CHALMERS
UNIVERSITY OF TECHNOLOGY

Mapping of current state and design of new production layout at a satellite equipment manufacturer

Master's thesis in Production Engineering

JONATAN BERG
CARL-JOHAN GULDSTRAND

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

Mapping of current state and design of new production layout at a satellite equipment manufacturer

JONATAN BERG
CARL-JOHAN GULDSTRAND

Supervisor: Erik Lindskog

Examiner: Björn Johansson

Department of Product and Production Development

Division of Production Systems

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden, 2014

Mapping of current state and design of new production layout at a satellite equipment manufacturer

JONATAN BERG
CARL-JOHAN GULDSTRAND

Department of Product and Production Development

Division of Production Systems

Chalmers University of Technology

SE-412 96 Gothenburg, Sweden

Telephone: +46 (0)31-772 1000

Cover:
The cover picture is taken from an internal document intended for commercial purposes at RUAG Space.

Reproservice, Chalmers

Gothenburg, Sweden, 2014

Abstract

At RUAG Space, a satellite equipment manufacturer in western Sweden, the company has identified an increased demand for shorter lead times. To meet the customers' demand, the company rearranged its organization from a functional oriented to a product oriented organization. However, the production layout is still based on the old functional organization resulting in a complex production flow. Thus, a new layout is requested that can better reflect the overall business strategic focus of a product flow oriented organization.

The purpose of the thesis is to map the current layout and production flow and to suggest a flow oriented production layout within RUAG Space that meet the individual requirements of the product families.

In order to develop a new product flow oriented layout, the current state layout and production flow was mapped and analysed using process mapping. Based on the current state analysis, a future state layout could be developed using three main methods: Factory Flow Analysis, Systematic Layout Planning and Group Analysis. To validate that the generated concept would meet the company's strategy of becoming more flow oriented, the concept was evaluated based on its production flow. Furthermore the generated concept was also evaluated whether it contributed to the product families' individual requirements in terms of their performance objectives.

The results shows a holistic view of the current state production layout, including the current production flow. Furthermore, the results provides a new product flow oriented layout concept in accordance to RUAG Space's new organization. This was mainly achieved by separating the Digital and Microwave productions. Lastly, the evaluation of the generated concept shows that the suggested layout contributes to fulfil each of the product families' individual performance objectives. The future state layout supports both Antenna and Digital to have a flexible production whereas Microwave are enabled to have a more flow oriented production with faster throughput times.

Keywords: *Production layout, Systematic Layout Planning, Factory Flow Analysis, Process mapping, Production flow.*

Acknowledgement

The authors would like to thank Chalmers University of Technology and RUAG Space for initiating an interesting and educative master thesis work. We would especially like to thank our supervisor Erik Lindskog and our examiner Björn Johansson at Chalmers. Special thanks also go to the project board at RUAG Space for their great support throughout the thesis work. We would finally like to thank employees at RUAG Space for their patience with guiding us through the facilities and participating in interviews.

Gothenburg, May, 2014
Jonatan Berg & Carl-Johan Guldstrand

Table of contents

1 Introduction

This chapter introduces the background to the thesis which is carried out at RUAG Space's production site in Gothenburg. The company and their products are briefly presented followed by a problem discussion, purpose, objectives, research questions and delimitations for the thesis.

1.1 Background

Product quality is very important for RUAG Space and their customers. Their customers put a heavy emphasis on compact, lightweight products in order to reduce the payload of their satellites and rockets. They also demand reliable products that will not break down since the options for maintenance once the products are in space are very limited.

Another critical success factor for RUAG Space, besides product quality, is the time-to-market and an important part of reducing the time-to-market is to have a short production lead time. Over the years RUAG Space has gradually changed and expanded their business and production capabilities. However, when new production functions and processes were installed they were installed incrementally without looking at the larger picture. As a consequence of the incremental installation the process flow has become somewhat complex, which may have an impact on the product lead times. RUAG Space has therefore identified a need for an overall evaluation of the production layout in order to reduce the lead time without compromising on the quality of their products.

1.2 Company introduction

RUAG Space is a leading supplier of products related to the space industry in Europe and is a part of the RUAG Group, which is an international group of aerospace and defence technology companies. RUAG Space employs around 1100 people and has a total of seven production sites located throughout Switzerland, Sweden and Austria. RUAG Space has two production sites in Sweden, one located in Linköping and the other in Gothenburg. Gothenburg is the largest of these production sites with its 320 employees (2012). RUAG Space in Gothenburg comprises three main production areas: digital electronics, microwave electronics and antennas.

