inspiration and aid in deciding appropriate, increasingly detailed, analysis for each separate product unit. The map was generated through a combination of qualitative interview data as well as observations performed in the physical manufacturing area.

Establish Representative Flows (Framework Step 2)

Analyzing each product or product family was deemed unsustainable. The reason for this is that each product in an ETO-environment has its own routing created specifically for that product, which differs according to customer specifications, thus creating variations. There is no static process by which manufacturing occur, and it was decided that the most prominent products would be selected to represent the general production for each product unit. This would likely provide the most accurate picture while at the same time provide a viable representation of the flow.

The data, consisting of products, projects, volumes, routings and Bill of Materials (BOM) collected from the ERP-system were compiled and analyzed. This made it possible to differentiate products existing within each product unit, their volumetric distribution and finally their manufacturing sequences.

The reason why the most statistically significant product (with regard to highest volume) was not immediately selected for mapping is due to the expected changes in market demands. Thus, the focus group discussions held with each product unit were covered with regard to two aspects. The first aspect was future customer needs. As the demand is expected to change, and with it the internal production system, it was necessary to understand if certain products would be removed from the portfolio as a consequence of those predictions. This would render eventual products unfit for mapping. The second aspect was that, since a single MO refer to a product which can be either a complete product or a sub-assembly, the decision also had to be made in accordance to one of the following two criteria, see Table 3.

Table 3 Criteria for selection

Criteria	Definition
Product type	Individually select the most representative product type
Parent unit	Select the most representative Top Assy and, as it is the parent unit, obtain the attached sub-assemblies at the same time.

Current state mapping (Framework Step 3)

Before initiating the current state mapping, it had to be decided which particular process data would be collected during the mapping. This was not obvious as the framework would stop at the current state mapping and not continue to explore a possible future state, which would have required a different approach and mentality when conducting the current state mapping with regard to detecting waste. In light of this, theory mention multiple data parameters which are commonly sought in a flow set to be subjected to a VSM process. However, as the understanding of the company and its manufacturing system was increased, some of those parameters were regarded as irrelevant in the context. Instead, a modified questionnaire was developed to capture what was deemed relevant parameters for the outcome.

In the next step, a detailed analysis of the product hierarchy was executed to determine exactly what the structure following the parent product looked like and thus discern what should be mapped. This analysis provided exact information regarding what routings should be extracted from the ERP system and help navigate the mapping process. Once the hierarchy and relevant routings had been determined, data were collected using the questionnaire as a platform for semi-structured interviews and observations. A visualization of the product system was created using the Visio software.

2.3.5 Step 5 - Analyze Framework

To determine whether or not there is a framework that can support the current state mapping, the analysis examines the framework development. The different constituents of the developed framework are compared to existing methods and analyzed. Furthermore, the analysis investigates the practical application of the framework at RUAG Space. This is followed by an investigation of the results in terms of how it managed to capture the process data and describe the current state of the production system.

2.3.6 Step 6 - Discussion

Developing, applying and analyzing a new framework require an objective verdict. In the discussion, the framework and its outcomes are scrutinized from an objective perspective, as well as the method used during its application.

2.3.7 Step 7 - Conclusion and future work

The final step of the thesis provides conclusive answers to the posed research questions. This was achieved by extracting and summarizing the vital parts from the analysis chapter.

2.4 QUALITATIVE AND QUANTITATIVE DATA

Eriksson and Wiedersheim-Paul (2014) state that there are various forms of empirical data which are classified and analyzed differently. These various forms of empirical data ranges from analyzing primary- or secondary data, different methods, direct sources to direct or indirect observations. Primarily, the empirical data is classified into two main categories: qualitative and quantitative data.

Hennink et al. (2011) explain that qualitative research is a broad term which includes multiple techniques and philosophies. In essence, it revolves around examining the experience of people in detail by using methods such as observation, interviews, visual methods or content analysis. Qualitative research is conducted by studying things in their natural environment to interpret a certain phenomenon. It is a powerful research method to utilize to gain understanding of complex issues or investigate new topics. It is appropriate to aim the effort at answering the question "why" or "how" to understand an issue or process. Saunders (2009) stress the importance of categorizing collected data. When the research has provided a large pool of data it is often necessary to condense it for it to become meaningful. The process of categorizing is divided in two activities - to develop categories and to attach relevant data to each category. Performing this activity will generate an understanding of relationships which may be facilitated by developing subsequent categories. The aim is to create categories leading to a structure that is relevant to the research.
Quantitative data differ from qualitative in the sense that it focuses on utilizing methods to investigate a phenomenon using numerical or statistical data. A presumption is that the subject of study can be measured. In essence, the process of quantitative data research boils down to: performing measurements, apply analysis and draw conclusions (Watson, 2015). In this study, quantitative data were mainly used during the mapping process and during the processing of

data from the ERP system. Qualitative data were used during the analysis and interpretation of data which were gathered during interviews and performed observations.

2.5 RESEARCH ETHICS AND TRUSTWORTHINESS

There are three important, ethical considerations connected to qualitative research. These are: informed consent, anonymity and confidentiality, and risk. Informed consent dictate that the researcher is obliged to inform the respondent about what it means to participate in the research project and if the person wants to partake or not. This includes making the respondent aware of things such as: why is the research taking place, who funds it, what does their part in the research mean, what will happen to the results, and how issues such as anonymity and confidentiality will be managed. Anonymity and confidentiality in turn relate to the respondent being informed about how the data will be reported, what will happen to the data, and if it is possible that the respondent may be identified from the data; and what the consequences of this could entail. Finally, risk is linked to any research which is deemed sensitive and might pose a threat for the respondent to participate in. This is especially true if the topic involves personal or taboo issues (Wiles, 2013). In this study, during the qualitative data gathering sessions which involved communicating with respondents, a briefing of the purpose of the project being performed was held to meet the three ethical considerations. Respondents could then determine whether they wanted to participate. Furthermore, every person directly mentioned in the report first gave consent.

Brin (1993) state that both reliability and validity are key aspects of any research. The two elements exist to provide other researchers with the possibility to assure the credibility and trustworthiness of the research. The importance of these aspects is especially profound in a qualitative research setting, as the researcher investigate systems and processes from the perspective of people who are subject for the research. That makes the research more subjective than quantitative research and does not involve empirical calculations. Bryman and Bell (2011) state that reliability is concerned with whether it is possible to repeat the results of the study. Validity aims at covering the integrity of the conclusions which are drawn from a research. Denscombe (2014) state that validity can be strengthened by applying triangulation. O’Gorman and MacIntosh (2015) explain that by using information from multiple sources, triangulation is achieved and researchers can enhance and further validate the essence of the research. In this study, reliability is fulfilled since information and methodology regarding how the study was performed is described and documented throughout the thesis report. Data gathering has been performed by different means; interviews, observations, focus groups, internal company data and literature survey to meet the conditions for triangulation.

3. THEORETICAL FRAMEWORK

This section outlines the theoretical foundation that is used as a guide throughout the research process. It includes concepts and methods used to support the development of the framework.

3.1 CUSTOMER ORDER DECOUPLING POINT

There are multiple ways of which enterprises and their base of operations can be classified. From an operations planning and control perspective two similar aspects are suggested by Mattsson and Jonsson (2003) to perform the classification. First, the degree of integration between the product functionalities and specifications in relation to what is specified by customer orders. Second, to what extent the operations planning and control are dependent on the incoming customer orders. These aspects could be further specified by determining the location of the customer order decoupling point (CODP). The CODP defines where, in relation to time or location in the material structure, the product receives its customer specific characteristics. Mattsson and Jonsson (2003) and Olhager (2000) describe four main categories, see Table 4.

Table 4 The classification of different production systems (Mattsson and Jonsson, 2003; Olhager, 2000)

Category	Definition
Make-To-Stock (MTS)	The CODP is located at the finished goods storage or in a distribution center. Thus, the planning has been based on forecasts on the finished products and all production related activities have occurred before the customer order is received.
Assembly-To-Order (ATO)	The CODP is located at a module level which implies that most module manufacturing and procurement activities have been performed independently in relation to the actual customer order. Final assembly of modules and/or final customer specific activities is performed as the customer orders are received.
Make-To-Order (MTO)	The CODP is located before production has been initiated. Generally all engineering activities, procurement and manufacturing preparations have been performed, and await the customer order to initiate manufacturing.
Engineer-To-Order (ETO)	This category implies that the product, to a large extent, is shaped according to what the customer desire. Engineering, design, manufacturing and procurement are controlled, both from a time and content perspective, completely by the customer order. Thus, the CODP is located at an early design development stage.

According to Olhager (2003), placing the CODP far upstream in the planning process, such as in an ETO setting, implies a situation where flexibility, design and short lead times are typical order winners. A general illustration of the ETO process is provided by Zhou et al., (2016), see Figure 2. Here, the CODP is located before the design, procurement and initial production planning has occurred.

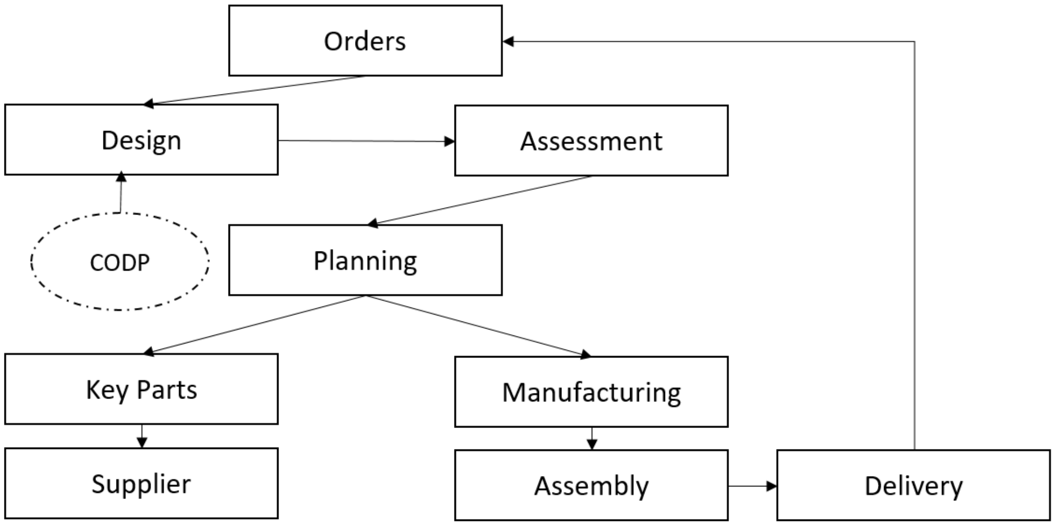

Figure 2 Illustration of an ETO system (Mattsson and Jonsson, 2003)

Mattsson and Jonsson (2003), suggest that these categories are characterized by certain measures related to factors such as time to customer, production volumes and product variation, see Table 5.

Table 5 Differences in factors between the four categories (Mattsson and Jonsson, 2003)

Factor	**ETO**	**MTO**	**ATO**	**MTS**
Time to Customer	Long	Average	Short	Very Short
Production Volumes	Small	Small	Average	Large
Product Variation	Very High	High	High	Low

3.2 CURRENT STATE MAPPING METHODS

There are several methods and techniques which can be used to create a map that visualizes the current state. This part presents classical methods as well as other methods used in complex manufacturing environments where the classic methods are not adequate.

3.2.1 Process Mapping

According to Olhager (2000), Process Activity Mapping is a method used to increase understanding and reveal potential improvement areas by describing a process in a compact, detailed, and graphical fashion. Kalman (2002) describe it as an analytical method used to visually describe how work-activities relate to each other in terms of cross-functional relationships between organizational units. Generally, the level of detail and information differ due to the specific purpose of the analysis. Further, the extent of the analysis can vary from covering a whole production system, a production process, or a detailed map of selected activities (Olhager, 2000).

The method includes five fundamental steps, see Table 6 (Olhager, 2000).

Table 6 The five steps of Process Mapping (Olhager, 2000)

Step	Definition
1	Identification and structuring of process activities
2	Documentation of the process
3	Analysis and identification of potential improvements
4	Recommendation of suitable process changes
5	Implementation of agreed changes

While mapping, each process and activity are examined by quantitative and qualitative data to pose questions related to what, how, why, where, who, and when an activity is performed (Hines and Rich, 1997). To visualize different types of activities certain symbols are used, each one representing a specific category. Olhager (2000) describes the five basic categories, see Table 7.

Table 7 The five basic categories (Olhager, 2000)

Category	Description
Operation	Includes activities that deliberately changes the physical characteristics of a product, such as assembly or machining. It also includes administrative activities such as planning or transmitting data.
Transportation	Comprises all activities that move or reallocate the product from one location to another, while not changing its physical characteristics.
Inspection	An activity that verifies the result or outcome of another activity. It contains activities such as determining the correct components or quantity attached to a product, measurement of mechanical characteristics, or in any way determining the quality of the product relative external or internal standards and requirements.
Storage	Storage implies that a component or product is waiting for an operation, inspection, or transportation to be performed. Often it requires some initiation, physical or administrative, to occur before it can be reallocated to the next activity.
Handling	Handling (or delay) can be described as short transportations or movement within or between activities. These could for example occur within a specific operation as the operator moves the product from one equipment or machine to another. It could also occur between activities such as the physical handling between an operation and transportation.

To practically visualize and describe the process, using the methodology described above, Olhager (2000) suggest two techniques; process flow chart and layout flow diagram. Further, Damelio (2010), presents a similar technique using basic flowcharts. These techniques are briefly described and exemplified below.

3.2.2 Process Flow Chart

Olhager (2000) presents a technique where all activities, including transportation and time measures etc., are documented in a matrix-like scheme. The scheme is then used to summarize the various activities, operating times, distances and provides a distinction between value adding (V), non-value adding (N) and unknown value adding (U) effects. The technique provides the user with a detailed picture of the current process including quantitative data to be further analyzed. An example is presented below, see Figure 3.

Process Flow Chart		Object: Circuit Board						
Process: Existing [x] Proposed [ ]								
Step. No	Description	Assembly	Transportation	Inspection	Storage	Time (h)	Distance (m)	Value Code (V/N/U)
1	Activity 1				X			I
2	Activity 2		X				60	I
3	Activity 3	X				6		V
4	Activity 4		X				70	I
5	Activity 5			X		2		U
6	Activity 6				X			I
7	Activity 7		X				50	I
8	Activity 8	X				4		V
9	Activity 9				X			I
	Sum:	2	3	1	3	12	180	-

Figure 3 Illustration of a Process Flow Chart (Olhager, 2000)

3.2.3 Flow Chart

Damelio (2010) argues that the reason for mapping a process is to add knowledge regarding the flow or system that the map represents so that, eventually, the knowledge can be used to achieve a specific goal or intention, see Figure 4.

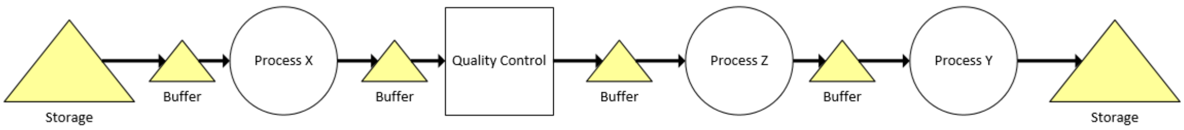

Figure 4 Visualization of a process map using a Flow Chart (Damelio, 2010)

Seven steps are suggested for creating a flowchart, either by working manually or using computer-based software, see Table 8.

Table 8 Seven steps for creating a Flow Chart (Damelio, 2010)

Step	Definition
1	Define the boundaries of the process.
2	Arrange the flow of work from left to right, or from top to bottom.
3	Make use of all suitable symbols in order to build intelligence into the flow chart.
4	All symbols should be approximately the same distance from each other.
5	Avoid confusion by not crossing lines.
6	Label all branches of the decision symbols.

7	Identify the output of each process.

3.3 VALUE STREAM MAPPING

The pressure on industries to reduce lead time to market is increasing in most sectors. The concept of Lean and its various tools has become almost synonymous in this endeavor, as it strives towards maximizing value by minimizing waste (Locher, 2008;2011). Rother and Shook (2004) state that a value stream considers every activity (value- as well as non-value adding) which are required to bring a product from raw material to the end customer. Each of these production flows is in turn consisting of two overlapping flows which control information and material associated with a particular stream. VSM is a method designed to map these two flows to visualize and communicate the current state of production. The purpose is to detect waste and, by finding solutions to remove the waste from the value stream, develop a future state map. Furthermore, it is important to note that mapping an entire production is usually too complex to accomplish – unless it is a small, simple facility – which is why the mapping should be focused to encompass one product family for each VSM.

3.3.1 Waste

Waste, or Muda, is a core concept within VSM and consist of two main categories. The first category contains "necessary waste" and refers to non-value adding activities which include training, testing and other essential activities. Even though it would be beneficial to eliminate these activities, it might not be possible. The second category refers to seven (or eight) different types of directly non-value adding activities, see Table 9, and should be deliberately eliminated (Eaton, 2013).

Table 9 The eight wastes (Eaton, 2013; Liker and Meier 2006)

Waste	Description
Overproduction	Items are produced in greater quantities – or earlier – than the customer requires.
Waiting	Workers not able to work because of equipment downtime, bottlenecks etc.
Defects	Producing products with defects.
Motion	Any motion performed by workers that are not value-adding such as looking for, reaching for, tools etc.
Transport	Movement of work in progress (WIP) within or between processes.
Over-processing	Taking unnecessary steps to process parts, thus providing higher quality products than required by the customer
Inventory	Longer lead times, obsolescence, storage costs etc. as a consequence of excess WIP or finished goods.
Talent	Not taking advantage of employee creativity, ideas, skills etc.

3.3.2 VSM – Current State

Liker and Meier (2006;2005) state that prior to mapping the current state, it is important to define what the current situation is, identify the goal, and recognize the difference between what the future process should be and what it currently is. This is necessary to provide an understanding of what obstacles are in the way of achieving the future state. Rother and Shook (2004) suggest that the mapping of a current state should be initiated by first selecting a product family to map. It is appropriate to select by using a product family matrix, see Table 10. A product family refers to a set of products which all pass through similar steps in the manufacturing process. The matrix displays what steps and equipment are required in relation to different products.

Table 10 Example of a product family matrix (Rother and Shook, 2004)

Product / Assembly Step	1	2	3
A	X	X	X
B		X	X
C	X		

Charron (2015;2014;) states that the current state map should be developed by reviewing every single activity which is relevant to the flow. The map should provide a fairly accurate description of the organization's current state of business towards fulfilling customer demands. Simultaneously, the map should aid in detecting any of the eight wastes previously described. When defining the current state, Rother and Shook (2004) suggest different icons to be used as an illustration of various functions within the flow, see Figure 5.

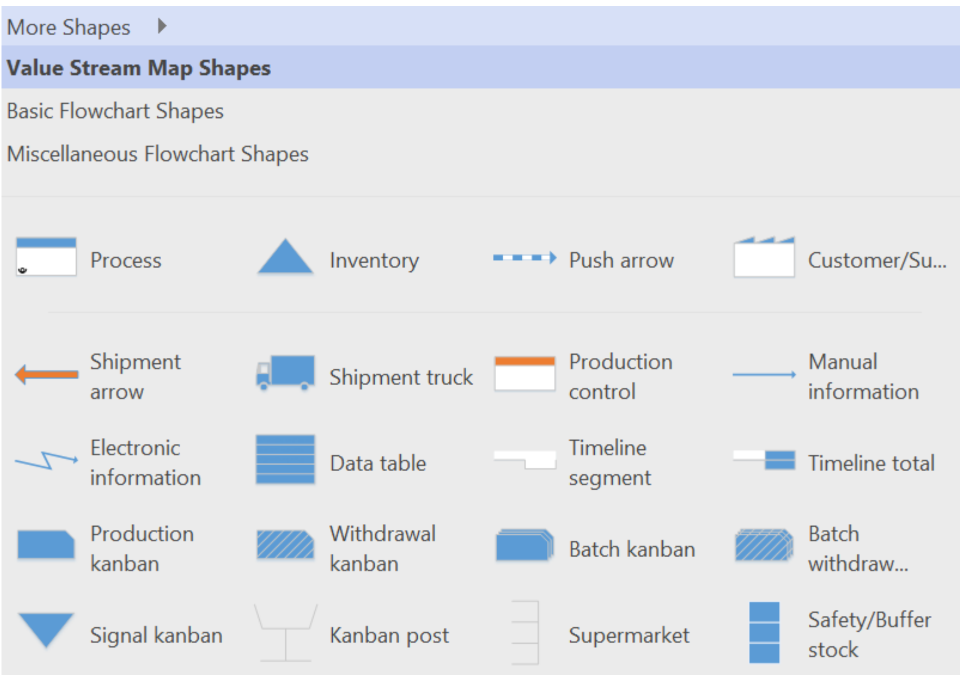

Figure 5 VSM icons used for visualization, extract from the Microsoft Visio Software

These should when necessary be accompanied by process boxes displaying data, see Table 11, which are relevant for the analysis.

Table 11 Process data (Rother and Shook, 2004; Womack and Jones, 2003)

Process data	Definition
Scrap rate	Percentage of material which after a process require rework, or scrapping.
Cycle time (C/T)	Time that elapses between one part coming of the process to the next part coming off.
Operators	Number of operators working in a process.
Product variations	Number of variations of a product.
Pack size	Number of pieces.
Change over time (C/O)	Time required to change production device to perform a different operation.
Production batch sizes	Batch of products within a certain time frame.
Working time (minus breaks)	Available working time where time for breaks, meetings etc. has been removed.
Uptime (on-demand machine uptime)	Probability that a certain asset is available at a specific timeframe for the appropriate functionality.

All personnel involved in the mapping process shall be made aware of what each symbol imply to generate understanding. The mapping should be initiated at the end of the flow and move towards earlier processes in the flow. The reason is because the mapping should be initiated as close to the customer demand as possible (Rother and Shook, 2004). Once an initial map has been generated, relevant data can be collected for the various processes. As the current state map is detailed and finished, the opportunity to identify waste in the various processes is possible. In conjunction, Bicheno et al. (2011) raises concerns regarding shared resources and variation when performing a current state analysis. It is faulty to perform a VSM and consider shared resources as dedicated. Therefore, it is important to pinpoint where these points exist within a flow and measure them correctly by considering all products passing by, including the ones belonging to other flows than the one being focused on the analysis.

3.3.3 VSM – Future State

Once the current state map is finished, it is time to use it as a platform upon which a future state map is constructed. Rother and Shook (2004) declare that in order to be effective in this endeavor, eight questions must be answered, see Table 12.

Table 12 The eight VSM questions (Rother and Shook, 2004)

Question	Definition
1.	What is the takt time, based on the available working time of your downstream processes that are closer to the customer?
2.	Will you build to a finished goods supermarket from which the customer pulls, or directly to shipping?
3.	Where can you use continuous flow processing?
4.	Where will you need to use supermarket pull systems in order to control the production of upstream processes?
5.	At what single point in the production chain will you schedule production?
6.	How will you level the production mix at the pacemaker process?
7.	What increment of work will you consistently release and take away at the pacemaker process?
8.	What process improvements will be necessary for the value streams to flow as your future-state design specifies?

These questions serve as a basis to detect improvements in the current flow. Kaizen bursts with correct descriptions are appropriate to attach to the map to indicate improvement potential. Bicheno et al. (2011) explain that the current state analysis also serves as a tool which is used to spawn ideas, with the aim of improving the value flow.

3.4 MODIFIED VALUE STREAM MAPPING

As can be understood from the VSM methodology described in the previous subchapter, and in accordance to Braglia et al. (2006), VSM aims at enhancing the flows of linear manufacturing systems. This part explores different approaches aimed at mapping dynamic manufacturing systems.

3.4.1 Value Network Mapping

Value Network Mapping (VNM) is a methodology originally developed to limit the restrictions imposed on the traditional VSM methodology in manufacturing environments characterized by complex material flows and multiple value streams that merge (Khaswala and Irani, 2001). Using the VSM methodology as a baseline, several steps are proposed to be carried out prior to establishing the current state map, see Table 13.

Table 13 Steps prior to current state mapping (Khaswala and Irani, 2001).

Step	Definition
Form a product family	To form product families, the VNM methodology utilizes a combination of tools and methods. These include; Product-Process Matrix and Product-Component Matrix
Visualize the flow	The flow is visualized using two techniques, which both utilize the Bill of Material (BOM) and Routings of all involved products. First, the flow is visualized in a Multi Process Products Chart (MPPC) where each component and sub-assembly in a specific product is represented on the horizontal axis, and each operation is represented by the vertical axis. Second, the routing for each component and sub-assembly is visualized in relation to the physical location of each operation, similar to a spaghetti diagram.
Collect data for the process boxes	Utilize a specific tool called enhanced Flow Process Chart (eFPC) which is a combination of a Process Chart that also attaches the material handling and scheduling-related information to the material flow from the Flow diagram.
Merge similar routings	The Multi Product Process Chart identify similar routings which could then be merged or aggregated in order to organize the Value Stream map.
Group Similar Routings into Component Families	Components are grouped together by similarities in routing by using dendrograms.
Draw the current state map	The current state map includes visualizations of two different levels. The first level provides the flow and information of the final product or, if possible, a family of products. This level includes the Multi Product Process Chart and the enhanced Process Chart. The second level focuses on the flow of components and sub-assemblies by using the same techniques, namely Multi Product Process Chart and enhanced Process Chart.

According to Thomassen et al., (2015), the major focus of the VNM methodology is to establish a current state map. Adding to this, Matt (2014) suggest that although the VNM methodology enables the mapping of complex networks of material flow and value streams it provides no specific recommendations regarding improvements or development of the future state map.

3.4.2 Improved Value Stream Mapping

As manufacturing processes intensify in complexity with merging flows of products and information, the traditional VSM methodology becomes increasingly difficult to apply as a straightforward approach. To confront these challenges Braglia et al., (2006) have developed a new methodology; Improved Value Stream Mapping (IVSM) consisting of seven steps, see Table 14.

Table 14 The seven steps of IVSM (Braglia et al., 2006)

Step	Definition
1. Select a product family	The selection is made by analyzing volumes and revenues for each product family. The underlying logic is that high-volume/high-value products are most likely to contain the most profound potential for boosting the overall performance of the production system.
2. Identify machine sharing	Equipment or machines which are shared by several product families are possible constraints for creating flows. Detecting this is achieved by analyzing the routing and use of equipment for each product.
3. Identify the main value stream	As the production system is often characterized by multiple flows that merge, the mapping process should only target the main (critical) value stream. Since it is an iterative method, the main (critical) value stream will change as the process progresses.
4. Map the critical path	This step is done similarly to developing the current state mapping according to the traditional VSM methodology. The data collection should begin at shipping while working backward to the source of the raw material or incoming goods. Since the map only relates to the critical value stream, increased emphasis must be put on the shared resources and other merging points.
5. Identify and analyze wastes	This step follows the same logic as the traditional VSM methodology. However, more emphasis is put on determining whether the waste is linked to the whole critical value stream or concentrated to the shared resources and merging points.
6. Map the future state for the critical/sub-critical path	Map the future state by answering the eight future state questions according to the traditional VSM methodology.
7. Identify the new critical path and iterate the process	Iterate the process by identifying the new critical path.

The methodology integrates the traditional VSM methodology with several other tools typically used in industrial engineering scenarios. The fundamental idea is to establish a current state map to identify a critical path. After improvements related to the critical path are made, the process is iterated, until a certain state of operations is reached (Braglia et al., 2006).

3.5 DATA CLASSIFICATION

Skoogh and Johansson (2008) state that simulations are heavily dependent on the input data quality, which in turn is considered the main disadvantage of the method in the sense that it requires extensive amounts of time to gather. For this reason, data are usually divided into three different categories, see Table 15, and require significantly different approaches while being collected.

Table 15 Data classification categories (Robinson and Bhatia 1995)

Category	Availability
A	Available
B	Not available but collectable
C	Not available and not collectable

Furthermore, Skoogh and Johansson (2008), it is important to understand how a company measures and define parameters to gather appropriate data without confusion. Typical category A data may be found within a company's systems such as order handling systems, material planning systems (MPS) or enterprise resource planning (ERP) systems. Category B and C data require manual gathering - or estimation. Using a stopwatch is a common way of collecting such data; by walking along a process and measuring relevant parameters. Estimations are required when a system does not currently exist meaning there are no available data. Furthermore, interviews or historical data from processes similar to the one being analyzed may serve as a platform for estimations.

4. FRAMEWORK DEVELOPMENT

This section explains the development of the framework used in this master thesis by motivating why certain aspects of certain theories are included.

There exist multiple different mapping methods with VSM and Process Mapping being two continuously occurring in academia. The initial research revealed that VSM is aimed at being applied in production systems which function in a linear fashion; that is for constant, non-complex production flows for a particular product family (Braglia et al., 2006). Companies in an ETO segment however, operates in a dynamic environment where the production system is characterized by several intertwining production flows where the components of the product families undergo changes as per customer requests (Mattsson and Jonsson, 2003; Olhager, 2000). Therefore, it is necessary to establish a proper context. This necessity is the first step of the framework, see Figure 6.

The Framework		

Step 1 - Establish Context
- Data Gathering
- Process Mapping
	Step 2 - Establish Representitative Flows
	- Collect ERP-Data
	- Analyze ERP-Data
	    - Volume Analysis
	    - P-P Matrices
	-Focus Groups
		Step 3 - Current State Mapping
		- Mapping Approach
		- Analyze Product Hierarchy
		- Establish Current State Map

Figure 6 Illustration of the framework

To understand what type of manufacturing context is being mapped, initial data gathering must be performed. This includes semi-structured interviews with key stakeholders and managers. Further, to properly visualize the gathered data from the interviews, Process Mapping is a suitable method as it increases the understanding (Olhager, 2000). This is appropriately converted to a Visio flowchart to generate a platform and aid in a further, increasingly detailed investigation.

Research shows that there have been attempts at mapping ETO systems with VSM methodology - IVSM and VNM (Khaswala and Irani, 2001; Braglia et al., 2006). As the theory related to VSM and different attempts at applying it in non-linear systems suggests, it is necessary to adjust the method when applying it to an ETO system to map a current state. As is common in ETO segments, product variation at companies has proved to be very high (Mattsson and Jonsson, 2003). Therefore, before a current state mapping process is initiated, it is crucial to determine what product flow should be mapped. This realization motivates the second step of the framework - to establish representative flows. The primary objective of this step is to find a product family to be mapped. However, since it is a complex system, Khaswala and Irani (2001) and Braglia et al. (2006) suggest that necessary steps should be taken prior to establishing a current state map. In accordance to this, the second step of the framework refers to quantitative data extraction from the ERP system for analysis and visualization. Since the data are extensive, analysis and visualization require a high degree of structure which is achieved through Pareto diagrams and Product-Process Matrices (P-P matrices). Additionally, since the product variation is high due to uncertain customer requirements, future aspects have to be considered as well. Therefore, focus group sessions are included in the framework to enhance understanding and aid the selection of products in an ETO-environment.

The final step provides guidelines for the actual current state mapping. The mapping approach itself reflects the method as described by Rother and Shook (2004) and Womack and Jones (2003), in terms of establishment of the current state map and what process data should be collected. However, as proposed by Khaswala and Irani (2001), the current state mapping could be based on two levels (product and component) which is why an analysis of the product hierarchy is included in the framework.

On an aggregated level, the framework does not fully abide traditional VSM methodology or Process Mapping, nor the two methods for complex manufacturing environments - VNM or IVSM. Instead it contains input from several methods along with additional elements proposed by the authors. These encompass tools for analysis such as the pareto-diagram and P-P matrix, qualitative data gathering through focus group sessions, process mapping for visualization, and traditional mapping of the flow. The framework is tailored to fit a complex production system in an ETO environment, with the purpose of finding a representative flow for the products found within the different product units to display the material and informational flows in the current state of operations. The methods found in the literature provided inspiration to the framework used.

5. APPLYING THE FRAMEWORK

This chapter is divided into four sections. The first section provides an introduction to each of the three product units to help provide context to increase the understanding. The second section presents how raw data was processed, and what the results were. The third section details how the results were used to create a current state analysis. The final section provides a summary of the current state maps along with the data gathered.

5.1 ESTABLISH EMPIRICAL CONTEXT

This section presents the results provided from the initial data gathering and process mapping session in the investigation launched to establish an empirical context. Early in the effort to establish context, it became evident that the CODP was located at an early stage which essentially makes it an ETO manufacturing environment and that it included high product variation - where no product is exactly the same as the previous - and low volumes. Each product unit, Digital, Microwave and Antenna, can individually be viewed as product families. However, each of these product units manufactures products in turn which adds a lower level of product families.

The process map, see Figure 7, provides a visualization (on an aggregated level) of the process steps forming the production system at RUAG Space. The reference letters indicate the organizational structure and more specifically to which product unit or function the processes belong. “A” represents the Microwave product unit, while “B” represent the Digital product unit, “C” represent the Antenna product unit, and lastly “D” represent the central Supply function.

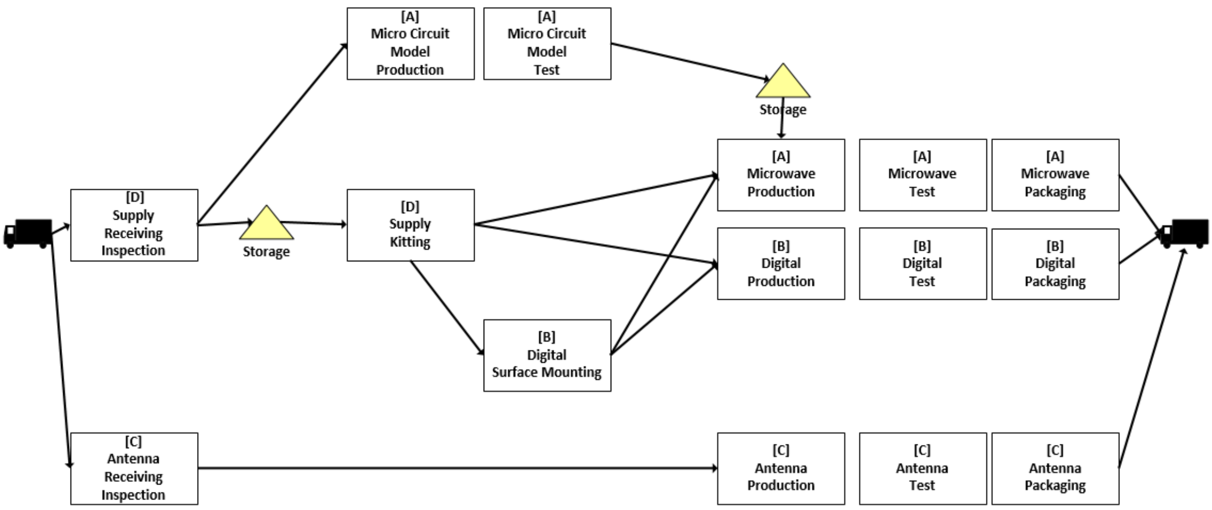

Figure 7 Process Map of the production system at RUAG Space

The following sub-chapters will present an introduction to each product unit, including the supply function described in the process map.

5.1.1 Product Unit Microwave

The Microwave product unit is the largest manufacturing unit in relation to volumes delivered - up to 270 units annually. It consists of approximately 60 full-time employees plus several consultants. These are organized into six departments including; project office, project management, unit development and electrical design, electrical design, operational development, and production. The project office serves a coordinating function between product development and production, involving quality, production planning and system configurations. The project management function includes a few project managers responsible for all projects within the Microwave product unit, whom all report directly to the unit manager. The development and electrical design unit work with new technologies along with the development of new products within the Microwave segment. Electrical design involves most activities related to the preparation and customization of previously, or to a high extent similar, manufactured products. Operational development currently consists of one employee managing the operational development and improvement projects. Finally, the production department consists of approximately 30 employees including contractors. It is organized into five different sub-functions; Assembly, Environmental-testing, Inline, PQA and Test. There are several different products being manufactured, but depending on customer requests they also come in different variants. There are no new products being developed in that sense; the foundation for different variants are the existing products. This falls within the "recurring products" category. The products include Micro Circuit Model (MCM) modules, which act as sub-components used in all Microwave products. Microwave try to measure lead times in their production which is difficult to establish exactly as demand - in conjunction with product variants - create a dynamic, complex manufacturing situation.

Communication takes place on several levels. Once per week, the management team (including all managers and project leaders in the product unit) meet to discuss current and potential future projects. The group also have improvement sessions each Monday. Furthermore, project meetings are held which include additional functions and aims at discussing the current state in regard to all projects Microwave. Smaller, "morning meetings" are held with the assembly team in production. Microwave differ from the other two product units in the sense that they have scheduled meetings for improvements. It is the sole product unit who currently works on an active basis with flow methodology and improvement techniques aimed at enhancing their production.

MCM Unit

The MCM unit is included in Microwave, but is considered a smaller "factory within the factory". MCM manufactures hybrids (Microwave components) in-house which are used when assembling converters. The hybrids are generic and, contrary to other product units, approximately 90% of the units are stored making this a more or less MTS system, where the production is planned according to forecasts produced by the supply function. There are currently five different products (with new being developed) and they come in a total of about 20 variants. The workforce itself is the smallest at RUAG Space and consists of nine people with two working in the physical production. In terms of manufacturing, each product undergoes similar process steps and the personnel possesses skills to a degree where they can overlap each other in the sense of performing different activities.

The storage function resembles a safety stock, but non-traditional means of deciding stock limits are used. Rather than having fixed numbers, the managers monitor and perform continuous assessments to decide the current need. This is achieved by manually checking the stock on hand against actual project demands and current quotas. Meetings are held at status boards to, for instance, analyze their KPIs after a batch is finished. This includes the whole workforce. Furthermore, a planning meeting is held once every week.

5.1.2 Product Unit Digital

Digital is the largest product unit generating most revenue at RUAG Space. It consists of a unit manager who is in charge of seven departments, which in turn are running their own subgroups. Project portfolio, operations and R&D are detached from the other departments in the sense that they exist to provide support and development for the whole Digital product unit. Project portfolio supports the other departments with resources in terms of project managers; the department itself act as a coordinating link from where resources and competence are distributed. Operations are essentially overseeing the digital operations, partly by distributing funds and approving investments. Research and development relate to technology development and intends to search beyond the current state of operations. It also works with improvements of current technologies and methods.

The remaining four departments relates to directly generating value for the customers either by designing new products or by manufacturing. These include product development representing three different types of products: computers, payload electronics, and data handling electronics. The three units are essentially design and product development oriented and create new products - alternatively performing modifications of previous products. Finally, recurring products represent the manufacturing department within the digital product unit which is where all manufacturing processes are performed.

From a flow oriented perspective almost all new projects go through one of the three product development departments. There is a fourth option for if the product is a “recurring product”, meaning that the product goes straight to production instead. A recurring product refers to a product that is, to a large extent, identical to a previously manufactured product. The recurring products department includes quality, production planning along with three sub-departments of which only one is directly connected to the manufacturing of digital products. This sub-department consist of approximately 20 employees, it includes assembly, inspection and test personnel as well as quality and system configuration. The manufacturing lead times vary due to customer specification and other circumstances but is suggested to be approximately five months. The final products being manufactured ranges from 20-25 annually, of which the majority move through a similar process flow. As a guiding principle, all orders/series which include less than three units are manufactured and managed by the product development departments respectively. The digital product unit also, from an organizational perspective, include a department that manages shared resources such as receiving, kitting and manufacturing of circuit boards. These resources are also used by the other product units but planned and administrated by the digital product unit. Lastly, the digital product unit includes a small unit producing circuit boards for other applications. This is known as “technology related”, and has been used to distribute machine capacity to other industries and customers.

5.1.3 Product Unit Antenna

The Antenna unit is the smallest product unit at RUAG Space, and it constitutes a small part of the company’s revenue. It consists of several different functions working in a holistic fashion with a total of approximately 30 people. Of this workforce, four work in production. However, currently the demand is not high enough to motivate four people thus it has been reduced to just two with the other two being lent to other product units. Each operator possesses enough individual knowledge and skill so that they may rotate internally between tasks. However, as the product unit works in a dynamic environment, each new project is usually unique and the required workforce varies with market demand. The main workforce consists of design and product development. The hierarchy includes a unit manager with the following departments;

product assurance, chief engineer, project managers, electrical design, mechanical design, and production.

As the Antenna unit is relatively small compared to the other two product units, the decision-makers have strived to detach the production flow from the other two. This essentially means that Antenna performs their own goods reception, inspection, and kitting. There are only a few so-called “shared” resources with the other units and those are various environmental test equipment stations. Once a project is initiated – through a customer order – the process is fairly static. The project develops a structure in their system displaying all included parts. This data is processed and purchasing is charged with sending requests to suppliers. Once the material arrives, it is checked against drawing and finally warehoused. Parallel to this process, one or several manufacturing orders have been initiated. Based on these, the operators kit the relevant material and begin assembling. Communication in the structure takes various forms. There is a bi-weekly planning meeting where the production department updates all active projects in the assembly facility. Furthermore, the whole unit has a meeting every other week where the overall antenna operations are discussed.

The complexity of each project can vary immensely ranging from an assembly time of 8 hours up to 120 hours. However, the general timeframe is between 24-40 hours. The various products are classified into either frequency or function, and are categorized accordingly. So, in the case of Antenna, there are no real product families in the sense they exist in the Microwave or Digital product units. Furthermore, most products are customer specific, and only two antenna types are similar to MTS as RUAG is certain, through forecasting, that those types sell. The lead time for ETO products range from 8-12 months and if RUAG would be able to make these products to stock, that lead time could be reduced by half.

5.2 ESTABLISH REPRESENTITATIVE FLOWS

The data collected from the ERP system included all MO:s from 2013-2017 that are either “completed”, “currently in manufacturing”, or “planned for manufacturing”. The data set was exported to an Excel-sheet, referred to as the “Raw Data File”. The separation of all the 8800 MO:s into product units and classification into product types was made in iterative sessions together with key personnel from each product unit, see Table 16.

Table 16 Participants during classifications of MO:s (conducted 13/3-17/3)

Participant	Occupation	Product Unit
Nils Andersson	Object Manager	Microwave
Magnus Årebro	Production Engineer	Digital
Niklas Hendtman	Object Manager	Antenna

As a result of the differentiation 6012 (76%) MO:s were allocated to the Microwave Product unit, 576 (7%) to the Antenna Product unit and 1348 (17%) to the Digital Product unit, see Figure 8, as part of the Raw Data File.

Manufacturing Order	Project Nam	Part Description	Product Unit	Product Type
42726	PROJECT A	RFKK4A ASSY FM	Microwave	RF Unit
43282	PROJECT B	TTRM PW ASSY	Digital	PW Assy
43283	PROJECT B	TTRM PW ASSY	Digital	PW Assy
43285	PROJECT B	TTRM PW ASSY	Digital	PW Assy
42100	PROJECT C	KK5 TOP ASSY	Microwave	TOP ASSY
42517	PROJECT A	KK1 TOP ASSY FM	Microwave	TOP ASSY
42518	PROJECT A	KK1 TOP ASSY FM	Microwave	TOP ASSY
42827	PROJECT A	LOCC ASSY FM	Microwave	LO Unit
42828	PROJECT A	LOCC ASSY FM	Microwave	LO Unit
41896	PROJECT D	S-BAND TOP ASSY RHCP	Antennas	Top Assy
41897	PROJECT D	S-BAND TOP ASSY RHCP	Antennas	Top Assy
41895	PROJECT D	S-BAND TOP ASSY LHCP	Antennas	Top Assy
41898	PROJECT D	S-BAND TOP ASSY LHCP	Antennas	Top Assy
42715	PROJECT A	RF COVER ASSY (D GASK PROF)	Microwave	Board & Filter

Figure 8 Part of an extraction from the Raw Data File

As each MO was categorized, the data were processed separately within the product units. The results for each product unit are presented in the following sub-chapters.