Since the thesis only concerns the production site in Gothenburg, it will for simplicity be referred to as *RUAG Space* throughout the report (and should thus not be confused with the site in Linköping or any of the other facilities in Austria or Switzerland)

1.2.1 Organization

Historically RUAG Space’s organization has been oriented around production functions rather than product families. Employees in one production function, such as testing or assembly, worked with several different types of products as they came in regardless of what product family it belonged to. This way of working is reflected in the current production layout as it is heavily function based with for example all test equipment gathered in one place without regards to what is actually being tested.

RUAG Space decided a few years back that this would not do and that the organizational structure had to be more flow oriented. As such the company adopted a new organization in 2013 that restructured the old function based organization into departments based on the three main product families. There were no changes to the production layout associated with this organizational change and as such the production layout remains the same as it was with the old organization. However, the operators are now divided organizationally and are dedicated to working with one product family only.

1.2.2 Products

The products manufactured at RUAG Space can be divided into three main product families; Antennas, Microwave Electronics and Digital Electronics. Each of the three product families are described below.

The *Digital Electronics* are RUAG Space's largest product family by sales volume. The product can mainly be divided into three main areas: Command & Data Handling Systems, Guidance & Control and Payload Control Computers. The Digital electronics produced at RUAG Space can be found in various applications such as telecommunications, earth observations, navigations and scientific satellites.

The *Microwave Electronic*s is the second largest product family by sales. The main products within the Microwave segment are Receivers and Frequency Converters. The receivers and converters are used in both communications and Earth observation satellites. The Microwave products have been experiencing a rise in competition during recent years.

The third product family is the *Antenna* segment. RUAG Space is supplying antennas to scientific, Earth observations and commercial satellites. The antenna product family can be divided into four sub categories; wide overage antennas, mobile communication antennas, X-band Helix antennas and antennas for GPS receivers.

1.2.3 Production

The production at RUAG Space takes place inside so called *Clean Rooms* or *Clean Environments* with the intention of reducing the risk of contaminating the products with unwanted particles. The clean room area is further split into 100k classifications and 10k classifications where the numbers entail the maximum amount of particles per cubic meter of air allowed within the rooms. To meet these conditions there are special ventilations in place and personnel and visitors have to follow strict routines and wear designated clothes. Consequently, every square meter of clean room is expensive to maintain and is extra expensive to make extensive changes to because of the need to re-adjust ventilation systems as well as bringing typically unclean tools inside.

A large part of the production equipment, such as fixtures and testing equipment, are tailored to specific production projects which means that the production equipment inside the clean rooms is constantly changing.

1.3 Problem discussion

Constantly changing production equipment tailored for special projects and an expanded need of capacity has resulted in equipment and personnel being placed where they fit for the moment without taking a holistic view of the entire production system. This in turn has led to the overall production flow being difficult to follow and supervise. It also stands in direct violation to the new organizational structure that has created strict administrative boundaries between the product families with a clear flow orientation. Furthermore, this lack of a holistic view has created a situation where it is hard to adapt the manufacturing to the individual requirements of the product families.

1.4 Purpose

The purpose of the thesis is to map the current layout and production flow and to suggest a flow oriented production layout within RUAG Space that meet the individual requirements of the product families.

1.5 Research questions

In order to fulfil the purpose the following research questions were put forth:

- What does the current state of the production layout and production flow look like?
- How can a production flow oriented production layout look for RUAG Space?
- How can a new production layout contribute to meet the requirements of the product families?

1.6 Delimitations

- The thesis will map, evaluate and suggest improvement potentials for the production flow and production layout. Other processes not directly linked to the production will not be included in the project. Furthermore, improvement potentials for individual processes will not be examined and the capacity of available personnel will not be changed.

- Detailed information from the production processes such as names of sub-assemblies and process times will be excluded from the report with respect to RUAG Space's classification policies.

- No exact costs for implementing the suggestions will be included in this thesis. This is because of the complexity of determining costs for changing conditions inside the clean room environment.

2 Theory

This chapter introduces the theoretical framework relevant for the thesis. General theories about production layout types and data gathering are presented. Furthermore, the theoretical framework includes theories related to the methods used both for analysing the current layout and for generating the future concept.