5.2.1 Product unit Microwave

Pareto-diagrams were created for all individual product types based on the volume of each product within each product type (Top Assy, RF Unit, LO Unit, Board and Filter, and MCM). These diagrams reveal which products are most commonly occurring in production during the chosen period of time, see Figure 9 and Figure 10. The columns represent the number of MO:s for each product manufactured while the curve represents the accumulated number of manufacturing orders in percentage for the selected product type. Note that only two of the diagrams are presented here while the remaining are confined to Appendix B.

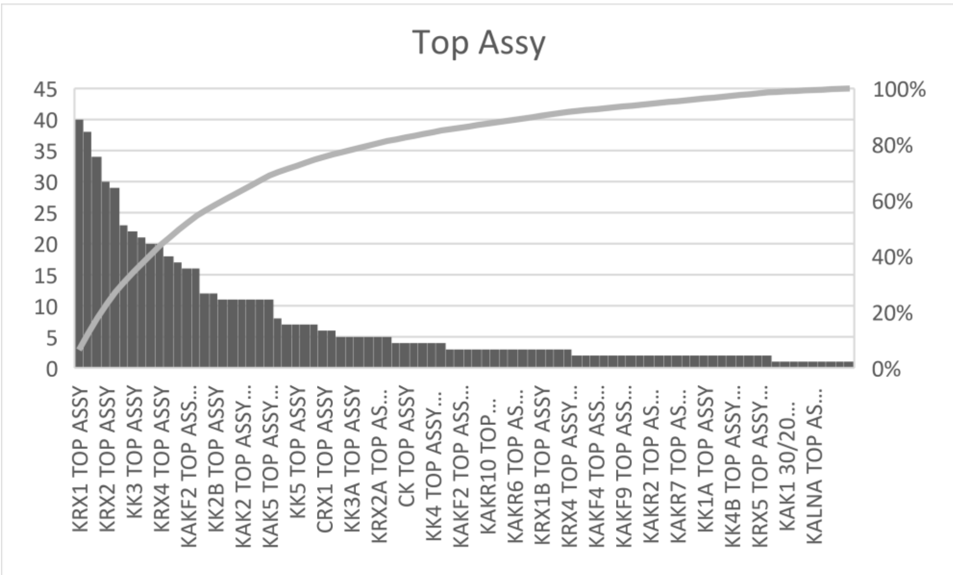

Figure 9 Pareto of Top Assy

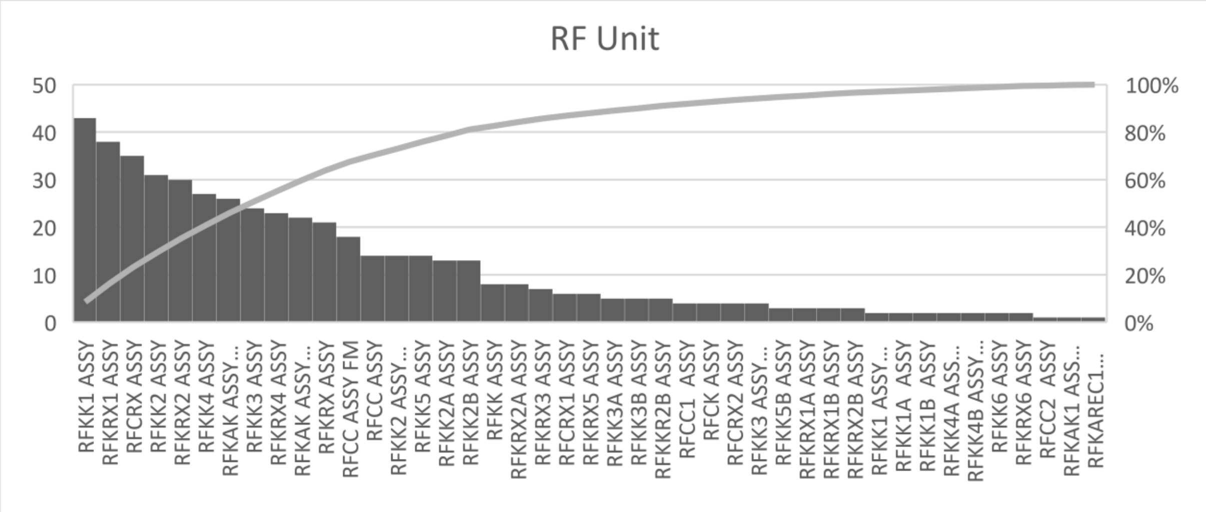

Figure 10 Pareto of RF Unit

These diagrams made it possible to statistically detect and motivate products which would be selected for further analysis. For instance, it is possible to separate the low volume products from those of high volume. This is an essential step in the decision making to discern between viable candidates. It is simply not interesting to proceed with a product that has historically only been demanded by customers on rare occasions. As the eight products representing the highest volume in each diagram were selected the next step was to extract the individual routings for each of these products. The routings for each individually selected product display each operation that need to be carried out in order to complete the product. Each of these operations are connected to a workcenter. In the actual process, a total of 40 products (8 from each Pareto-diagram) had their routing extracted and analyzed. However, due to the extensive nature of these routings, only one is presented in the report to illustrate the information, see Figure 11. The first column represents the reference number for each operation, followed by a brief description of each operation. The third column represents the acronym for the workcenter responsible for performing each operation. Finally, the fourth column specifies which role is required for performing each operation.

KRX1 TOP ASSY	Part no: 1000062627		
Operation No	Operation Description	Work Center No	Work Center Description
50	INDATA TILL MAKRO	MVOM	Microwave Object Manager
100	TEST - TOP ASSY A	MVOM	Microwave Object Manager
125	GRANSKA TEST-A	MVOM	Microwave Object Manager
150	Microwave Kitting	MVKIT	Microwave Kitting
175	MONTERING/LÖDNING	MVTAA	Manual Assembly Electronics
200	MONTERING/LÖDNING	MVTAA	Manual Assembly Electronics
250	MONTERING/LÖDNING	MVTAA	Manual Assembly Electronics
300	KONTROLLMÄTNING	MVMEC	Microwave Mechanical Measurement
325	INSPEKTION	MVTAI	Microwave TopAssy Inline
350	TEST - TOP ASSY B	MVTAT	Microwave TopAssy Test Engineer
550	TEST - TOP ASSY C	MVTAT	Microwave TopAssy Test Engineer
600	TEST - TOP ASSY D	MVTAT	Microwave TopAssy Test Engineer
650	MONTERING	MVTAT	Microwave TopAssy Test Engineer
685	TEST - MONTERINGSKONTROLL T	MVTAC	Microwave TopAssy Acceptans Test
690	EV MONTERING	MVTAT	Microwave TopAssy Test Engineer
700	TEST - M1 GAIN	MVTAC	Microwave TopAssy Acceptans Test
725	TEST - M1 RETURN LOSS	MVTAC	Microwave TopAssy Acceptans Test
750	MOMENTKONTROLL/LIMLÅSNIN(	MVTAA	Manual Assembly Electronics
800	RENGÖRING	MVTAA	Manual Assembly Electronics
825	MONTERING	MVTAA	Manual Assembly Electronics
850	SLUTINSPEKTION	MVTAI	Microwave TopAssy Inline
900	QA/QC	MVTAQ	Microwave TopAssy QC
950	MIP	MVTAQ	Microwave TopAssy QC
1000	FOTOGRAFERING	MVTAQ	Microwave TopAssy QC
1050	MONTERING	MVTAA	Manual Assembly Electronics
1100	TEST - PRE EMC	MVTAC	Microwave TopAssy Acceptans Test
1150	MOMENTKONTROLL, LIMLÅSNIN	MVTAA	Manual Assembly Electronics
1200	EV. APPLICERING ELECTRODAG	MVTAA	Manual Assembly Electronics
1250	EV. KONTROLLMÄT: PRE-EMC	MVTAC	Microwave TopAssy Acceptans Test
1300	TEJPNING	MVTAA	Manual Assembly Electronics
1350	INSPEKTION	MVTAA	Manual Assembly Electronics
1400	TEST - T1	MVTAC	Microwave TopAssy Acceptans Test
1450	TEST - T2A	MVTAC	Microwave TopAssy Acceptans Test
1500	TEST - T2B	MVTAC	Microwave TopAssy Acceptans Test
1550	TEST - T3	MVTAC	Microwave TopAssy Acceptans Test
1600	TEST - T5	MVTAC	Microwave TopAssy Acceptans Test
1650	TEST - T4 EMC	MVTAC	Microwave TopAssy Acceptans Test
1675	TEST - M2 EL PAR	MVTAC	Microwave TopAssy Acceptans Test
1700	TEST - T4 BONDING	MVTAC	Microwave TopAssy Acceptans Test
1725	DEMONTERING	MVTAC	Microwave TopAssy Acceptans Test
1735	VÄGNING	MVTAC	Microwave TopAssy Acceptans Test
1950	INSPEKTION	MVTAI	Microwave TopAssy Inline
1975	TEJPNING	MVTAA	Manual Assembly Electronics
2000	QA/QC	MVTAQ	Microwave TopAssy QC
2100	BESLUT	MVOM	Microwave Object Manager
2150	MONTERING, LIMLÅSNING	MVTAA	Manual Assembly Electronics
2200	INSPEKTION	MVTAI	Microwave TopAssy Inline
2250	PACKNING	MVTAQ	Microwave TopAssy QC
2300	INLEVERANS LAGER	MVOM	Microwave Object Manager

Figure 11 An illustration of the routing the KRX1 Top Assy

In the current state (as displayed in Figure 11), it was revealed that the operations included in a single routing were too numerous to individually cover in a P-P Matrix. For instance, at an individual workcenter there can be multiple distinctive operations occurring. Therefore, the operations carried out at different workcenters were consolidated, see Figure 12. This was necessary to detect where physical movements occurred in production between different workcenters.

KRX1 TOP ASSY	Part no: 1000062627	
Operation No	Operation Description	Work Center No
		MVOM Antal
		MVKIT Antal
		MVTAA Antal
		MVMEC Antal
		MVTAI Antal
		MVTAT Antal
		MVTAC Antal
		MVTAT Antal
		MVTAC Antal
		MVTAA Antal
		MVTAI Antal
		MVTAQ Antal
		MVTAA Antal
		MVTAC Antal
		MVTAA Antal
		MVTAC Antal
		MVTAA Antal
		MVTAC Antal
		MVTAI Antal
		MVTAA Antal
		MVTAQ Antal
		MVOM Antal
		MVTAA Antal
		MVTAI Antal
		MVTAQ Antal
		MVOM Antal

Figure 12 A consolidated routing for the KRX1 Top Assy

Subsequently, the consolidated routings for each product were allocated to the vertical axis of the matrices, while the products were allocated to the horizontal axis. The consolidated routings were used as basis for the P-P matrices, see Figure 13 and Figure 14. There is a total of 5 matrices for Microwave with two being presented here and the remaining presented in Appendix C. Each of these matrices present which of the 8 most voluminous products of each product type are processed in what workcenter and in which sequence.

Product/Process Matrix	KRX1 TOP ASSY	KK1 TOP ASSY	CRX TOP ASSY	KRX2 TOP ASSY	KK2 TOP ASSY	KK4 TOP ASSY	KK3 TOP ASSY	CC TOP ASSY FM
Microwave Object Manager	X	X	X	X	X	X	X	X
Microwave Kitting	X	X	X	X	X	X	X	X
Manuel Assembly Electronics	X	X	X	X	X	X	X	X
Microwave Mechanical Measurement	X	X	X	X	X	X	X	X
Microwave TopAssy Inline	X	X	X	X	X	X	X	X
Microwave TopAssy Test Engineer	X	X	X	X	X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Microwave TopAssy Test Engineer	X		X		X			
Microwave TopAssy Acceptans Test	X		X		X			
Manuel Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Inline	X	X	X	X	X	X	X	X
Microwave TopAssy QC	X	X	X	X	X	X	X	X
Manuel Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Manuel Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Manuel Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Inline		X			X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Microwave Mechanical Measurement			X	X				
Microwave TopAssy Inline	X	X	X	X	X	X	X	X
Manuel Assembly Electronics	X			X				
Microwave TopAssy QC	X	X	X	X	X	X	X	X
Microwave Object Manager	X	X	X	X	X	X	X	X
Manuel Assembly Electronics		X			X	X	X	X
Microwave TopAssy Inline		X			X	X	X	X
Manuel Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Inline	X		X	X				
Microwave TopAssy QC	X		X	X				
Microwave Object Manager	X	X	X	X	X	X	X	X

Figure 13 P-P matrix showing Top Assy candidates

Product/Process Matrix	RFKK1 ASSY	RFKRX1 ASSY	RFCRX ASSY	RFKK2 ASSY	RFKRX2 ASSY	RFKK4 ASSY	RFKAK ASSY (X4A)	RFKK3 ASSY
Microwave Object Manager							X	
Microwave Kitting	X	X	X	X	X	X	X	X
Manual Assembly Electronics					X		X	
Microwave RF Unit Assembly	X	X	X	X				
Microwave Mechanical Measurement		X	X		X			
Manual Assembly Electronics					X			
Microwave TopAssy Inline					X			
Manual Assembly Electronics					X			
Microwave TopAssy Inline					X		X	
Microwave TopAssy QC					X		X	
Manual Assembly Electronics					X		X	
Microwave RF Unit Assembly			X					
Microwave RF Unit Inline			X					
Microwave RF Unit Assembly			X					
Microwave RF Unit Inline			X					
Microwave RF Unit QC			X					
Microwave RF Unit Assembly			X					
Microwave Object Manager			X					
Microwave Kitting			X					
Microwave RF Unit Assembly			X					
Microwave Mechanical Measurement			X					
Microwave RF Unit Assembly		X	X			X		X
Microwave RF Unit Inline	X	X	X	X		X		X
Microwave RF Unit Assembly	X	X	X	X		X		X
Microwave RF Unit Inline	X	X	X	X		X		X
Microwave RF Unit QC	X	X	X	X		X		X
Microwave RF Unit Assembly	X	X	X	X		X		X
Microwave Object Manager	X	X	X	X	X	X	X	X

Figure 14 P-P matrix showing RF Unit candidates

These P-P matrices were the end result of the main ERP-data analysis, and acted as basis on which product should be selected for current state mapping in the focus group sessions. During the focus group sessions, the pareto-diagrams and P-P matrices were analyzed and it was discovered that the attached sub-assemblies followed the top-assemblies to a large extent in terms of volume. However, this was not true in all instances. Still, the anomalies were deemed negligible and thus the focus group decided to select product according to criteria 2, see Table 17.

Table 17 Criteria for selection

Criteria	Definition
1:	Individually select the most representative product type
2:	Select the most representative Top Assy and, as it is the parent unit, get the attached sub-assemblies at the same time.

The Microwave focus group, see Table 18, reached the conclusion that the product which could best represent a general flow was the *KRX1 Top Assy.* This decision was not only based on the fact that the manufacturing of that product had a high volume, but also that it had not suffered any setbacks (such as suppliers delaying the production due to late deliveries of components), which could be true for other products presented in the P-P matrices, thus distorting the data. The group also concluded that the routing for the KRX1 Top Assy, and its components, flowed through the most common process operations making it the most ideal candidate to represent a general flow.

Table 18 Focus group of Microwave (conducted 2/3-2017)

Department	Participants	Occupation
MW Production	Ulrika Larsson	Manager
MW Production	Mats Wahlström	Assisting Manager
MW Project Office	Nils Andersson	Object Manager
MW Product Unit	Camilla Malmer	Project Manager

5.2.2 Product unit Digital

Much like for Microwave, ERP data for Digital were gathered and analyzed regarding volumes and manufacturing sequences. The analysis produced three P-P matrices for the three product types (Top Assy, PW Assy and SMT). As the logic for deciding a product suitable to represent the Digital flow is the same as for Microwave only one of the P-P matrices, see Figure 15, used as platform during the focus group session is presented here. The results (Pareto-Diagrams) leading up to the P-P matrices, including the remaining matrices, are presented in Appendix D and E.

Product / Process Matrix	PLIU TOP ASSY FM	ARIANE 5 OBC-C TOP ASSY FM	S1 TCU TOP ASSY PFM+FM	VEGA OBC TOP ASSY FM	GALILEO BBP TOP ASSY FM	GALILEO CDU TOP ASSY FM	MTG DDU TOP ASSY EQM	ADSEM TOP ASSY PFM
501 - Kitting	X	X	X	X	X	X	X	X
100 - Manual Assembly Electronics	X	X	X	X	X	X	X	X
301 - In Line Inspection	X	X	X	X	X	X	X	X
100 - Manual Assembly Electronics	X	X	X	X	X	X	X	X
303 - Analyslab		X						
301 - In Line Inspection	X	X	X	X			X	
201 - Board (DIG) Test Engineer			X					X
100 - Manual Assembly Electronics		X	X	X				
301 - In Line Inspection		X		X				
201 - Board (DIG) Test Engineer		X						
100 - Manual Assembly Electronics		X						X
301 - In Line Inspection		X						
201 - Board (DIG) Test Engineer		X						
301 - In Line Inspection		X						
300 - QC in Production	X	X	X	X	X	X	X	X
100 - Manual Assembly Electronics		X	X					X
301 - In Line Inspection		X	X					X
100 - Manual Assembly Electronics		X	X					X
301 - In Line Inspection		X	X					X
300 - QC in Production		X						
100 - Manual Assembly Electronics		X	X					X
301 - In Line Inspection		X						X
100 - Manual Assembly Electronics		X						
301 - In Line Inspection		X						
300 - QC in Production		X						
502 - Inc Insp Mechanical and PCB	X	X	X			X	X	
207 - Vacuum-Vibration-Shock TestOperator	X	X						
201 - Board (DIG) Test Engineer				X		X		
300 - QC in Production			X					
210 - Acceptance (DIG) Test Engineer	X	X	X	X	X			
301 - In Line Inspection		X		X		X		
207 - Vacuum-Vibration-Shock TestOperator	X		X					
100 - Manual Assembly Electronics		X				X		
201 - Board (DIG) Test Engineer			X				X	
210 - Acceptance (DIG) Test Engineer	X		X					
100 - Manual Assembly Electronics			X	X			X	
301 - In Line Inspection	X	X		X			X	
100 - Manual Assembly Electronics							X	
300 - QC in Production	X	X	X	X	X	X	X	
100 - Manual Assembly Electronics	X	X		X			X	
400 - Object Mgmt in Prod	X	X	X	X	X	X	X	X

Figure 15 P-P matrix showing Top Assy

The focus group for Digital, see Table 19, reached a similar conclusion as the focus group for Microwave did. It was deemed appropriate to select a candidate from the parent product P-P (Top Assy) and thus get its attached sub-assemblies (PW Assy and SMT) automatically through its BOM.

Table 19 Focus group of Digital (conducted 28/3-2017)

Department	Participants	Occupation
Digital Production	Bengt Mattsson	Manager
Digital Recurring Products Production Common	Magnus Årebo	Production Engineer

The focus group reached the conclusion that the *S1 TCU Top Assy* is the best candidate to represent a general flow at Digital.

5.2.3 Product unit Antenna

Much like for Microwave and Digital, ERP data for Antenna were gathered and analyzed regarding volumes and manufacturing sequences. The analysis produced two P-P matrices for the two product types (Top Assy, Assy). As the logic for arriving at a product suitable to represent the Antenna flow is the same as for the other product units, only one of the P-P matrices, see Figure 16, used as platform during the focus group session is presented here. Note that in the case of the products at Antenna displayed in Figure 16, two adjacent columns constitute a product together (i.e. ANTENNA ELEM. R and ANTENNA L POL). The results leading up to the P-P matrices (Pareto-diagrams), including the remaining matrix, are presented in Appendix F and G.

Product/Process Matrix	ANTENNA ELEM. R	ANTENNA L POL	GNSS PEC ANTENNA WITH CHOKE RINGS T	GNSS PEC ANTENNA TOP ASSY	S-BAND TOP ASSY LHCP	S-BAND TOP ASSY RHCP	TEST CAP PEC ANTENNA TOP ASSY	TEST CAP TOP ASSY
Manual Assembly Antenna	x	x	x	x	x	x	x	x
PD ANTENN ILI	x							
QC in Production		x	x	x	x	x		
Manual Assembly Antenna	x	x	x	x	x	x		
QC in Production			x	x	x	x		
Manual Assembly Antenna			x	x	x	x		
ANTENN KONSTRUKTION TEST					x	x		
PD ANTENN ILI	x							
QC in Production	x	x						
Manual Assembly Antenna	x				x	x		
EXTERN BELÄGGNINGSGRUPP					x	x		
PD ANTENN ILI	x							
Manual Assembly Antenna	x				x	x		
QC in Production					x	x		
PD ANTENN ILI	x							
Manual Assembly Antenna	x							
PD ANTENN ILI	x							
Manual Assembly Antenna	x							
PD ANTENN ILI	x							
Object Mgmt in Prod	x	x	x	x	x			

Figure 16 P-P Matrix showing Antenna Top Assy

The focus group for Antenna, see Table 20, reached a conclusion which is diverging from Digital and Microwave. Instead of selecting one of the products with highest volume, the focus group chose a product from the other end of the spectrum. The reason is that the Antenna L POL is manufactured for a rocket which is going to be replaced with a new version in a few years. However, the S-BAND TOP ASSY RHCP has a demand which is forecasted to remain stable, or increase, which is why the focus group selected it to represent the Antenna flow.

Table 20 Focus group of Antenna (conducted 21/4-2017)

Department	Participants	Occupation
Antenna Production	Tom Seeman	Manager
Antenna Production	Niklas Hendtman	Object Manager

5.3 CURRENT STATE MAPPING

This chapter outlines the current state production processes and flows. The presentation consists of two elements. First, the maps for each flow are visually displayed in Visio software format providing a detailed picture of the material and information flows as well as each operation's associated process box providing data. Note that since the maps for each product unit are extensive, only extractions are included in the following sub-chapters to illustrate. The whole result is presented in Appendices H-J (Microwave-H, Digital-I, Antenna-J). To collect the data, a questionnaire was designed, see Figure 17. Second, a summary of complementary information is provided to simplify and clarify certain aspects.

Value Stream Mapping - Data Gathering / Questionnaire	
Activity type: Process / Storage / Transport	**Department:**
Process	**Storage**
Operation no:	Physical Location:
Operation name:	Quantity:
Work Center:	**Transport**
Process time (P/T):	From:
Cycle time (C/T):	To:
Change over time (C/O):	Distance:
Batch size (EPE):	**General Data**
Up-time:	
Number of operators:	
Dedicated/Shared resource:	
Scrap rate:	
Information flow:	
Product flow:	

Figure 17 Data gathering questionnaire

All parameters from the VSM methodology were included in the questionnaire apart from two; "Product variation" and "Pack size". The reasons for this decision is that the variation is so high it becomes irrelevant to measure, and pack sizes vary with each order and it would be unrepresentative for the system in the map. In addition to the VSM data parameters, the questionnaire also included complementary parameters; activity type, operation no, operation name, workcenter, dedicated/shared resource, information flow, product flow, storage data, transport data and general data. These were added for two reasons: to provide structure in the data gathering process and to adapt to the terminology used at the case company.

5.3.1 Product unit Microwave

As mentioned in 4.1, a Microwave product consists of four sub-assembly types which together culminate in the final product - the Top Assy. Each of these sub-assemblies, and the Top Assy, have individual flows. The routings for these were extracted for the KRX1 Top Assy and its constituents, starting at the BOM parent level, see Figure 18. Each reference letter equal a product type while each box equal an individual flow. The number in parenthesis in each box indicate how many of that specific sub-assembly are required in the final product.

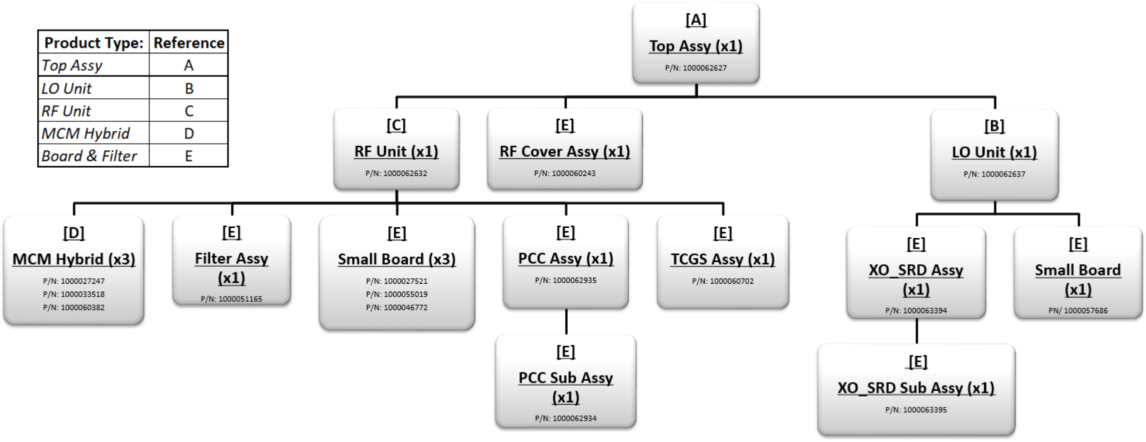

Figure 18 BOM hierarchy, Microwave

The routings were extracted from the ERP system and used as support to provide guidance and structure to the process of mapping. Note that it is important to understand that the routings are administrative formalities and the real world presented in the maps does not necessarily reflect the routing sequences, albeit they do to a large extent. The routing is binary and static while the real current state is varying and dynamic in terms of what exact order the operations are carried out.

The mapped flows merge at various choke points (where products of finished flows are assembled before entering the next flow) in the main flow. The flows have each been analyzed and translated into maps, described in the following subchapters. For a summary of the capacity (labor) for the entire flow, see Table 21.

Table 21 Displaying roles, descriptions, and capacities of Microwave

Role	Description and Tasks	Personnel
Object Manager	Order initiation - Excel-script is fed with information regarding trim components, hybrids and LO. The script generates propositions as to what shall be assembled. It also reserves those components in the ERP system.	4 CU
Inline Inspection	Perform inspection of technical and/or administrative character	6 CU
Quality Control	This can either be performed by the customer (MIP), or the customer can choose to delegate the operation to RUAG Space (ordinary QA/QC inspection). Information is sent to the customer 5 days prior to the scheduled MIP to inform well in time	6 CU
Test Engineer - Filter	Perform test operations in the Filter Flow	2 CU
Test Engineer - LO	Perform test operations in the LO Flow	4 CU
Test Engineer - Top Assy	Perform test operations in the Top Assy	6 CU
Test Engineer - Acceptance Test	Perform acceptance test operations (Top Assy Flow)	4 CU
Assembly Board and Filter	Perform assembly operations in the Board and Filter Flow(s)	10 CU
Assembly RF	Perform assembly operations in the RF Flow	6 CU
Assembly LO	Perform assembly operations in the LO Flow	4 CU
Assembly Top Assy	Perform assembly operations in the Top Assy Flow	4 CU

As the entire flow is complex, certain parts of each map have complementary information attached to help increase the understanding. At the end of the chapter, a brief summary of the flow is presented. Furthermore, when there is an indication of electronic information being sent or received, it is always connected to the ERP system unless stated otherwise. Also, the outer border of the data boxes in the map are separated to full-drawn (majority of operation time is active labor time) and dashed (majority of operation time is machine/equipment time, while change over time is active labor time). Further, if a databox is striped it indicates that the resource or operator is shared between one or several product units.

KRX1 - Top Assy Flow

Once the RF Unit, RF Cover Assy and LO Unit flows are finished and the final operations for each sub-assembly (order administration) has been performed by the Object Manager, they converge in the first assembly sequence of the Top Assy Flow, see Figure 19. At the end of this flow, the product is finished.

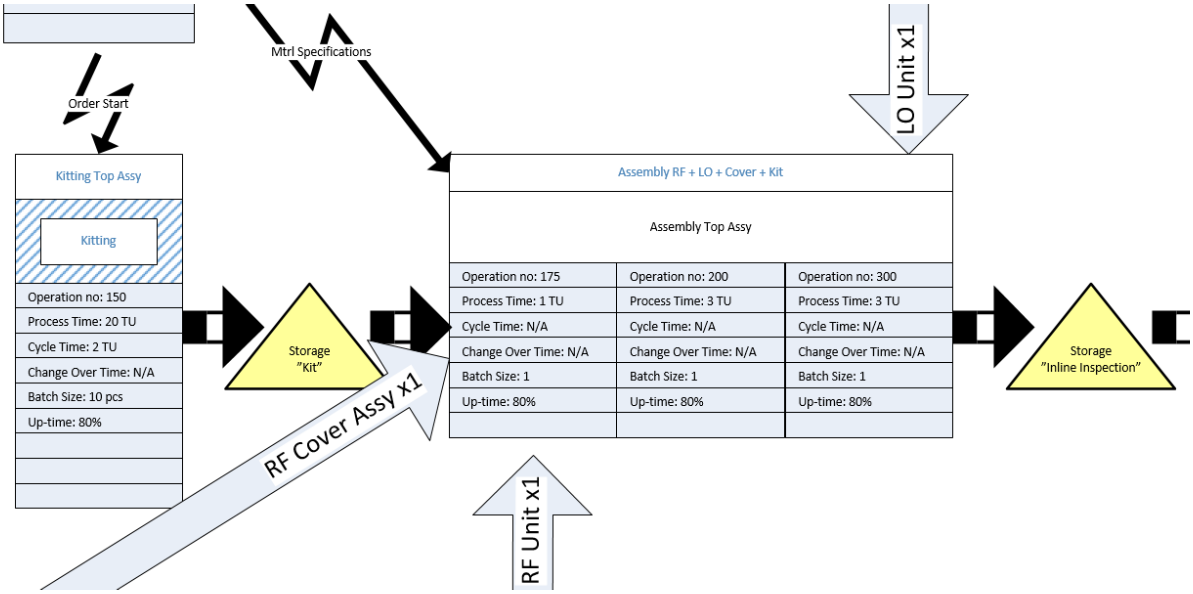

Figure 19 Sub-assembly flows merging to initiate the Top Assy flow

LO Flow

The LO flow is deviating from the other flows in the sense that the entire main flow, to a large extent, is based on a particular component (a crystal) entering the LO flow. This crystal is considered the most critical component of the entire KRX1 Top Assy product. Therefore, the LO flow is considered to regulate the overall pace of the Microwave product unit, including the Top Assy flow. Before initiation of the LO flow, two sub-assemblies (XO_SRD Assy and TRSN Assy) needs to be completed, see Figure 20.

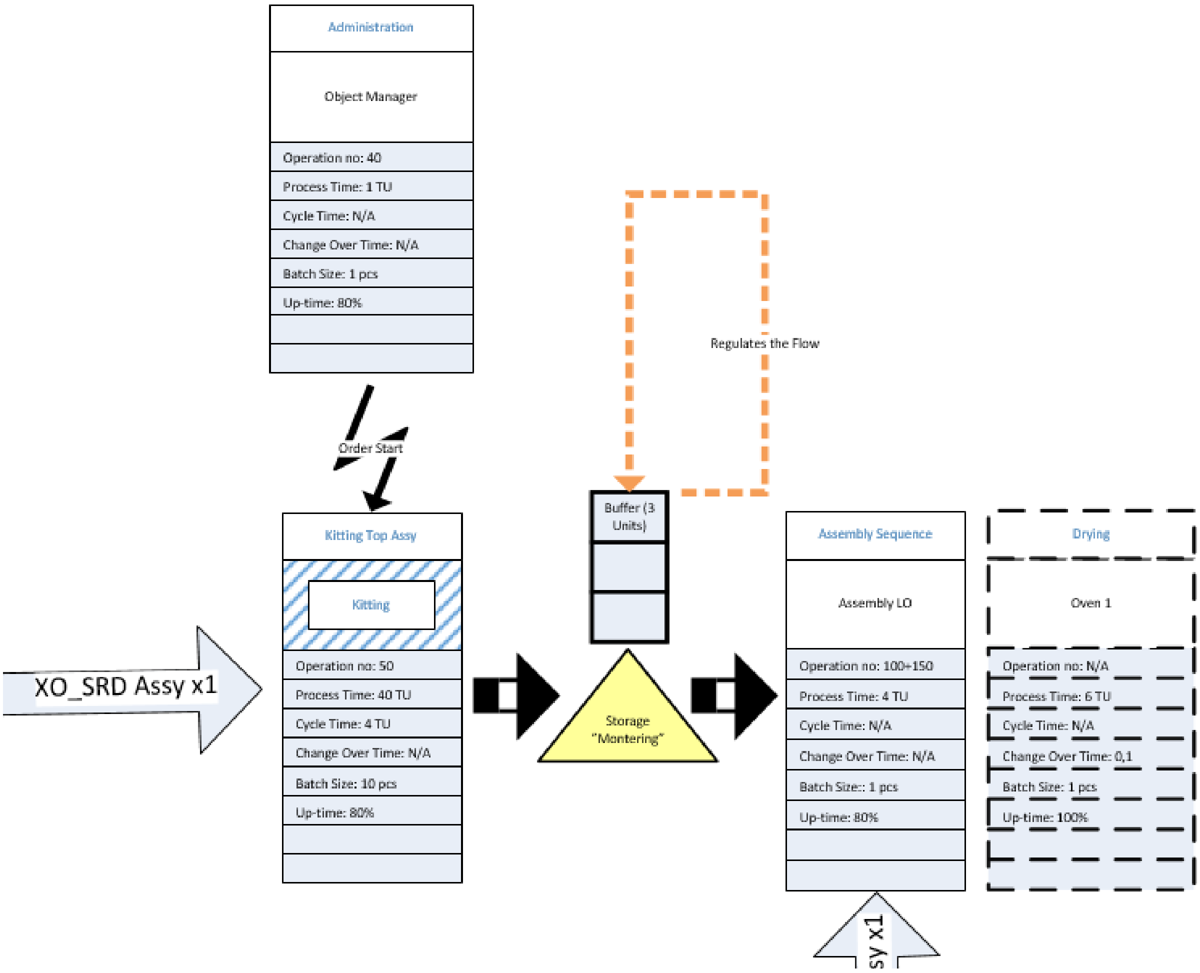

Figure 20 Illustration of the first part of the LO flow

RF Flow

The RF flow can only begin after 9 sub-assemblies from 5 previous flows have been finished, see Figure 21. Adding to this complexity does the MCM flow. It is not known beforehand what type of MCM hybrid should be included in the final product. This means that the MCM flow will keep producing hybrids in a MTS fashion, and only before the initiation of the RF flow will it be decided which specific MCM hybrids should be included. The other sub-assemblies are designed and manufactured after customer specifications in an ETO fashion.

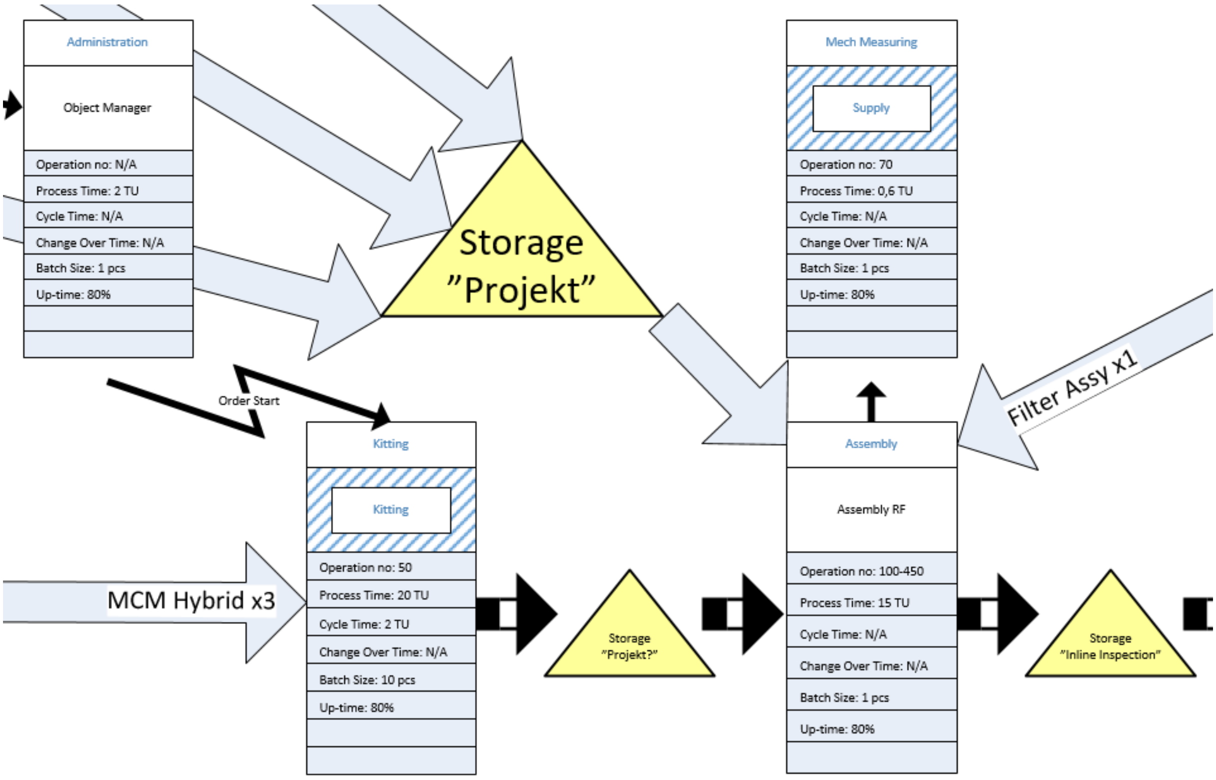

Figure 21 Illustration of the first part of the RF flow

MCM Flow

The products manufactured in the MCM flow differ from the other flows. These hybrids are to a large extent MTS, with the exception of the rare customer demand for a unique hybrid. Also, the quantities scheduled for manufacturing along with administrative tasks such as forecasting are performed by the RUAG Space supply function rather than the Microwave product unit. Finally, the MCM is the only flow which has connection to an external company to which hybrids are sent for welding, see Figure 22.

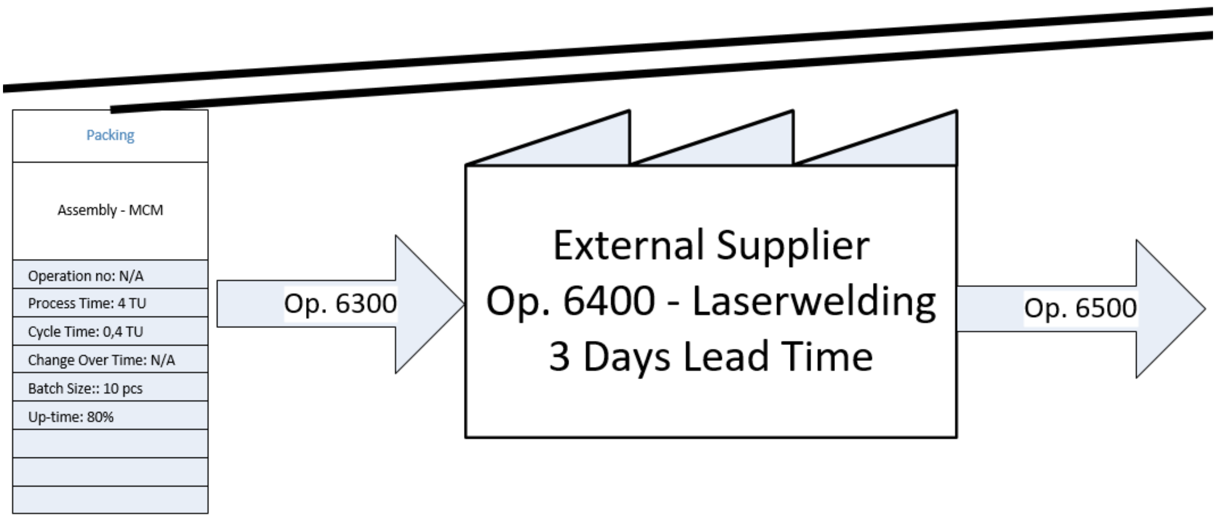

Figure 22 Extract of the MCM flow

Board and Filter Flow

The Board and Filter flow differ from the other flows in the sense that it is an aggregated level consisting of 6 minor flows of various complexity, these include the; RF Cover, Filter, PCC, TCGS, XO_SRD and Small Board flows. These flows, along with the MCM flow produce the lower-level sub-assemblies that are fed to the major flows (LO, RF and Top Assy). Some of these flows go through the SMT department, and include the only machine operations in the entire flow. Further, these flows are all part of the Microwave product unit map and are presented in Appendix H.

Summary Microwave

The mapping has covered all flows which together form one product: the KRX1 Top Assy. It is however important to remember that this is, as previously mentioned, a general flow. Microwave manufactures many products which in several ways are similar, spread across multiple number of projects.

5.3.2 Product unit Digital

The product which has been mapped for Digital is the *S1 TCU Top Assy PFM+FM*. Even though the Digital products are more complex in terms of technology than the products at Microwave or Antenna, the actual flows are more straightforward. It is not, as opposed to its equivalent at Microwave, consisting of multiple, intertwined sub-assemblies causing an intricate total flow. Instead, it is made of an automated board flow (SMT Flow), a manual board flow (PW Assy Flow), and finally the top assembly (Top Assy Flow), see Figure 23.

Product Type:	Reference
Top Assy	A
PW Assy	B
SMT	C

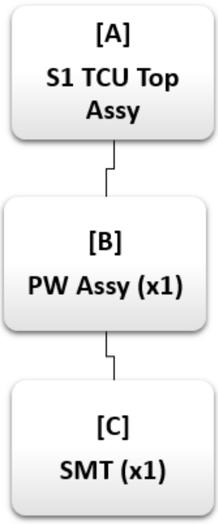

Figure 23 BOM hierarchy, Digital

The flows have each been analyzed and translated into maps, described in the following subchapters. For a summary of the capacity (personnel) for the entire flow, see Table 22.

Table 22 Displaying roles and capacity for the digital production department

Role	Personnel
Object Manager	4 CU
Inline Inspection	4 CU
Quality Control	4 CU
Assembly PW Assy	14 CU
Assembly Top Assy	8 CU
Test Board PW Assy	10 CU
Test Top Assy	10 CU
SMT Operator	6 CU

Top Assy Flow

In this instance, the circuit boards are fitted in mechanical components to create the final product. The product also undergoes extensive testing in this stage. Note that final product which is analyzed in this flow consist of a single circuit board, but this number can range up to several circuit boards. This factor decides the size of the Top Assy which is also very varied. From a flow-oriented perspective it is however not as important to take a Top Assy with several circuit boards into consideration as the PW Assy - and SMT-flows are simply iterated to produce the required number of boards, albeit with minor variation.

PW Assy Flow

The PW Assy is oriented towards manually adding components and fine-tuning the aspects of the circuit board which cannot be achieved through the previous processing in the machines, see Figure 24.