2.1 Performance objectives

The customers' requirements need to be reflected in the operations strategy decision making (Slack and Lewis, 2011). In order to ensure this connection there needs to be objectives in place that are applicable to the operations but still reflects the customer requirements (Slack et al. 2007). It is also important that these objectives provide a balanced picture of the organization (Neely A, 2002). The five *generic performance objectives* is a defined set of objectives that links the customer requirements to the business operations. These five generic performance objectives are:

- Quality
- Speed
- Dependability
- Flexibility
- Cost

The relative importance of these five performance objectives differs from business to business depending on how they are competing on the market (Slack and Lewis, 2011). For instance, if a company competes on a high degree of customization its operations should put emphasis on *flexibility*. Likewise, if the market requires short delivery times, emphasis should be put on *speed* in terms of for example faster throughput time (Slack, Lewis, 2011). Important to note is that the relative priority of the performance objectives might differ from different product families within the same company (Slack and Lewis, 2011).

An illustrative way to present the relative importance between the performance objectives is the *polar diagrams* (Slack et al. 2007). The polar representation can be used to compare different products or services or to relate the actual performance with the required performance, see Figure 2-1 below.

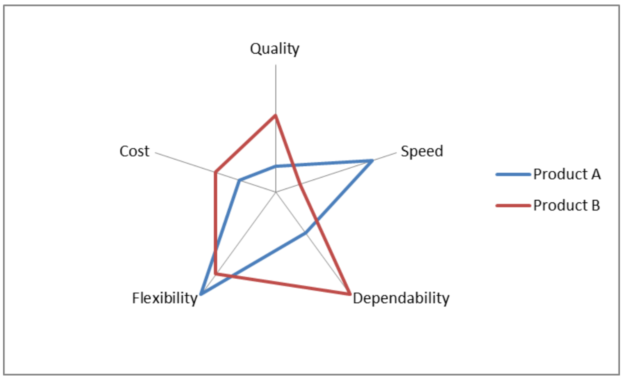

Figure 2-1 Polar diagram. The example compares the performance objectives of two products, A and B, within the same business

2.2 Production layout types

It is important that the production layout support the visions of the organization (Tompkins, J.A, 1996). There are four main layout types; fixed position layout, functional layout, cell layout and product layout (Slack et al., 2007). The four production layout types are here closer described together with their relative advantages and disadvantages.

In a *fixed position layout* the production is arranged in such way that the activities and operations are performed at one place and the product itself is not moving. Instead the resources (people, material, machines) are relocated to the product. This type of production layout is typically common for larger projects in small or single quantity such as ship building or motorway constructions (Slack et al., 2007). Reasons for having a fixed position layout may be that the product is being too bulky or fragile to be moved.

A *functional layout* groups similar resources or functions together. This layout type is typically found in productions where large numbers of different products are produced in small volumes. A functional layout often provides a relatively easy supervision of equipment and plant (Slack et al., 2007) and can theoretically enable a high utilization of resources (Bellgran and Säfsten,2010). It also serves to provide a high mix and product flexibility while still being insensitive to disruptions (Slack et al., 2007). However, a functional layout often result in a very complex flow pattern since different products will take different routes depending on which operations that are needed (Slack et al., 2007). It is also characterized by long throughput times and complex production planning and control with queues and waiting times for transportation between machine groups (Bellgran and Säfsten, 2010).

In a *cell layout* production the resources needed to process similar product families or parts are located together in cells. Within each cell the resources can be arranged in either functional or product layout (Slack et al., 2007). This layout type can provide a good compromise between cost and flexibility in a relatively high variety environment (Slack et al., 2007). Cell layout have an increased flow orientation compared to functional layout and can simplify the complexity of flow often found in a functional layout (Slack et al., 2007). Furthermore, it provides the possibility for short throughput times and fewer planning points compared to a functional layout (Bellgran and Säfsten, 2010). It also reduces material handling, inventory and space requirements (Maynard and Zandin, 2001). Drawbacks may include a high cost for rearranging existing layout, the need for more equipment and lower plant utilization (Slack et al., 2007).

A *product layout*, or line-based layout, arranges the resources in accordance to how the product is being produced. Each product follows a predetermined and sequential route. This production layout is common for mass production of standardized products (Slack et al., 2007). The flow is relatively easy to control and can provide low unit costs for high production volumes. However, the product layout has a low flexibility and is sensitive to disruptions. Another disadvantage might be problems with highly repetitive work (Slack et al., 2007).