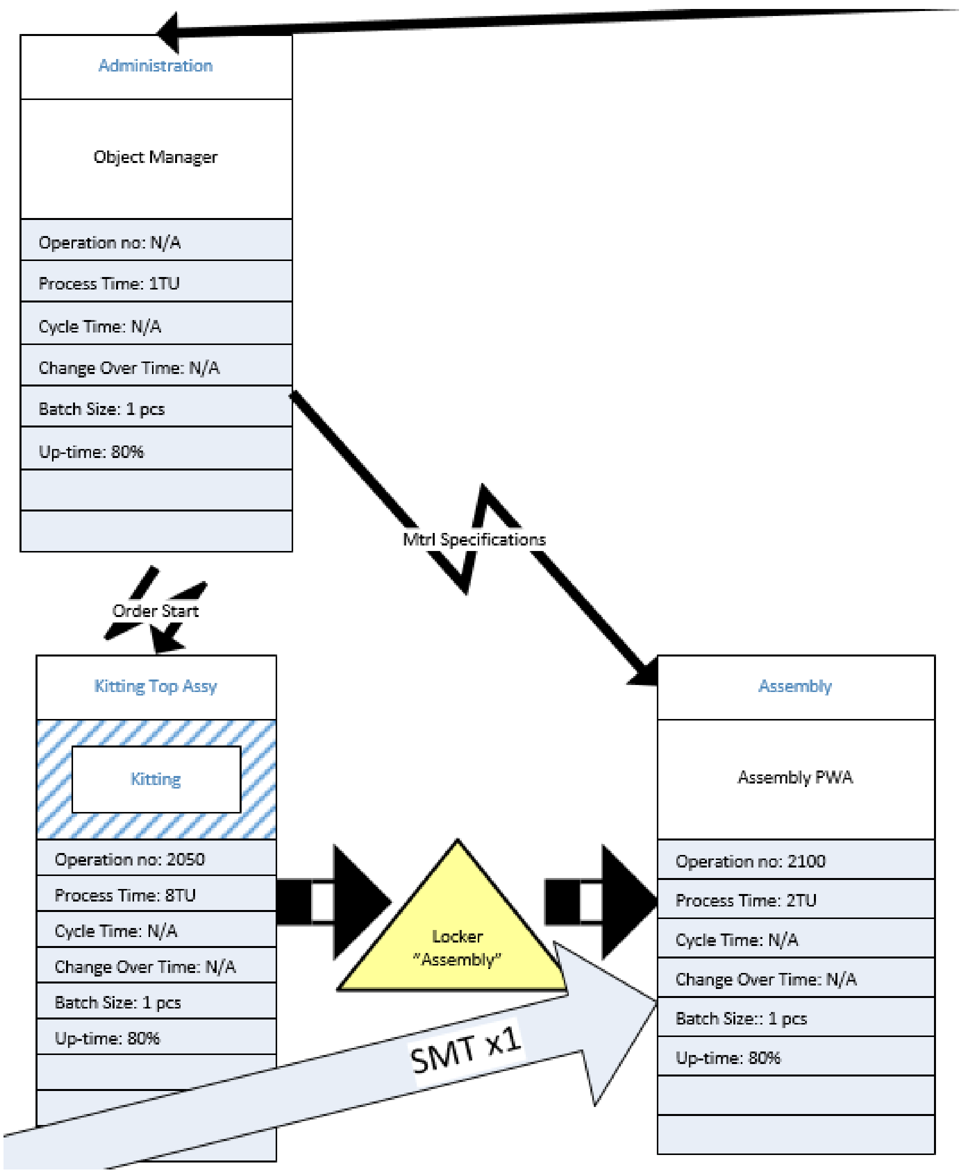

Figure 24 Extract from the PW Assy flow

SMT Flow

In SMT, the actual circuit boards are initially manufactured by surface mounting components onto previously printed circuit boards, see Figure 25. This flow is to a large extent automated using advanced surface mounting and printing machines, assisted by operators. Further, it is a separate department which is used as a shared resource for all product units. From an organizational aspect, SMT is allocated to the Digital product unit.

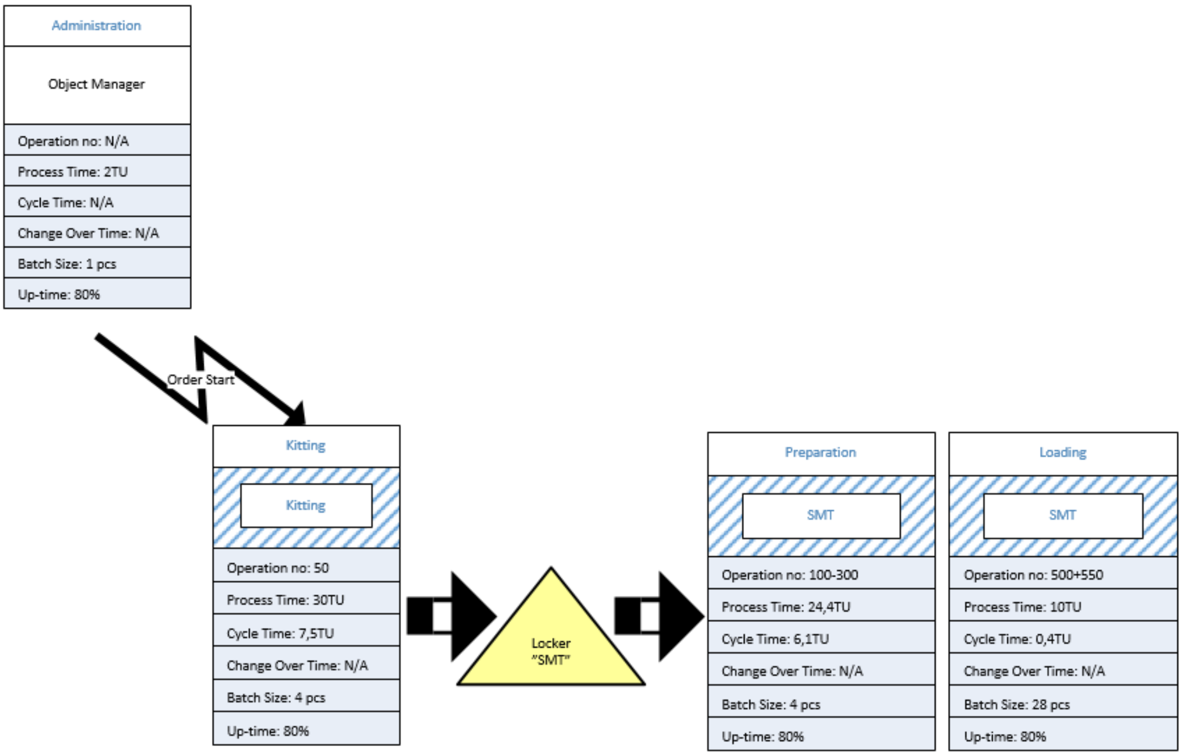

Figure 25 Extract from the SMT flow

Summary Digital

The analysis has covered all flows which together form one product: the S1 TCU Top Assy PFM+FM. It is however important to remember that this is, as previously mentioned, a general flow. Digital manufactures many products which in several ways are similar, spread across multiple number of projects.

5.3.3 Product unit Antenna

The product which have been mapped in the Antenna flow is the S-Band Top Assy RHCP. According to the initial classification into product types, there are only two (Top Assy and Assy). However, a more detailed analysis of the BOM revealed that the Assy include four individual sub-assemblies which are included in the final product, see Figure 26. The sub-assemblies are produced according to the MTS principle, while the Top Assy is configured and manufactured towards specific customer orders.

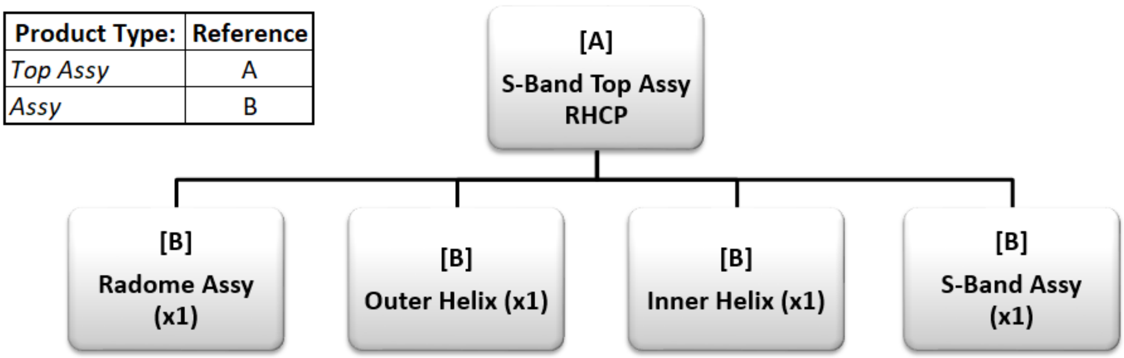

Figure 26 BOM hierarchy, Antenna

The flows have each been analyzed and translated into maps, described in the following subchapters. The capacity in terms of personnel in production is eight CU. Unlike the Microwave and Digital product units, Antenna has no specific division of work tasks. Instead they are highly flexible and each operator is able to perform almost all operations and sequences in any flow.

Top Assy Flow

The Top Assy flow is initiated as the sub-assemblies in storage (which in some cases have been manufactured to a customer order, thus excluding the storage) converges in the first step of the Top Assy flow, see Figure 27. Once the entire flow is completed, the final product is packaged and stored.

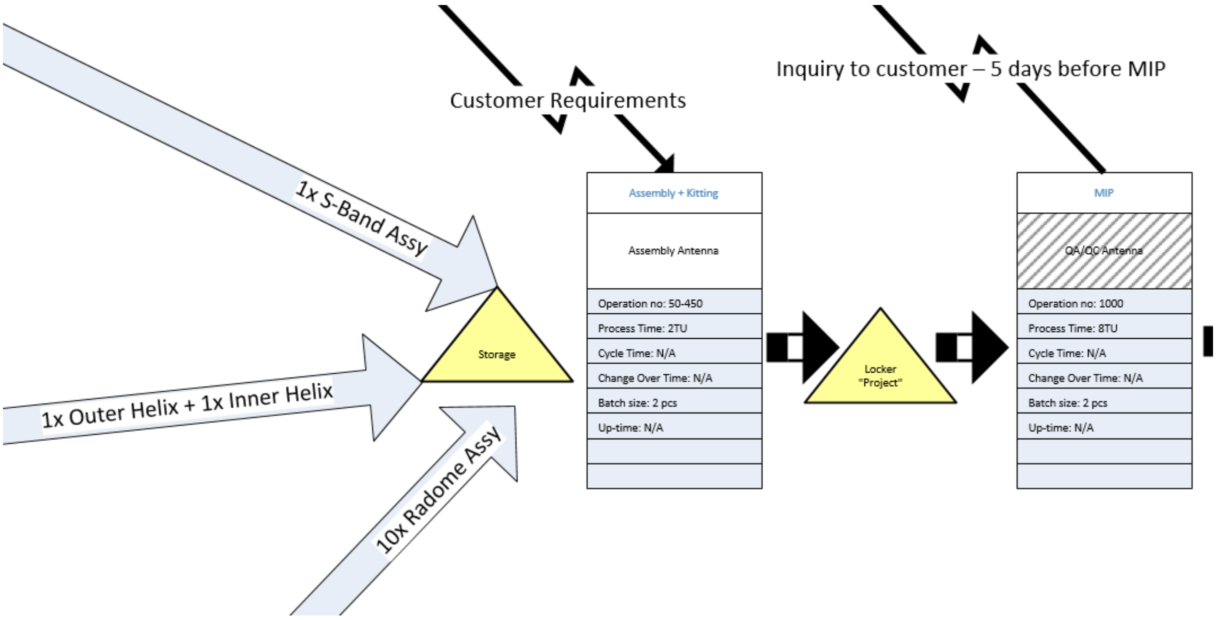

Figure 27 Initiation of the Top Assy flow

S-Band Assy Flow

The S-Band Assy flow is, compared to the other flows at the Antenna product unit, rather generic. The product is manufactured in batches of six in a MTS fashion, and are stored until requested to be part in a final product.

Outer and Inner Helix Flows

The two sub-assemblies (Outer Helix and Inner Helix) are from a flow perspective identical, which is why they are manufactured in the same flow with equal assembly and test operations. However, due to differences in size and technical configurations they are still manufactured in separate sequences, i.e. a batch of Inner Helixes is manufactured prior to the initiation of manufacturing of a batch of Outer Helixes. Further, an external resource (RUAG:s laboratory, which is considered external since it does not belong to the Antenna product unit) manages the surface treatment operation within the flow, see Figure 28.

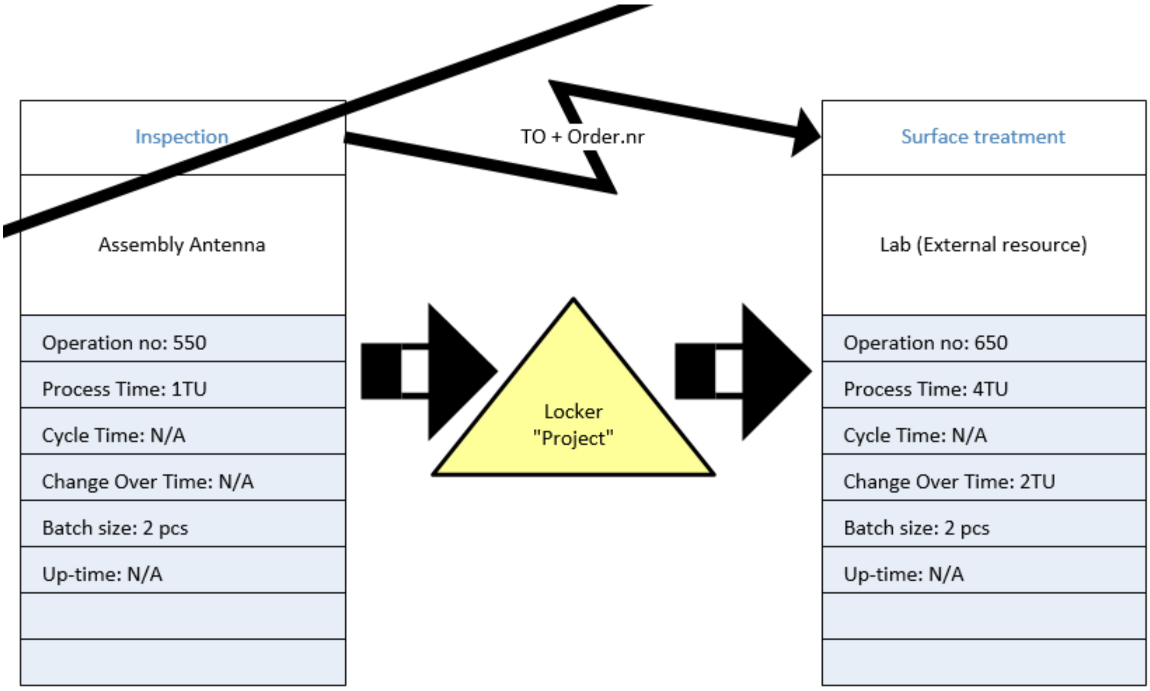

Figure 28 Extract from the inner/outer helix flow

Radome Assy Flow

The Radome Assy is mainly manufactured in-house, although an external supplier performs the final painting. It is put in storage at RUAG Space until a customer order match the specific Radome Assy, after which it will be inspected and delivered to the external supplier. It is upon return inspected and attached to the Top Assy, see Figure 29.

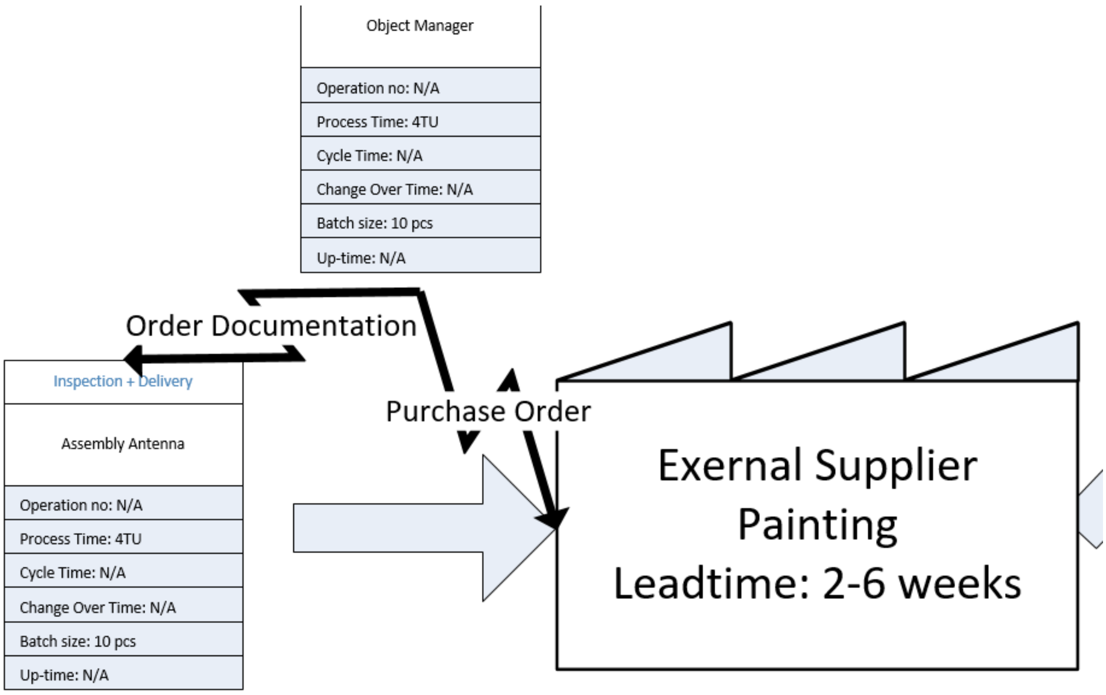

Figure 29 Extract from the Radome Assy flow

Summary

The mapping has covered the manufacturing of the flow for the S-Band Top Assy, including the flows linked to the manufacturing of the attached sub-assemblies. Unlike its counterparts, Antenna products do not travel between different operators in the same extensive way and the whole production is confined to a, in comparison, small area.

5.4 SUMMARY OF CURRENT STATE MAPPING

The mapping of the actual production system does not differ so much in its execution from how it is performed in the conventional VSM method. As the mapping commenced, it quickly became evident that the production system at RUAG Space was not entirely suitable to be mapped in this regard. Since the production system consist of three distinctive elements - high variation, complexity, and labor-intensive work - it proved to be a difficult task to capture some of the selected parameters, especially those concerning machinery such as change over time and up-time. Therefore, an explanation of the gathered VSM parameters and their meaning in this particular study is provided in the following section.

Scrap rate refer to rework or scrapping of material. In the case of RUAG Space, whenever a product is damaged - or presumed damaged - a Non-Conformance Report is filed to register the extent of the damage and provide information in regard to whether the material should be scrapped or not. Even though those reports are stored within the ERP, it would be faulty to use what statistics it could represent to generate a number for the scrap rate KPI. The reason is that operators only report when something is severe (that is, something which could require scrapping or further investigation due to damage), but no reports are made when a product require lesser rework. In the mapping, it became evident that rework often occur in those instances when a value-adding operation is in close proximity to an inline inspection. This means that rework occur fairly frequently, but without being documented which is necessary to calculate statistics.

Cycle time generally refers to time that elapses between two parts coming of a process - that is how often a product leaves the operation. In the case of RUAG Space, there are no operations where the cycle time differ from the process time. However, by dividing the process time with the batch size, an average cycle time can be determined. It was included to provide a sense of time elapsed.

Number of operators simply refer to the number of operators working in a particular process. At RUAG Space, the number of operators at each workcenter fluctuates. Due to the constant cyclical demand changes, there are no static workforces, but rather operators intermingle between workcenters and even product units.

The number of product variations measures what the name suggests. In this study, this was however deemed irrelevant. The variation was essentially what caused the decision to generalize the flow by selecting one product per product unit. This was a major contribution as to why the number of product variations was not considered during the mapping of the flow.

Considering the pack size (number of pieces), this measure vary with each project and customer order so it would was deemed irrelevant to measure this parameter for the selected products of each product unit as it would not in any way be representative for that particular flow.

Change over time in traditional sense refer to the time required to make necessary changes to accommodate for a different operation. This often refers to machines which needs to be reconfigured once a different product is due to be processed. Machines in that sense barely have a place in the manufacturing system of RUAG Space. This particular KPI was instead modified to differentiate the duration of an activity. This essentially means that the time spent performing manual labor in a machine oriented operation, is represented by the change over time while the process time is the time spent in the machine (most commonly a heat treatment unit).

The mapped flow considers production batch sizes. In most instances, the activities are performed in a one-piece flow fashion meaning the “batches” often refer to single products. However, when batch sizes greater than one occur, the object leader or operator plan a batch size while the downstream process varies. In essence, this means that just because a batch size originally is X, this can become Y in the next process. For example, as shown in Figure 30, the object leader has planned a batch of 28 pcs. In the kitting process however, this batch has been reduced to 10 pcs. This batch is then reduced yet again to 1 pcs in the assembly phase.

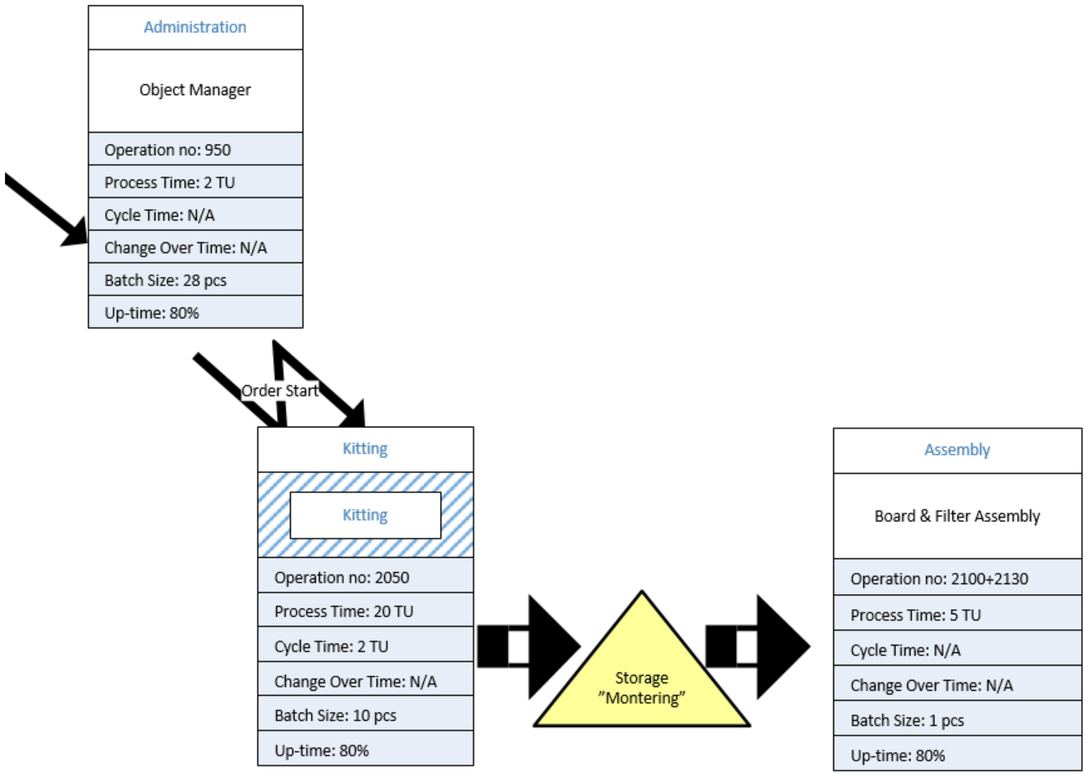

Figure 30 Illustration of a sequence with varying batch sizes

There are several reasons for this. The production planning is performed manually and there is no “real” product flow standardization. As the kitting operation is informed about the batch size of 28, they reduce it amongst themselves to 10 in this case. The reason is that a batch of 28 pcs is unmanageable in terms of handling (difficult to keep track off, and limitations in workspace area). Reversed, if the new batch is reduced beyond 10 pcs, it would result in additional searching and gathering of components to be kitted. Therefore, the kitters have with time and experience found the sweetspot for what “optimizes” their process times. As a result, buffer levels (in this example, Storage “Montering”) differ heavily where the batch sizes are varying. Finally, as the 10 pcs from kitting are stored in “Montering”, only one of those will be retrieved at a time to be processed in the next-coming operation. Note that there are instances in the flows where this is reversed i.e. an operation finishes 1 piece which goes into storage, but the next-coming operation demands 10 pcs, which requires the storage to house 10 pcs before commencing.

Working time exist according to standard, union times. Therefore, it was included in the study simply as an eight-hour work day applicable to all workers regardless of role. This has been approximated in the study to account for 80% of the operator uptime (the remaining 20% account for breaks, meetings etc.). Uptime per definition was not applicable in the case of RUAG Space. The current state analysis collected the statements of operators but there was no definitive answer as to if and when a machine would be available to any operator. The general opinion was that there was no downtime or that a machine would not be available at any given time of need.

To summarize, the resulting maps and the data they present yield a degree of uncertainty in multiple regards. As much of the data is not accountable for through the ERP system, much stems from the statements of those responsible for performing the operations. This will be further explored in the analysis chapter.

6. ANALYSIS

In this chapter, the framework is analyzed regarding its development, its application to a complex manufacturing system and its capability in capturing a complex, non-linear flow.

6.1 FRAMEWORK DEVELOPMENT

It has previously been declared that performing a mapping of a complex production system is not entirely suitable from a VSM perspective. The original method was designed and meant for linear production systems. Following this, there have been various attempts at constructing a VSM method able to capture a dynamic production system (Braglia et al., 2006; Khaswala and Irani, 2001). However, it has been previously mentioned that these methods fall short in terms of production systems with high variations. The framework developed in this thesis aims at approaching these complications and enables a current state mapping to be performed. Furthermore, as the desired outcome of the framework differs from the desired outcomes of the methods found and analyzed in theory, none of those could be directly utilized in the context of RUAG Space. It was therefore deemed necessary to analyze how these methods differ from the developed framework used in this study.

The common denominator for VSM, VNM and IVSM is that each method is initiated through the forming of a product family (Rother and Shook, 2004; Braglia et al., 2006; Khaswala and Irani, 2001). This selection decides what particular flow is to be mapped. However, this was not a straightforward aspect in this thesis. In the context of RUAG Space, the term “product family” is ambiguous. It could either refer to the organizational structure representing the company - Microwave, Digital and Antenna - or it could refer to products which undergo similar processing sequences regardless of which organizational structure they belong to. Instead, the initial step in the developed framework included efforts in establishing a company context and a structure regarding terminology which would standardize the approach and avoid confusion.

Once a product family has been selected, it can be noted that the methods for performing a VSM take different approaches in achieving the map. The traditional VSM can, in its intended linear systems, initiate the current state mapping as soon as a family has been selected. This is not true for VNM or IVSM and their intended complex systems, nor is it true for the framework used in this thesis. This is also where the main differences in each method manifest. In essence, VNM is trying to translate the production processes into a network of intertwining activities to provide a picture of the current state. It is focused towards describing a current state rather than finding improvements. IVSM is rather a systematic improvement method where the most critical part of a flow is frequently changing and targeted for improvement. The methods are designed, each to their own, to generate a better future state through reducing waste in complex environments. The framework however, is instead aimed towards producing a current state mapping and therefore disregards the aspects following this aspect of the VSM. In a sense, the framework share similarities with the VNM method. However, it also draws inspiration from IVSM. Since the variation in production at RUAG Space borders on totality, the main difference between the framework and the other methods is the selection of a product to be mapped. In the developed framework, this is achieved through a combination of data analysis, which is related to the other two methods, but also with the addition of a soft aspect - the direct communication with key personnel. Solely letting quantitative data dictate the decision in selecting a product was considered unsatisfactory as there are unknown parameters such as expected volumes, predictions regarding changes in market and lack of detailed knowledge of the manufacturing system. This imposed the necessity of engaging key personnel. To approach these unknowns, speculative criteria were established in several instances. Presenting the difficulties to personnel well knowledgeable in the system lead to an informed decision, thus circumventing much of the complexity which would otherwise have been reduced to guesses by the framework practitioners.

The actual mapping of a product flow through the system did not differ significantly between the framework and the other methods. However, as the intended outcome of the end-product differed, the approach used still had some variation. The purpose was not to detect and map issues within the manufacturing flow, ergo the interviews conducted to gather data were strictly confined to determining selected process data. The consensus after having selected a product for each product unit (Microwave, Digital and Antenna) was that it could theoretically represent a general flow. In summary, the framework used differ from the others in two general regards, see Table 23.

Table 23 General differences between methods

Difference	Definition
Prior effort	The work effort prior to the actual mapping procedures
Outcome	The desired outcome of the mapping

6.2 FRAMEWORK APPLICATION AND OUTCOME

To determine the suitability of the mapping framework when applied to a complex production system, two particular aspects need to be considered. First, the viability of creating a generalized map of the current state for a product unit. Second, consider if the collected data were adequate and appropriate for the purpose of the map.

A current state analysis in a VSM perspective is a “snapshot” of how the system is currently operating. It is suitable for a linear production with low variability and high volume. In the case of this thesis, it was not possible to fully display the flows of a product unit in this fashion since the variation was too great and the production too complex. Instead, after an extensive data research and interview meetings with key personnel, a single product was selected for each product unit to be representative on a general level.

The framework allows for taking a statistically motivated, and qualitatively sound, decision to single out a product to be representative. The mapping of this product then allowed consideration to be made in regard to the majority of all operations occurring within the production system of each product unit. This resulted in maps which are accurate, but not without a certain degree of uncertainty. In particular, uncertainty manifests in three aspects: process time, number of operators and planning. What is common for the three product units analyzed at RUAG Space is that the duration of manual labor work registered for each operation is at best vague. This is the result of a lack of standardized routines in this regard. Unfortunately, this is also reflected in the data presented in the maps. In addition, the product selected through statistical analysis and focus group session for Microwave - the KRX1 Top Assy - was not recently manufactured. The qualitative data collected for this flow could thus be distorted as the operators had to recall the specifics from memory, which has likely diminished over time. Furthermore, the number of operators able to carry out a certain operation or test is varying. Due to irregular market demands, RUAG Space has to semi-frequently reallocate operators leaving the production system in a state of flux. It is simply not possible to standardize the work for each individual at the floor by assigning more permanent tasks. Finally, the planning routines controlling the manufacturing are primarily based on customer demand for specific deliveries of certain projects. From the perspective of the performed mappings, this has not been captured in a systematic way. What has been included is when and where in the flows information is conveyed - but not exactly what the information carries.

Despite these uncertainties, the current state mapping delivered a result which captured the essence of each product unit as a result of the framework used in selecting the product to be mapped. This was decided in unity with key personnel. The purpose of the map is to deliver data to be provided as input to a future project. This data usually goes along the line of the process box data parameters suggested to be collected in the mapping by the VSM models. Due to the nature of the production system at RUAG Space, several of those parameters were not collectable i.e. category C data. This is a consequence of the high variety in the production along with the fact that the majority of operations are performed in a manual fashion and there are just a handful of machines in production. Data that is time-related could have been collected with increased accuracy by monitoring and registering the duration which the operators require as they performed operations. However, there are two risks in doing this. Deductive reasoning leads to the first risk which is connected to statistics. Simply performing the clocking of an operator performing a certain objective one time is not enough - it would have to be performed multiple times to reach a reliable result. The second risk is achieved in the same manner and is connected to variation. Since the products come with such high variation, the probability of the next product manufactured being the same is minimal. This means that the data collected during the time measurement of the previous product will not be reliable.

The fundamental idea behind the framework is to find a way to generalize a flow within a complex production system, and then to proceed and map that flow to provide a current state map. The framework is suitable at RUAG Space, and presumably suitable in equally complex environments. There is a profound reason for this. Using a traditional, or modified, VSM method would, after mapping the selected flow, scan for improvement areas, and provide suggestions as to improve the flow. In the case of this thesis, optimizing a flow which was selected due to its ability to generalize multiple varying flows in a product unit to a single flow could potentially be counterproductive. If the analyzed flow was to be improved - there could be ramifications to the other flows that in this case are represented by the selected flow. It is important to understand that this framework allows for the mapping of a product in a complex environment to provide a realistic overview. While keeping this reason in mind it is still possible to analyze the production flow on an aggregated level and, by cross-referencing against routings of other flows (advantageously the remaining 7 flows presented in the P-P matrices), find room for major improvements common for all flows. It is the improvements found at a detailed level, for instance in operations belonging to one of the sub-assembly flows, which could have unpredictable, negative consequences to other flows within the same product unit.

7. DISCUSSION

This chapter presents a discussion about the framework development, the application of the framework, and implications regarding sustainability.

7.1 DEVELOPMENT OF FRAMEWORK

The framework used in this thesis is visually straightforward but not without complications. As the scope of the thesis was to create a current state mapping of the company as input for another ongoing project, the authors initially assumed that the mapping process of the VSM methodology - or similar - could be applied. This assumption was obstructed as the authors visited the company and the true complexity of its internal operations surfaced. This complexity manifests in two particular regards. First, RUAG Space consist of three product units - Microwave, Antenna and Digital. However, each of these three product units are so fundamentally separated from each other that they can be viewed as individual companies within the company. Second, the profound product variation is consistent throughout all three product units, with a semi-exception of Antenna.

To handle these difficulties, a literature study of theory had to be performed regarding complex production systems and the possibility to conduct mapping in such environments. The literature study revealed that besides the VSM methodology which is suited for linear production systems, there also exist methods similar to VSM but modified to be applied in complex systems. Unfortunately, these methods turned out to be insignificant in the context of RUAG Space. The authors had to scrutinize the theory while working in parallel to establish an empirical context. This combination allowed for the development of a framework with which the complex production system in such an environment as at RUAG Space could be mapped. The framework aims at enabling practitioners working in similar environments to map the production system on a general level. If each product is different from the previous, this dynamic complexity would require a new mapping to be performed for each new product to accommodate for the variations. Instead, it was decided to select the most appropriate product for each product unit through a combination of statistical analysis of historical data and focus interviews in a structured manner. This proved to be the most challenging task of the thesis for three reasons, see Table 24.

Table 24 Difficulties in the development of the framework

Difficulty	Explanation
Complex flows	The complexity of the operations performed made it necessary to map the flows on a generalized level
High variation and lack of documentation	Little to none documentation made it particularly difficult to capture certain parameters such as scrap rate, pack size and number of product variations
Labor intensive work	Since most of the production is performed in a manual fashion, certain traditional mapping parameters were insignificant - such as change over time and up-time

The challenge in the task was augmented by the fact that the products selected for mapping were not currently, or had not recently been manufactured. This led to difficulties in gathering certain data as the operators had to recall and approximate from memory.

7.2 APPLYING THE FRAMEWORK

The authors were successful in terms of gathering empirical data as the personnel at the company were accommodating and curious about the project. However, due to the difficulties in gathering completely accurate data the current state map held a certain degree of uncertainty. The authors tried to mitigate these uncertainties to the largest possible extent through a combination of historical data analysis regarding reported times - where it existed - in combination to the statements of the interviewed operators. Furthermore, the mapping which was originally intended to represent RUAG Space had to be divided to represent the three product units, as it became evident that they differed significantly from each other. This increased the complexity, and a process map displaying each product unit was created to reinforce the understanding of the company by providing an overhead perspective. In addition, RUAG Space's three product units display their respective flows at an aggregated sub-assembly level on their homepage. It was unbeknownst to the authors that this was the case, and as the routings and BOMs were extracted from the ERP system and analyzed, multiple flows emerged which had to be individually treated during the mapping process. However, once the understanding of each product unit had been solidified and a clear structure as of how to conduct the mapping was decided, the mapping itself proved to be a straightforward process.

Additionally, a complication occurred during the analysis and mapping of the Antenna flow. After the mapping sequences had been completed it was revealed, by chance, that there was a flow beyond the final Top Assy flow. In this flow, the majority of the testing procedures for the final product were performed. The reason why this flow remained hidden was because of the delimitations set for the thesis. The tests are performed outside of any production flows, by engineers, and as the established delimitations confined the research to the physical initiation to physical storing of the product this flow was not detected. This is a major difference which separates Antenna from the Microwave and Digital production units, as the latter have their product test operations directly part of their production flows.

Finally, the authors would like to raise an issue related to the esthetics and visualization of the resulting current state maps, presented in Appendices H-J. As the data for each product unit had been gathered, it was translated to a digital visualization using the Visio software. In the case of this thesis, this turned out to be both positive and negative. The positive aspect was that structured and visually agreeable maps could be created. In a negative way, due to the complexity of the product units and the sheer amount of operations, the resulting maps were immense. It was simply not possible to include each aspect of the maps directly in the report. Extractions and compromises had to be made by the authors to display the results, and the remaining parts had to be confined to the appendices. This was however not considered a major drawback as the maps could easily be printed for use by RUAG Space, or digitally examined by other stakeholders. The fragments displayed in the report served as clarifications and complementary information in conjunction to the developed framework.

7.3 SUSTAINABILITY

Considering sustainability in this thesis can only occur in an indirect manner, as there are no suggestions proposed on how to improve the existing system. However, the current state mapping as well as the developed framework enables the company (and future practitioners) to work in a sustainable fashion. If the framework had not been developed, companies may use a traditional VSM for their complex systems which could generate questionable results. The framework provides a possibility for mapping a complex system which allows the practitioner to integrate sustainability in the solutions whilst knowing the mapping is accurate.

8. CONCLUSION AND FUTURE WORK

In this study, a framework for mapping complex production systems has been developed and applied to capture and visualize the current state at RUAG Space. Here, the research questions are answered based on the literature study, results and the analysis of the framework.

8.1 ANSWERING THE RESEARCH QUESTIONS

RQ1: How can a value stream framework support the current state mapping of a complex production system?

It has been discussed throughout this study whether or not it is possible to capture and map the current state of a complex production system. Existing theory and semi-structured interviews were analyzed, and provided inspiration to build the framework which was applied in this thesis. It was shown that the framework can support a current state mapping in this endeavor. The framework provides a structured way to take informed decisions, and makes it possible to select and map products in non-linear environments which are not otherwise suitable for mapping using a VSM methodology.

RQ2: How could a value stream framework aid in selecting representative products for mapping?

It was possible for the framework to capture the flow to a certain degree. The framework targets the production system on a general level, to generate a representative map in a production system where there is great product variation. To capture such an entire complex system, like the one at RUAG Space, in its true state would require mapping of each product due to the variation between each project. It is a futile enterprise, since the variation is a constant factor. To handle this complication, it is therefore necessary to perform considerable context research before initiating the mapping, to select products to generalize the flow in such a way that it mitigates the uncertainties to the largest possible extent. In the framework, this refers to quantitative analysis from ERP-data which are structured in pareto-diagrams to provide an historical perspective of the production. This allows possible candidates to be eliminated immediately solely based on production volumes. Following, the operations performed for the remaining products were, through their respective routings, aggregated on a workcenter level to simplify and add structure. These factors were then combined to form P-P matrices which allow for an overhead comparison of the products, both with regards to volume as well as similarities in routings. However, as uncertainties regarding future customer demand and whether a product that is either a parent or sub-assembly should be selected, a qualitative dimension was added through the focus group sessions.

8.2 FUTURE WORK

In a future scenario, it would be beneficial to evaluate the potential of the framework by applying it in other complex systems. This would aid in confirming the conclusions drawn from the application during this study. Furthermore, the delimitations in this thesis prevented analysis from occurring regarding the processes of the planning and organization departments. The aspects (such as order planning and structural organization) would have increased the understanding of certain parts of this work, for instance how the batches in the flows are initiated and the reasoning behind them. In future efforts, the framework would therefore benefit from having its first step (establish context) expanded to include those aspects and aid in generating a more enhanced understanding. Furthermore, a weakness which was discovered during the project was the lack of reliable KPI data which could be used to describe the current state during the mapping phase. It would therefore be beneficial for the company to implement standardizations to report data (such as scrap rate and actual times) to the ERP system which can be statistically analyzed after a new mapping has occurred. This would help to further increase the understanding as well as allow the practitioners to locate problem-areas.

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APPENDIX A - QUESTIONNAIRE AND INTERVIEWEES

Appendix A display the relation between the interviewees and the discussed topics used during the semi-structured interviews.