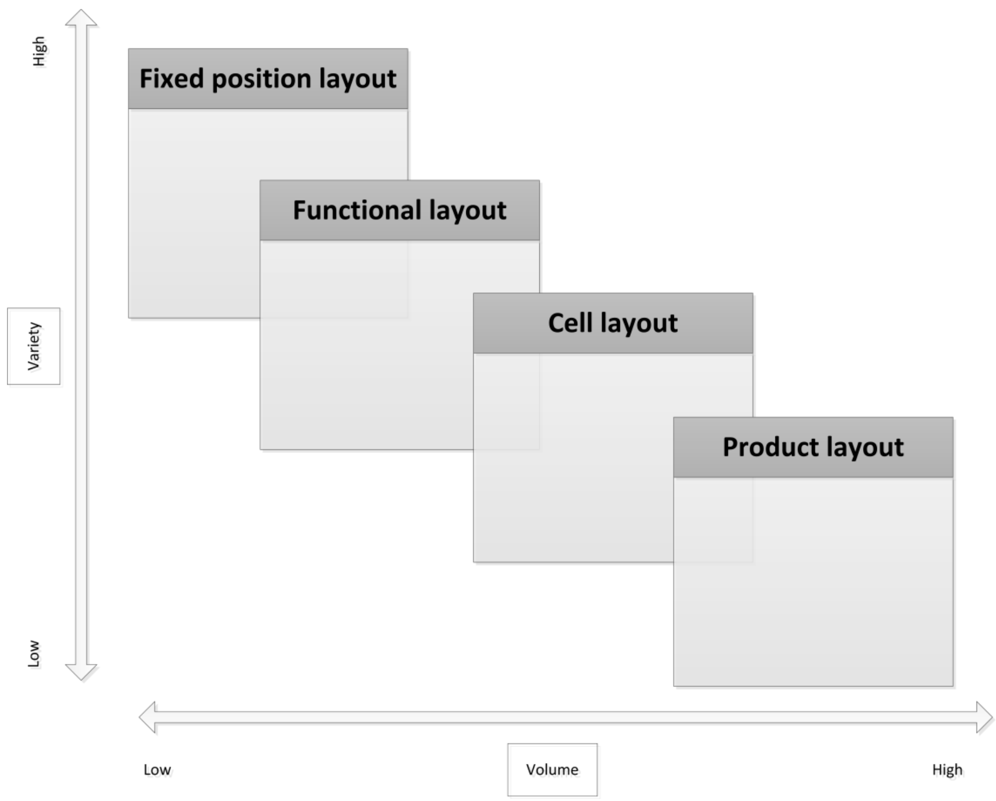

Figure 2-2 The feasible production layout type is influenced by the volume-variety characteristics of the processes. The overlapping of the blocks illustrate that more than one layout type can be possible for a specific process characteristics.

The four production layout types rarely exist completely alone. Instead it is common to combine elements from the different types into hybrids or having some or all of the basic layout types in different parts of the production (Slack et al., 2007). Which layout types that is suitable depends highly on the volume and variety characteristics of the operations, which can be illustrated by the volume-variety matrix in figure 2-2 above. However, since different layout types are possible for the same volume-variety characteristics (Bellgran and Säfsten, 2010; Slack et al., 2007) one must also take into consideration the relative advantages and disadvantages of the different production layout types, such as throughput time, cost or flexibility (Slack et al., 2007). When the layout type is chosen, the advantages and disadvantages should then conform to the business's overall performance objectives (Bellgran, and Säfsten,2010).

2.3 Process mapping

There is a great opportunity for improvements in nearly every process. (Liker and Meier, 2006). It is therefore worth the effort to carefully study the processes in a systematic way in order to identify the improvement potentials (Bergman and Klefsjö, 2010). Process mapping provides an analytical tool (Kalman, H.K. 2002) that aims at thoroughly understand the process and what tasks within the process that are value adding and non-value adding (Vance, D.E. 2009). If carefully carried out, the knowledge and understanding gained from the process mapping can then function as a platform for the development of new improved processes (Bergman and Klefsjö, 2010).