Interviewee	Product Unit	Organization	Manufacturing	Information	Strategy
Ulrika Larsson	Microwave	X			
Mats Wahlström	Microwave		X	X	
Stefan Persson	Microwave	X	X	X	
Bengt Mattsson	Digital	X			
Magnus Årebro	Digital		X	X	
Niklas Hendtman	Antenna	X	X	X	
Joakim Anjeby	RUAG Space				X

Organization related topics
Roles and responsibility
Shared resources
Workforce/Staff
Flexibility of workforce/staff

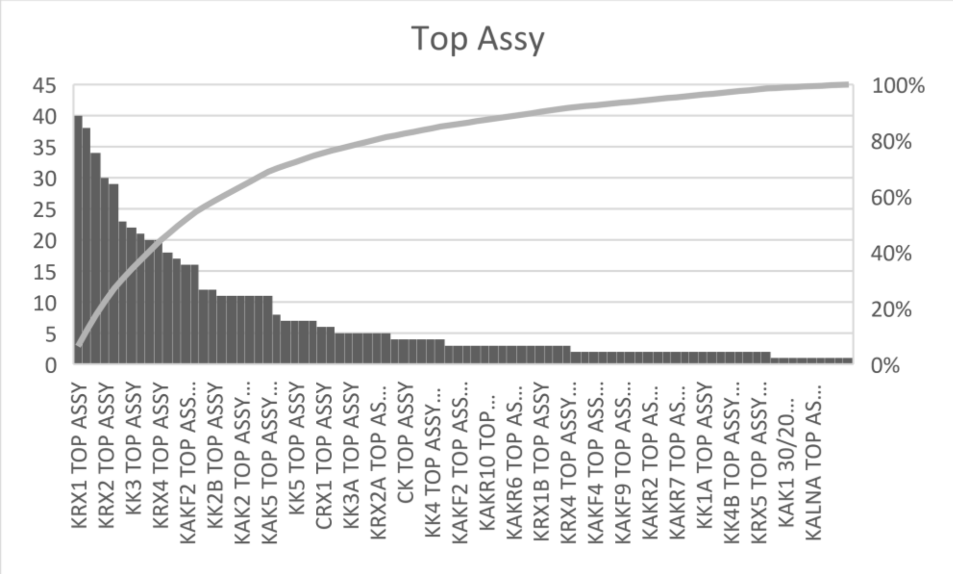
Manufacturing related topics
Product portfolio and variants
Manufacturing steps and processes
Customer Order Decoupling Point
Differences/Similarities in BOM/Routing
ERP Statistics/Data
Subassemblies and components

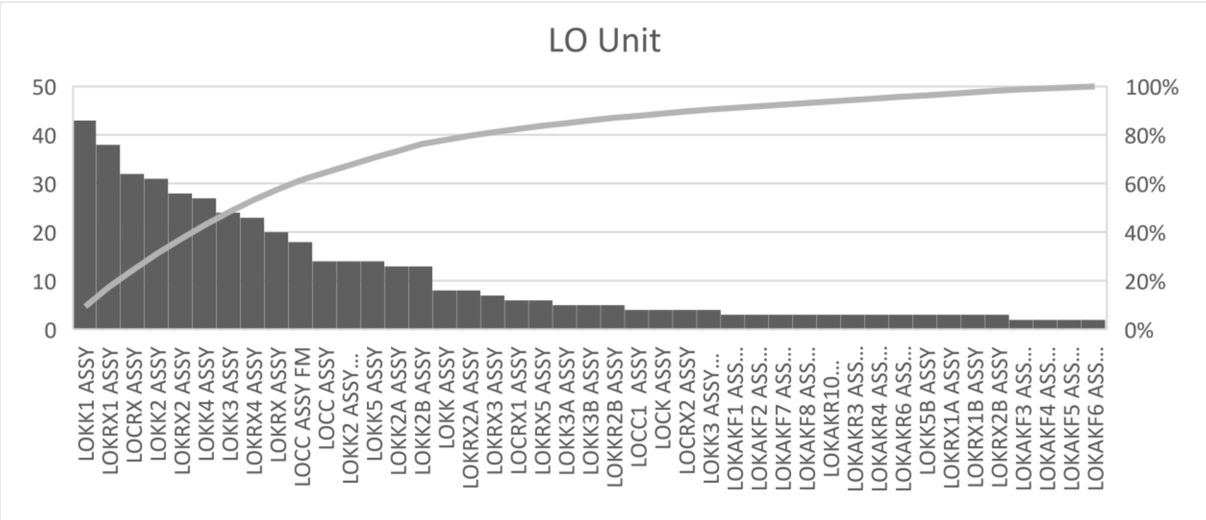
Information related topics
Meeting/Communication structure
ERP-system functionalities/structure
Communication within the organization

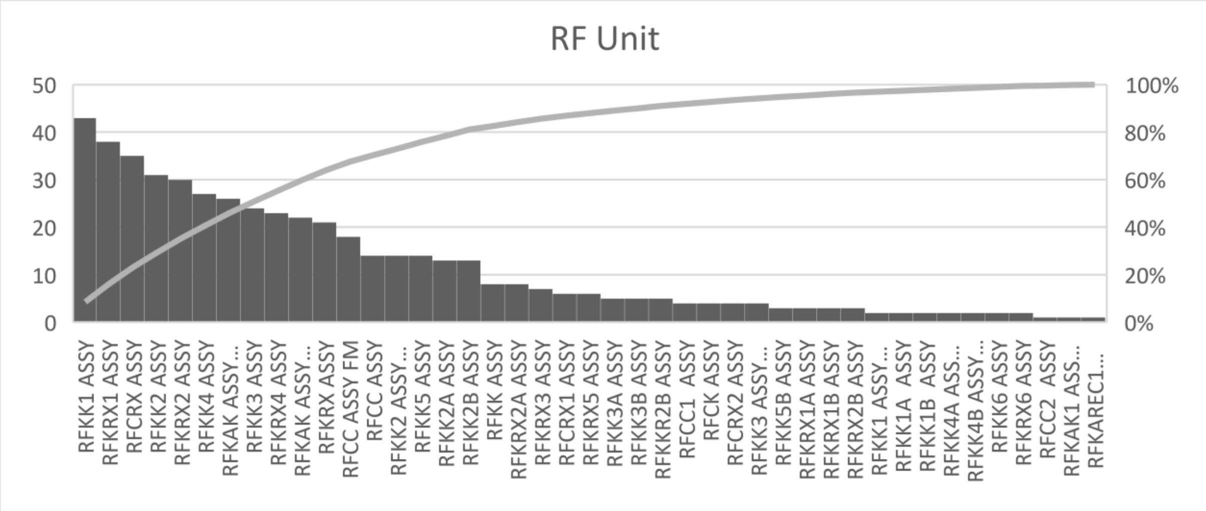
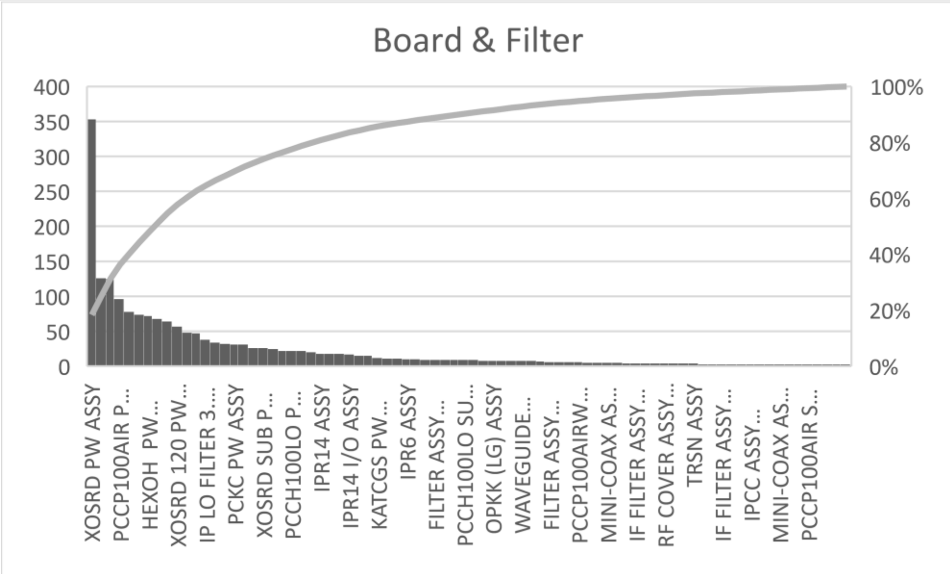
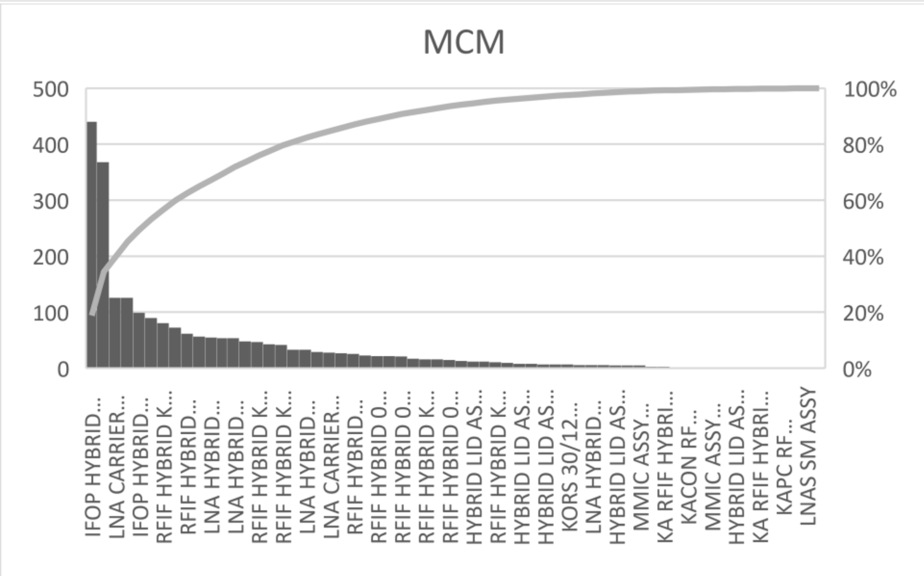
Strategy related topics
Corporate strategies and future development
Competition
New markets and customer requirements
New vs recurring products
Product development and trends
Inhouse vs outsourcing of manufacturing
Synergies between product units and support functions

APPENDIX B - PARETO DIAGRAMS, MICROWAVE

Appendix B contains the Pareto Diagrams for the five product types at the Microwave Product Unit, these include; Top Assy, LO Unit, RF Unit, MCM and Board and Filter.






RF Unit
50
40
30
20
10
0
100%
80%
60%
40%
20%
0%
RFKK1 ASSY
RFKRX1 ASSY
RFCRX ASSY
RFKK2 ASSY
RFKRX2 ASSY
RFKK4 ASSY
RFKAK ASSY...
RFKK3 ASSY
RFKRX4 ASSY
RFKAK ASSY...
RFKRX ASSY
RFCC ASSY FM
RFCC ASSY
RFKK2 ASSY...
RFKK5 ASSY
RFKK2A ASSY
RFKK2B ASSY
RFKK ASSY
RFKRX2A ASSY
RFKRX3 ASSY
RFCRX1 ASSY
RFKRX5 ASSY
RFKK3A ASSY
RFKK3B ASSY
RFKKR2B ASSY
RFCC1 ASSY
RFCK ASSY
RFCRX2 ASSY
RFKK3 ASSY...
RFKK5B ASSY
RFKRX1A ASSY
RFKRX1B ASSY
RFKRX2B ASSY
RFKK1 ASSY...
RFKK1A ASSY
RFKK1B ASSY
RFKK4A ASS...
RFKK4B ASSY...
RFKK6 ASSY
RFKRX6 ASSY
RFCC2 ASSY
RFKAK1 ASS...
RFKAREC1...

Board & Filter
400
350
300
250
200
150
100
50
0
100%
80%
60%
40%
20%
0%
XOSRD PW ASSY
PCCP100AIR P...
HEXOH PW...
XOSRD 120 PW...
IP LO FILTER 3....
PCKC PW ASSY
XOSRD SUB P...
PCCH100LO P...
IPR14 ASSY
IPR14 I/O ASSY
KATCGS PW...
IPR6 ASSY
FILTER ASSY...
PCCH100LO SU...
OPKK (LG) ASSY
WAVEGUIDE...
FILTER ASSY...
PCCP100AIRW...
MINI-COAX AS...
IF FILTER ASSY...
RF COVER ASSY...
TRSN ASSY
IF FILTER ASSY...
IPCC ASSY...
MINI-COAX AS...
PCCP100AIR S...

MCM
500
400
300
200
100
0
100%
80%
60%
40%
20%
0%
IFOP HYBRID...
LNA CARRIER...
IFOP HYBRID...
RFIF HYBRID K...
RFIF HYBRID...
LNA HYBRID...
LNA HYBRID...
RFIF HYBRID K...
RFIF HYBRID K...
LNA HYBRID...
LNA CARRIER...
RFIF HYBRID...
RFIF HYBRID 0...
RFIF HYBRID 0...
RFIF HYBRID K...
RFIF HYBRID 0...
HYBRID LID AS...
RFIF HYBRID K...
HYBRID LID AS...
HYBRID LID AS...
KORS 30/12...
LNA HYBRID...
HYBRID LID AS...
MMIC ASSY...
KA RFIF HYBRI...
KACON RF...
MMIC ASSY...
HYBRID LID AS...
KA RFIF HYBRI...
KAPC RF...
LNAS SM ASSY

APPENDIX C - PRODUCT-PROCESS MATRICES, MICROWAVE

Appendix C contains the P-P Matrices for the five product types at the Microwave Product Unit, these include; Top Assy, LO Unit, RF Unit, MCM and Board and Filter.

Product/Process Matrix	KRX1 TOP ASSY	KK1 TOP ASSY	CRX TOP ASSY	KRX2 TOP ASSY	KK2 TOP ASSY	KK4 TOP ASSY	KK3 TOP ASSY	CC TOP ASSY FM
Microwave Object Manager	X	X	X	X	X	X	X	X
Microwave Kitting	X	X	X	X	X	X	X	X
Manual Assembly Electronics	X	X	X	X	X	X	X	X
Microwave Mechanical Measurement	X	X	X	X	X	X	X	X
Microwave TopAssy Inline	X	X	X	X	X	X	X	X
Microwave TopAssy Test Engineer	X	X	X	X	X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Microwave TopAssy Test Engineer	X		X		X			
Microwave TopAssy Acceptans Test	X		X		X			
Manual Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Inline	X	X	X	X	X	X	X	X
Microwave TopAssy QC	X	X	X	X	X	X	X	X
Manual Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Manual Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Manual Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Inline		X			X	X	X	X
Microwave TopAssy Acceptans Test	X	X	X	X	X	X	X	X
Microwave Mechanical Measurement			X	X				
Microwave TopAssy Inline	X	X	X	X	X	X	X	X
Manual Assembly Electronics	X			X				
Microwave TopAssy QC	X	X	X	X	X	X	X	X
Microwave Object Manager	X	X	X	X	X	X	X	X
Manual Assembly Electronics		X			X	X	X	X
Microwave TopAssy Inline		X			X	X	X	X
Manual Assembly Electronics	X	X	X	X	X	X	X	X
Microwave TopAssy Inline	X		X	X				
Microwave TopAssy QC	X		X	X				
Microwave Object Manager	X	X	X	X	X	X	X	X

Product/Process Matrix	IFOP HYBRID ASSY (12 GHZ) CERAMIC,	RFIF HYBRID ASSY (14/12) Ceramic, 1	LNA CARRIER ASSY (14 GHZ, 3X NEC)	LNA HYBRID ASSY (14 GHZ) Kovar, 3 t	IFOP HYBRID ASSY (4 GHZ) CERAMIC, 4	RFIF HYBRID ASSY (6/4) Ceramic, 12	RFIF HYBRID KA SLICE ASSY VAR 02	RFIF HYBRID KA SLICE ASSY VAR 02
MCM-Common	X	X	X	X	X	X	X	X
MCM-Die bonding	X	X	X		X	X	X	X
MCM-Wedge bonding	X	X	X	X	X	X	X	X
MCM-Die bonding	X							
MCM-Test				X			X	X
MCM-Wedge bonding							X	X
MCM-Test	X					X	X	X
MCM-Common	X	X	X	X	X	X	X	X
MCM-PQA	X	X	X	X	X	X	X	X
MCM-Common							X	X
MCM-MIP	X	X	X	X	X	X	X	X
MCM-Common	X	X	X	X	X	X	X	X
EXTERN BELÄGGNINGSGRUPP	X	X	X	X	X	X	X	X
MCM-Common	X	X	X	X	X	X	X	X
MCM-Test	X	X	X	X	X	X	X	X
MCM-Common	X	X	X	X	X	X	X	X
MCM-OM	X	X	X	X	X	X	X	X

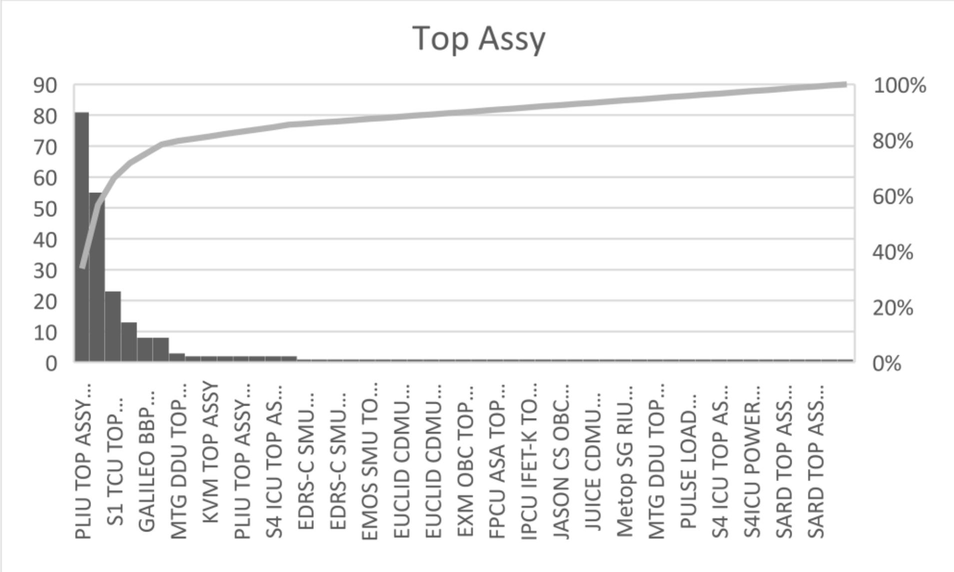
Product/Process Matrix	LOKK1 ASSY	LOKRX1 ASSY	LOCRX ASSY	LOKK2 ASSY	LOKRX2 ASSY	LOKK4 ASSY	LOKK3 ASSY	LOKRX4 ASSY
Microwave Object Manager	X	X	X	X	X	X	X	X
Microwave Kitting	X	X	X	X	X	X	X	X
Microwave LO Unit Assembly	X	X	X	X	X	X	X	X
Microwave LO Unit Inline	X	X	X	X	X	X	X	X
Microwave LO Unit QC	X	X	X	X	X	X	X	X
Microwave LO Unit Assembly	X	X	X	X	X	X	X	X
Microwave LO Unit Test Engineer	X	X	X	X	X	X	X	X
Microwave LO Unit Assembly	X	X	X	X	X	X	X	X
Microwave LO Unit Test Engineer	X	X	X	X	X	X	X	X
Microwave LO Unit Assembly	X	X	X	X	X	X	X	X
Microwave LO Unit Inline	X	X	X	X	X	X	X	X
Microwave LO Unit QC	X	X	X	X	X	X	X	X
Microwave LO Unit Assembly	X	X	X	X	X	X	X	X
Microwave LO Unit Inline	X	X	X	X	X	X	X	X
Microwave LO Unit Assembly	X	X	X	X	X	X	X	X
Microwave Object Manager	X	X	X	X	X	X	X	X

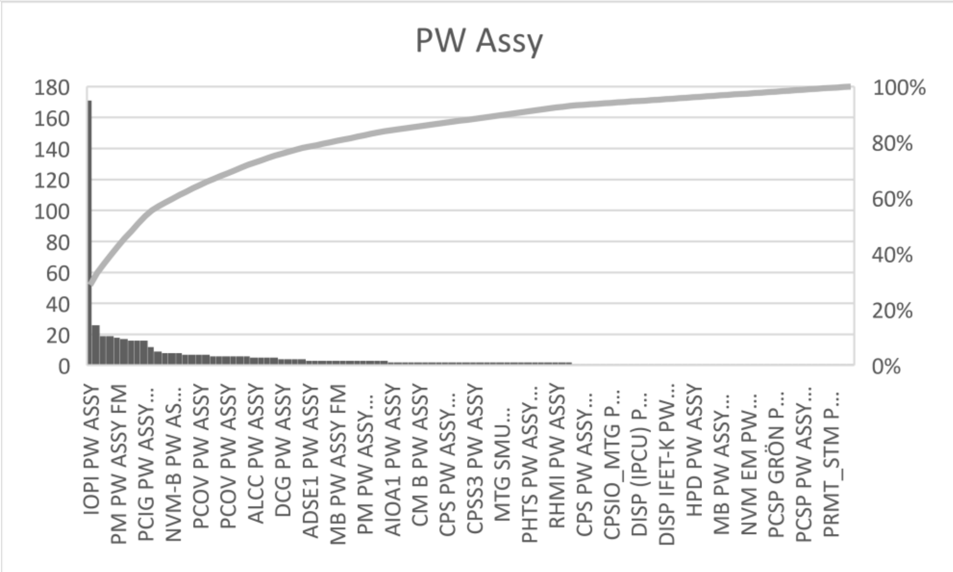
Product/Process Matrix	RFKK1 ASSY	RFKRX1 ASSY	RFCRX ASSY	RFKK2 ASSY	RFKRX2 ASSY	RFKK4 ASSY	RFKAK ASSY (X4A)	RFKK3 ASSY
Microwave Object Manager							X	
Microwave Kitting	X	X	X	X	X	X	X	X
Manual Assembly Electronics					X		X	
Microwave RF Unit Assembly	X	X	X	X				
Microwave Mechanical Measurement		X	X		X			
Manual Assembly Electronics					X			
Microwave TopAssy Inline					X			
Manual Assembly Electronics					X			
Microwave TopAssy Inline					X		X	
Microwave TopAssy QC					X		X	
Manual Assembly Electronics					X		X	
Microwave RF Unit Assembly			X					
Microwave RF Unit Inline			X					
Microwave RF Unit Assembly			X					
Microwave RF Unit Inline			X					
Microwave RF Unit QC			X					
Microwave RF Unit Assembly			X					
Microwave Object Manager			X					
Microwave Kitting			X					
Microwave RF Unit Assembly			X					
Microwave Mechanical Measurement			X					
Microwave RF Unit Assembly		X	X			X		X
Microwave RF Unit Inline	X	X	X	X		X		X
Microwave RF Unit Assembly	X	X	X	X		X		X
Microwave RF Unit Inline	X	X	X	X		X		X
Microwave RF Unit QC	X	X	X	X		X		X
Microwave RF Unit Assembly	X	X	X	X		X		X
Microwave Object Manager	X	X	X	X	X	X	X	X

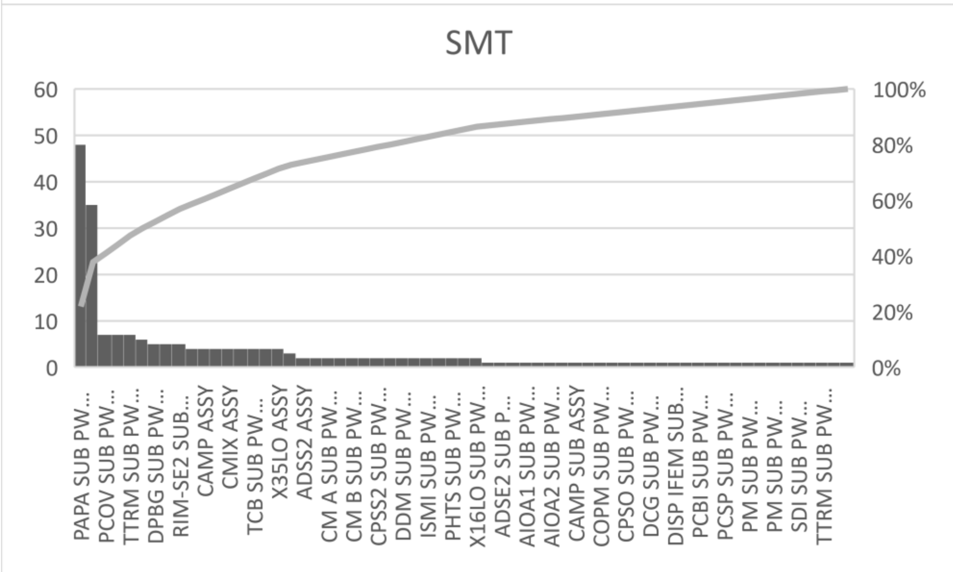
Product/Process Matrix	XOSRD PW ASSY	TRSN ASSY (XOSRD)	PCCP100LO PW ASSY	PCCP100AIR PW ASSY	OPKK ASSY FM	TCGSC X1/X4 PW ASSY FM	HEXOH PW ASSY FM	PCCK50AS PW ASSY
Microwave Kitting	X	X	X	X	X	X	X	X
Microwave Small Board Assembly		X			X	X		
Microwave Small Board Inline		X			X	X		
Microwave Small Board QC						X		
Microwave Small Board Assembly						X		
Microwave PCC Assembly			X					
Microwave PCC Inline			X					
Microwave PCC Assembly			X					
Microwave PCC Inline			X					
Microwave PCC Assembly			X					
Microwave PCC Inline			X					
Microwave PCC Test Engineer			X					
Microwave PCC Assembly			X					
Microwave PCC QC			X					
Microwave PCC Assembly			X					
Microwave PCC Inline			X					
Microwave PCC Assembly			X					
Microwave PCC Inline			X					
Microwave XOSRD Assembly	X							
Microwave XOSRD Inline	X							
Microwave XOSRD Assembly	X							
Microwave XOSRD Inline	X							
Microwave XOSRD QC	X							
Microwave XOSRD Assembly	X							
Microwave XOSRD Inline	X							
Manual Assembly Electronics				X				X
Microwave TopAssy Inline				X				X
Manual Assembly Electronics				X				X
Microwave TopAssy Inline				X				X
Manual Assembly Electronics				X				X
Microwave TopAssy Inline				X				X
Microwave TopAssy Acceptans Test				X				X
Manual Assembly Electronics				X				X
Microwave TopAssy Acceptans Test				X				X
Manual Assembly Electronics				X			X	X
Microwave TopAssy Inline				X			X	X
Manual Assembly Electronics				X			X	X
Microwave TopAssy Inline				X			X	X
Microwave Object Manager	X	X	X	X	X	X	X	X

APPENDIX D - PARETO DIAGRAMS, DIGITAL

Appendix D contains the Pareto Diagrams for the three product types at the Digital Product Unit, these include; Top Assy, PW Assy and SMT.







APPENDIX E - PRODUCT-PROCESS MATRICES, DIGITAL

Appendix E contains the P-P Matrices for the three product types at the Digital Product Unit, these include; Top Assy, PW Assy and SMT.

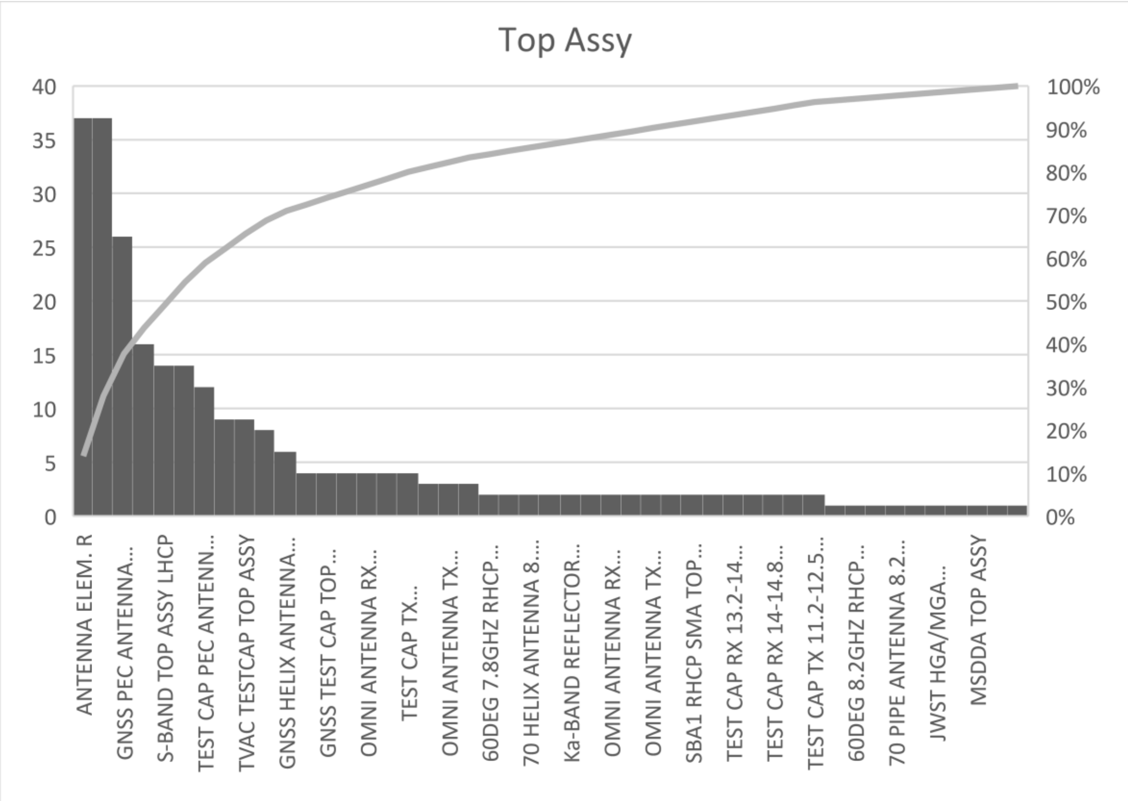
Product / Process Matrix	PLIU TOP ASSY FM	ARIANE 5 OBC-C TOP ASSY FM	S1 TCU TOP ASSY PFM+FM	VEGA OBC TOP ASSY FM	GALILEO BBP TOP ASSY FM	GALILEO CDU TOP ASSY FM	MTG DDU TOP ASSY EQM	ADSEM TOP ASSY PFM
501 - Kitting	X	X	X	X	X	X	X	X
100 - Manual Assembly Electronics	X	X	X	X	X	X	X	X
301 - In Line Inspection	X	X	X	X	X	X	X	X
100 - Manual Assembly Electronics	X	X	X	X	X	X	X	X
303 - Analyslab		X						
301 - In Line Inspection	X	X	X	X			X	
201 - Board (DIG) Test Engineer			X					X
100 - Manual Assembly Electronics		X	X	X				
301 - In Line Inspection		X		X				
201 - Board (DIG) Test Engineer		X						
100 - Manual Assembly Electronics		X						X
301 - In Line Inspection		X						
201 - Board (DIG) Test Engineer		X						
301 - In Line Inspection		X						
300 - QC in Production	X	X	X	X	X	X	X	X
100 - Manual Assembly Electronics		X	X					X
301 - In Line Inspection		X	X					X
100 - Manual Assembly Electronics		X	X					X
301 - In Line Inspection		X	X					X
300 - QC in Production		X						
100 - Manual Assembly Electronics		X	X					X
301 - In Line Inspection		X						X
100 - Manual Assembly Electronics		X						
301 - In Line Inspection		X						
300 - QC in Production		X						
502 - Inc Insp Mechanical and PCB	X	X	X			X	X	
207 - Vacuum-Vibration-Shock TestOperator	X	X						
201 - Board (DIG) Test Engineer				X		X		
300 - QC in Production			X					
210 - Acceptance (DIG) Test Engineer	X	X	X	X	X			
301 - In Line Inspection		X		X		X		
207 - Vacuum-Vibration-Shock TestOperator	X		X					
100 - Manual Assembly Electronics		X				X		
201 - Board (DIG) Test Engineer			X				X	
210 - Acceptance (DIG) Test Engineer	X		X					
100 - Manual Assembly Electronics			X	X			X	
301 - In Line Inspection	X	X		X			X	
100 - Manual Assembly Electronics							X	
300 - QC in Production	X	X	X	X	X	X	X	
100 - Manual Assembly Electronics	X	X		X			X	
400 - Object Mgmt in Prod	X	X	X	X	X	X	X	X

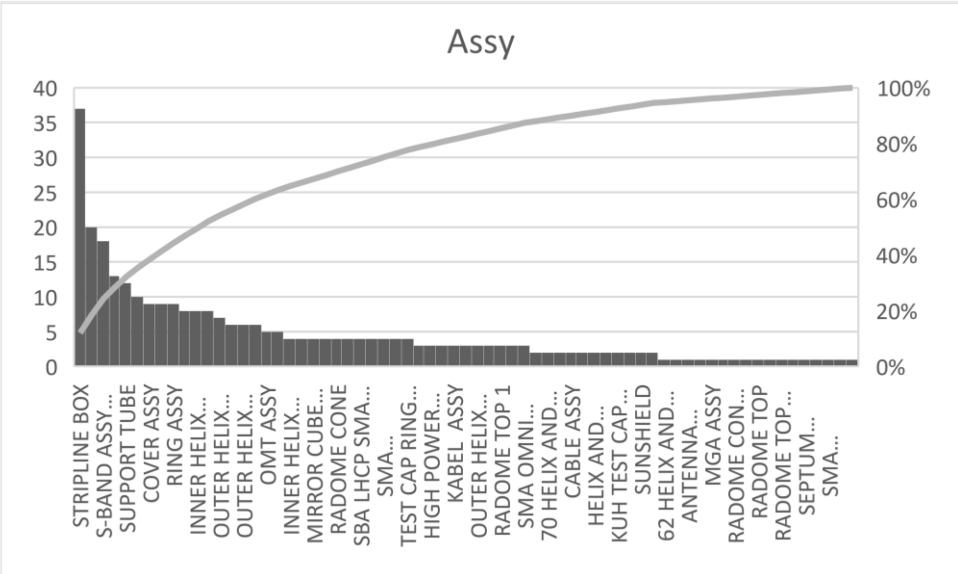
Product / Process Matrix	PW Assy 1	PW Assy 2	PW Assy 3	PW Assy 4	PW Assy 5	PW Assy 6	PW Assy 7	PW Assy 8
901 - BB Obj. Mngt BB		X						
900 - BB Montering		X						
500 - SMT		X						
302 - X-ray inspection		X						
900 - BB Montering		X						
901 - BB Obj. Mngt BB		X						
501 - Kitting	X		X	X	X	X	X	X
100 - Manual Assembly Electronics	X		X	X	X	X	X	X
301 - In Line Inspection	X		X	X	X	X	X	X
100 - Manual Assembly Electronics	X		X	X	X	X	X	X
301 - In Line Inspection	X		X	X	X	X	X	X
100 - Manual Assembly Electronics			X					X
301 - In Line Inspection								X
201 - Board (DIG) Test Engineer	X			X	X	X	X	X
100 - Manual Assembly Electronics					X	X	X	X
301 - In Line Inspection					X			X
201 - Board (DIG) Test Engineer					X			X
100 - Manual Assembly Electronics								X
502 - Inc Insp Mechanical and PCB				X	X			
301 - In Line Inspection	X		X	X	X			
300 - QC in Production	X		X	X	X	X	X	X
100 - Manual Assembly Electronics	X		X	X	X	X	X	X
301 - In Line Inspection	X		X	X	X	X	X	X
100 - Manual Assembly Electronics	X		X	X	X	X	X	X
301 - In Line Inspection	X		X	X	X	X	X	X
100 - Manual Assembly Electronics			X					
400 - Object Mgmt in Prod	X	X	X	X	X	X	X	X

Product / Process Matrix	SMT 1	SMT 2	SMT 3	SMT 4	SMT 5	SMT 6	SMT 7	SMT 8
501 - Kitting	X	X	X	X	X	X	X	X
303 - Analyslab		X						
500 - SMT	X	X	X	X	X	X	X	X
302 - E-ray Inspection						X		
301 - In Line Inspection	X	X	X	X	X	X		
400 - Object Mgmt in Prod	X	X	X	X	X		X	X

APPENDIX F - PARETO DIAGRAMS, ANTENNA

Appendix F contains the Pareto Diagrams for the two product types at the Antenna Product Unit, these include; Top Assy and Assy.





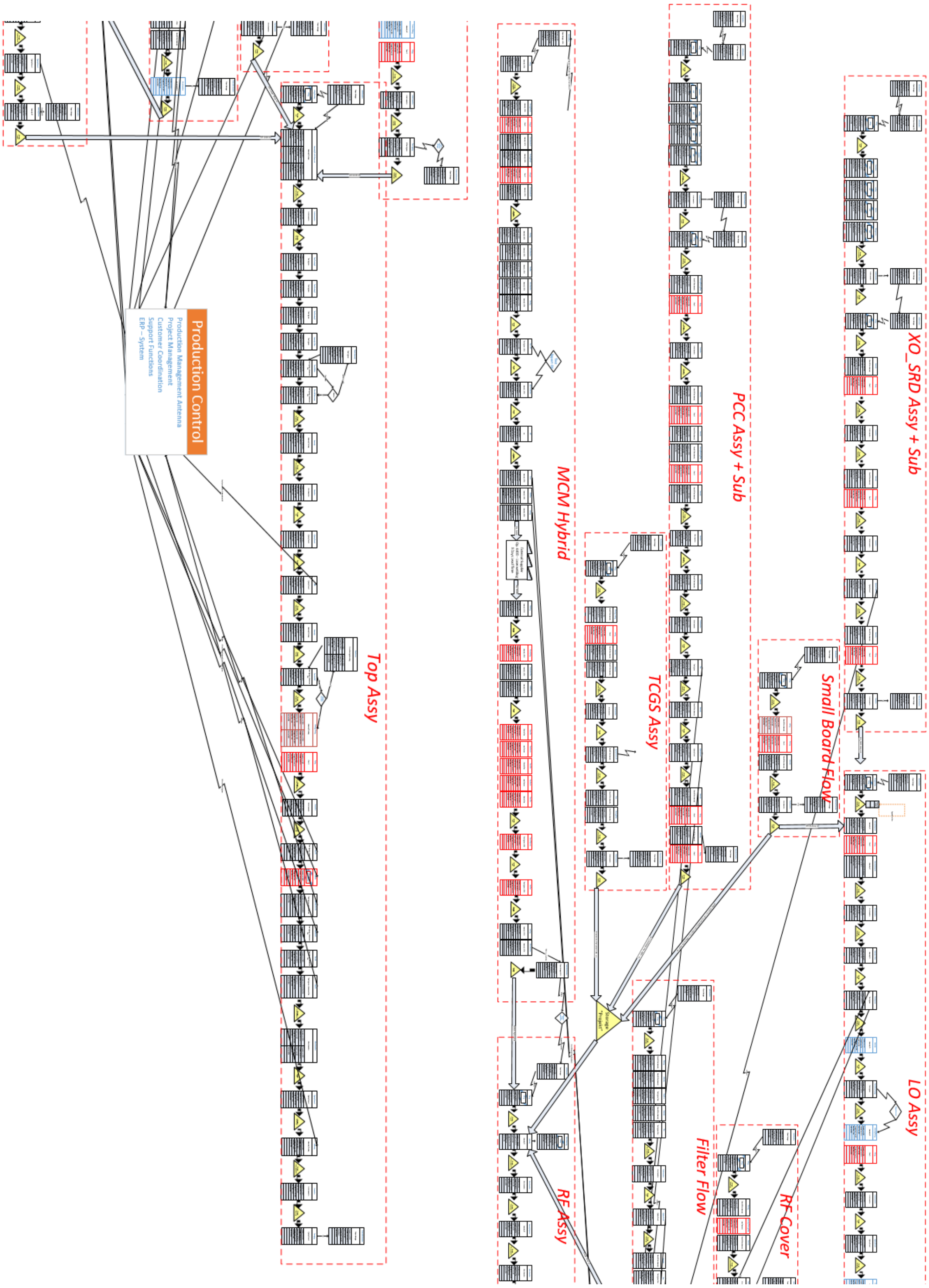
APPENDIX G - PRODUCT-PROCESS MATRICES, ANTENNA

Appendix F contains the P-P Matrices for the two product types at the Antenna Product Unit, these include; Top Assy and Assy. In the first matrix, two adjacent columns constitute a product (i.e. S-BAND TOP ASSY LHCP and S-BAND TOP ASSY RHCP).

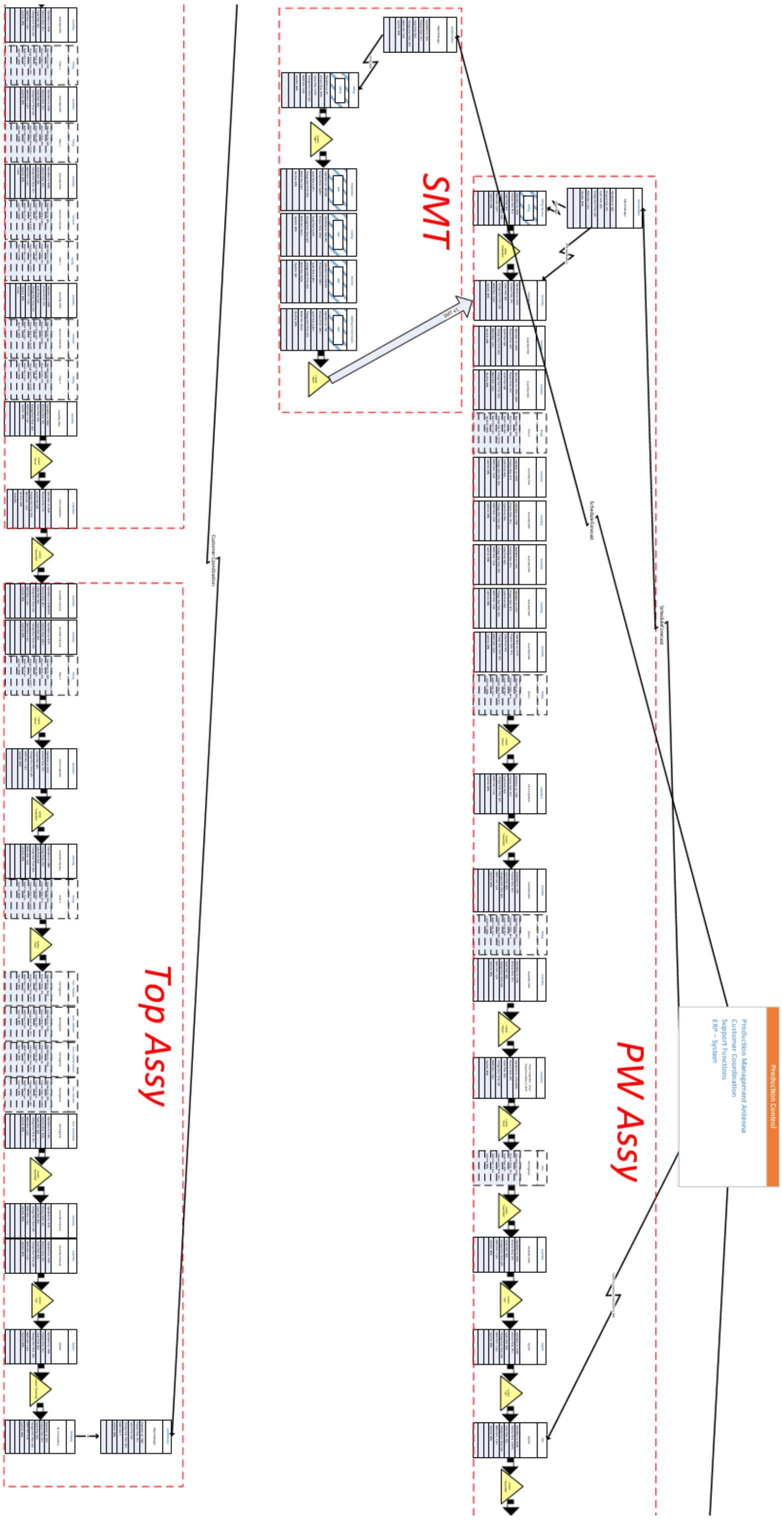
Product/Process Matrix	ANTENNA ELEM. R	ANTENNA L POL	GNSS PEC ANTENNA WITH CHOKE RINGS T	GNSS PEC ANTENNA TOP ASSY	S-BAND TOP ASSY LHCP	S-BAND TOP ASSY RHCP	TEST CAP PEC ANTENNA TOP ASSY	TEST CAP TOP ASSY
Manual Assembly Antenna	X	X	X	X	X	X	X	X
PD ANTENN ILI	X							
QC in Production		X	X	X	X	X		
Manual Assembly Antenna	X	X	X	X	X	X		
QC in Production			X	X	X	X		
Manual Assembly Antenna			X	X	X	X		
ANTENN KONSTRUKTION TEST					X	X		
PD ANTENN ILI	X							
QC in Production	X	X						
Manual Assembly Antenna	X				X	X		
EXTERN BELÄGGNINGSGRUPP					X	X		
PD ANTENN ILI	X							
Manual Assembly Antenna	X				X	X		
QC in Production					X	X		
PD ANTENN ILI	X							
Manual Assembly Antenna	X							
PD ANTENN ILI	X							
Manual Assembly Antenna	X							
PD ANTENN ILI	X							
Object Mgmt in Prod	X	X	X	X	X			

Product/Process Matrix	STRIPLINE BOX	RADOME ASSY	S-BAND ASSY LHCP	S-BAND ASSY RHCP	SUPPORT TUBE	OUTER HELIX CONE	COVER ASSY	CYLINDER ASSY
Manual Assembly Antenna	X	X	X	X	X	X	X	X
QC in Production	X		X	X				
Manual Assembly Antenna	X		X	X				
QC in Production	X							
Manual Assembly Antenna	X							
QC in Production	X							
Manual Assembly Antenna	X							
BEREDARE P	X							

APPENDIX H - CURRENT STATE MAP – MICROWAVE



APPENDIX I - CURRENT STATE MAP - DIGITAL



APPENDIX J - CURRENT STATE MAP – ANTENNA