There are many reasons for why performing a process map. Firstly, it can be used to document and visualize the current workflow within an organization. The documentation will then function as a common frame of reference for the people involved in the process (Damelio, R. 2010). The mapping of the current processes can also be used to orient other people not familiar with the process such as new employees. Besides being useful to show how work currently gets done in an organization, process mapping is also a prerequisite when developing and evaluating future state process flows (Damelio, R. 2010).

2.4 Production flow analysis - PFA

Production Flow Analysis (PFA) is a method for identifying and cluster families of components and their associated machines into cells (Burbidge, J.L. 1971). The method is based on the process routings for the component and the machines and resources needed to process the components. A PFA comprises three stages; Factory Flow Analysis, Group Analysis and Line Analysis (Burbidge, J. L. 1971). Each stage is closer described below.

The first stage of a PFA is the *Factory Flow Analysis* (FFA). The objective with the FFA is to identify major departments and allocate plant, product and resources to departments in such way that the material flow is simplified as far as possible (Burbidge, J.L. 1971). This objective is mainly achieved by studying the process routes for the components and identifying the "natural" processing stages on an inter-department level (Burbidge, 1971; Dale, B.G. et al., 1984).

The second level, *Group Analysis* (GA), the identified departments are further divided into groups (Burbidge, J.L. 1971). The aim is to identify and group the components within each department into cells in such way that the components are fully processed within each cell (Burbidge, J.L. 1971). The main approach used to identify and group component families is to construct a component-machine-chart. The chart helps to identify components that utilizes the same resources and thus naturally fit together.

The third and most detailed level of the PFA is the *Line Analysis* (LA). In the LA-phase, the layout of the groups is designed (Dale, B.G. et al., 1984). The method used is similar to the FFA method where network diagrams are performed in order to simplify the flow systems (Dale, B.G. et al., 1984). The aim is to arrange the machines in such way that it will generate the nearest approximation to line flow, hence the name Line Analysis.

When following the PFA procedure, it is not always possible to evenly distribute the machines to the identified cells (Slack et al., 2007). There might be cases where some machines need to be represented in more cells than there are machines available. In those cases decisions have to be taken whether to purchase more machines to put in the concerned cells or to let some of the components be processed in more than one cell, and consequently allowing a more complex material flow. A third option is to devise a special area that supports the other cells (Slack et al., 2007).

2.5 Systematic Layout Planning - SLP

Systematic Layout Planning (SLP) is a general method for designing and improving plant layout in various types of factories (Watanapa and Wiyaratn, 2012). It uses the so called *activity relationship chart* as its foundation when analysing how to arrange the new layout (Muther, 1973; Tompkins, J.A. 1996). With the guidance of SLP an improved production layout can be developed that aims at increasing the productivity and facilitates an efficient workflow (Watanapa and Wiyaratn, 2012). SLP consist of three main elements: a *framework of phases*, a *pattern of procedures* and a *set of conventions* (Muther, 1973), each element is described closer below.

The *framework of phases* consists of four phases that a layout improvement project passes through (Muther, 1973). Even if the phases are sequential, they are recommended to slightly overlap each other. The four phases are:

Phase 1: Location – Determine the location of the area to be planned and the space available.

Phase 2: Overall Layout – Plan and establish the general arrangement of departments.

Phase 3: Detailed Layouts – Plan the arrangement, locate the specific machinery and equipment.

Phase 4: Installation – Plan and prepare the installation, train workers and follow through.

A *pattern of procedures* is followed in order to plan the phase 2 and phase 3 (Overall layout and Detailed layouts). According to Muther (1973), the procedures of patterns help to avoid errors, save time and produce better solutions. Following the procedures will result in a number of alternative solutions, which has to be evaluated in terms of costs, safety, employee preference etc. After sorting out alternative solutions that are not feasible (for practical or other reasons) the remaining alternatives may be adjusted and combined in order to create a final overall layout. The pattern of procedures can then be iterated on a more detailed level (phase 3) in order to create detailed layouts for the different production areas.

The third element of SLP is a *Set of conventions*. The conventions are mainly adopted from various standards such as the A.S.M.E. standard for process charting. Those conventions are used to describe processes and activity relationships etc. and include colour codes, symbols, numbers, letters and lines (Muther, 1973).

2.6 Data gathering

There are three main types of data gathering: documental studies, observations and direct questioning (Andersen, H. 1994). The three types will be described shortly below as well as when it is appropriate to use them.

Documental studies are the indirect observation of events or phenomena (Andersen, H. 1994). The object of the study is not directly observed. Instead by-products, written documents or oral recollections are studied in order to get an understanding about the studied object. This type of study is typically used when researching historical events or sociology due to the inaccessibility of direct observations (Andersen, H. 1994). The main reason for using document studies, excepting unavailability of direct observation, is the fact that it is often a very cheap method and is a way of determining what has been done before and providing a way of evaluating results of previous research (Andersen, H. 1994). A restraining factor to this kind of study however is that the amount of documentation available is set and limited from the start, which could inhibit the study or even direct it in a pre-determined way as the material might present a biased view(Andersen, H. 1994).

Observational studies refer to directly observing the object of the study and are mostly used when studying items that you cannot communicate with and when the other main methods are not applicable (Cresswell, J.W. 2003). It is often most used when studying social situations or animals because of the indirect role of the observant but is of limited use when studying organizations and the like (Cresswell, J.W. 2003). Tours through factories could be described as an observational study but is seldom enough to get a thorough understanding of an enterprise (Cresswell, J.W. 2003).

The final type of data gathering is direct questioning to an individual or group of individuals (Andersen, H. 1994). This type aims at getting information regarding an individuals' knowledge about the object of the study. The questioning can be done either by conducting oral interviews or by sending out questionnaires and polls (Andersen, H. 1994). When conducting an interview it is important to remember that the communications are two-way and that the interviewer is affecting the interviewee, either by asking loaded questions, being a figure of authority, ability to draw out certain answers etc. (Andersen, H. 1994). There are also different types of interviews, structured, semi-structured and non-structured, referring to the degree of openness of the questions (Andersen, H. 1994). Open questions are questions pertaining to the broader spectre giving the interviewer a broad understanding of a situation. It also allows for interviewees with greatly varying degrees of knowledge about a subject (Andersen, H. 1990).

3 Method

The overall systematic approach used in the thesis followed four steps illustrated in figure 3-1 below. Initially, basic data concerning the current layout, organization, products and processes were gathered to provide an overview of the current state. The gathered information could then be analysed in order to identify improvement potentials in accordance with the research questions. Based on the current analysis an alternative future concept was generated. Finally, the alternative future concept was evaluated based on how the research questions were fulfilled. A closer description of the methods and tools are described in the following sub-chapters.

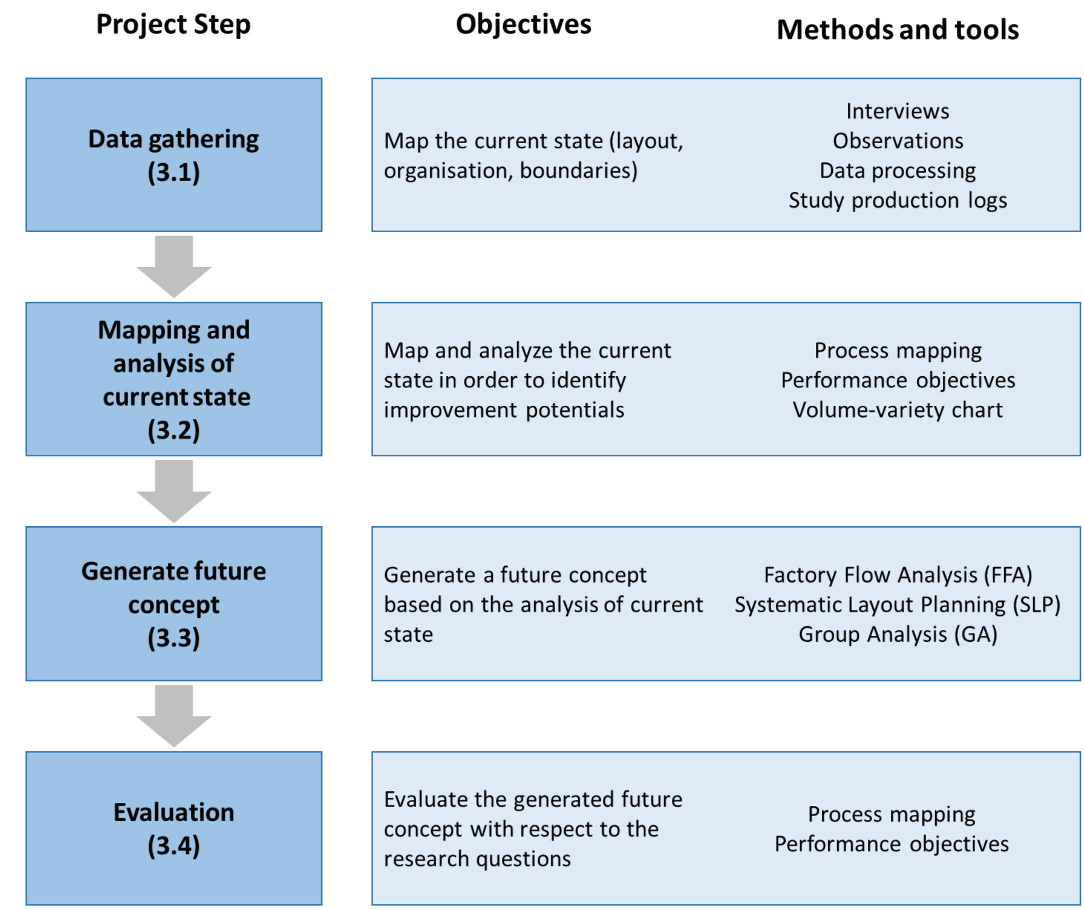

Figure 3-1. The systematic approach used in the thesis. The project step is complemented with the objectives as well as the methods and tools used in each project step. The chapters for each project step are indicated in brackets.

3.1 Data gathering

All three of the main data gathering methods, as described in chapter 2.6 on page 9, were used to some extent. *Documental studies* were used in mapping the flow of products between operations and units. These flows were confirmed by the individual unit supervisors before being used for the SLP and VSM. *Observations* were used as guided tours through the production during the introduction to the thesis and when mapping the processes as well as when mapping out the current layout. Finally, *questions* were asked to operators and line supervisors in the form of interviews. These interviews are described below in chapter 3.1.1 and 3.1.2.

3.1.1 Choice of respondents

The interviews were supposed to provide insight and a general overview of the current production situation and for that reason the interviewees needed to be knowledgeable about the manufacturing of one or several of the product families. Thus individual interviews were conducted with the line supervisors and with operators in the production that their respective supervisor recommended as suitable. There is a risk that operators suggested by their supervisors in such a manner could be biased in their presentations but this risk was deemed negligible, especially since such a presentational bias would not be very likely to significantly alter the final results of the study. The line supervisors also made up the project board which meant that they could provide their view and goals with the project during the interviews.

3.1.2 Interviews

The interviews were conducted in a semi-structured manner as the interviewees had very little knowledge about the production from the start. A number of questions pertaining the production, products and organization that the interviewees wanted answered was listed and was used as a base for the individual interviews. During the interviews the interviewed subjects were still allowed to speak freely about other things, if they wished.

3.2 Mapping and analysis of current state

The current state mapping and analysis was conducted in five main steps. The product families' performance objectives were studied followed by the production processes, production layout and the production flow. Lastly, an analysis of the suitable production layout types for each product family was conducted.

3.2.1 Performance objectives

When the performance objectives were studied, all three main data gathering methods described in chapter 2.6 were used to some extent. The performance objectives for each of the product families were mainly identified by performing semi-structured interviews with managers from each of the three product family. Three managers from both Microwave and Digital were interviewed whereas one manager representing the Antenna product family where interviewed. The interviews with the managers were complemented with non-structured interviews with operators from the respective product family as well as documental studies of the production logs and guided tours in the production facility. The collected information was compiled in a polar diagram as suggested by Slack and Lewis (2011) to visualize the relative importance of the performance objectives for the product families.

3.2.2 Production processes

In order to narrow down the feasible production layout types for the respective product families, their process characteristics were positioned in a volume-variety chart as proposed by Slack et al. (2007). The current process characteristics for the Antenna, Microwave and Digital product family were studied in terms of production volume, variety and operation processes. The production volumes were studied through interviews with managers from the respective product family whereas the varieties were studied by comparing the product structures for ongoing projects. Information about the product structures were not readily available but had to be gathered. Gathering this data was done by interviewing managers and operators as well as studying the production logs which recorded all the production orders and the ingoing sub-components.

3.2.3 Production layout

The current state production layout was mapped both in order to fulfil the purpose of mapping the current state layout and as an input to the analysis of current state process flows. The current state production layout was mapped in three stages. Initially, the production layout was mapped by measuring the size and location of machines, equipment and storages. Secondly, the operations performed at the mapped equipment and machines were investigated through interviews with operators. Lastly it was examined which of the three product families (Antenna, Digital and Microwave) that utilized the functions by studying production logs complemented by interviews with operators.

3.2.4 Production flow

Process mapping was used to map and visualize the current process flow for all three product families at RUAG Space. According to Kalman, H.K. (2002) process mapping provides an analytical tool that aims at thoroughly understanding the processes. Furthermore, the knowledge and understanding gained from the process mapping can then function as a platform for the development of new improved processes (Bergman, B. and Klefsjö, K. 2010).

Since nearly all of RUAG Space’s products are highly customized, few products follow the exact same path in the production processes. However, by studying earlier produced units it was possible to get a generalized picture of the main process flows throughout the factory. To determine what products to study the line managers were asked in interviews what they considered to be most representative for the production. The products mentioned were compared to the product structure and variety mix in order to see if and how they differed. Lists of all operations involved in producing these products from start to finish were then mapped on to the production layout in order to see how the product was moving throughout its production. The mapping is based solely on interviews with the operators performing the listed operations because they were estimated to be the most credible source of this information.

3.2.5 Suitable production layout type

The volume-variety matrix was used as a first guidance when selecting an appropriate production layout type for the product families, as suggested by Slack et al. (2007). Since there are more than one production layout type that can be feasible for a specific volume-variety characteristic (Slack et al., 2007), the identified performance objectives for each product family was compared with the relative advantages and disadvantages of the different production types in order to decide upon a suitable layout type.

3.3 Generate future concept

The suitable production layout types identified in the current state analysis acted as guidance throughout the development of the future concept. The following sub-chapters describes both the methods used for developing the overall factory flow as well as the methods used for designing the individual product family's flows and layouts. Finally, the method used for evaluating the generated future concept is presented.

3.3.1 Factory Flow Analysis - FFA

A factory flow analysis, as a part of the overall Production flow analysis described in chapter 2.4 on page 8, was made with the mapped process flows as a baseline with the intent of identifying major departments and getting an idea about to which extent the production flows for the product families were connected. This was done by taking all the operations included in the process flows, numbering the processes and placing them in roughly the order they are performed into a basic flow network chart. The chart was then simplified by separating the processes that were only used by one family and the ones that were used by both into three groups.

3.3.2 Overall layout design

According to Watanapa and Wiyaratn (2012) an improved production layout that facilitates an efficient workflow can be developed by using the SLP method. When the major departments had been identified, the SLP-method was used to arrange the identified departments in the production facility.

3.3.3 Detailed layout design

Only the Digital and Microwave department were designed on a detailed level since it was concluded during the overall design phase that the other departments should be arranged in the same way as they are in the current state layout.

When the Digital department's layout were designed in detail the SLP method, as described in chapter 2.5, was used. According to Slack et al. (2007) the SLP method is recommended for functional layouts which was the case for the Digital department. The design followed three basic steps: identification of relationships, space requirements and adjustment to the facility.

For the Microwave department the GA method, as described in chapter 2.4, was used when designing the detailed layout. The GA method is recommended for designing cell layouts (Slack et al., 2007), which the Microwave product family had been assigned. In order to secure a flow oriented production, the Microwave product structure was used as guidance when the cells were identified. The GA was performed in three main steps:

1. Identification of cells using the machine-component matrix
2. Decision on whether to split shared resources or not
3. Allocation of resources to respectively cell.

The cell-design of the Microwave department can be found in chapter 5.3.2 on page 33.

3.4 Evaluation of generated concept

To fulfil the purpose of the thesis the generated concept was evaluated first on how it contributes to a flow oriented production and secondly how it meets the product families individual requirements.

In order to evaluate the contribution to a flow oriented production, a comparison of the current process flow and the new suggested process flow was performed; see chapter 5.4.1 on page 36. To evaluate how the individual requirements of the product families were fulfilled, it was assessed how the future concept influenced each of the identified performance objectives, see chapter 5.4.2 on page 37.

4 Mapping and analysis of current state

This chapter covers a presentation and analysis of the current state production processes, layout and flows.

4.1 Performance objectives

The performance objectives can act as a link between customer requirements and operations according to Slack and Lewis (2011). The identified performance objectives were guiding for choosing the right layout type as well as evaluation for the final future state. The five generic performance objectives for Antenna, Digital and Microwave product family are here analysed and displayed in figure 4-1 below.

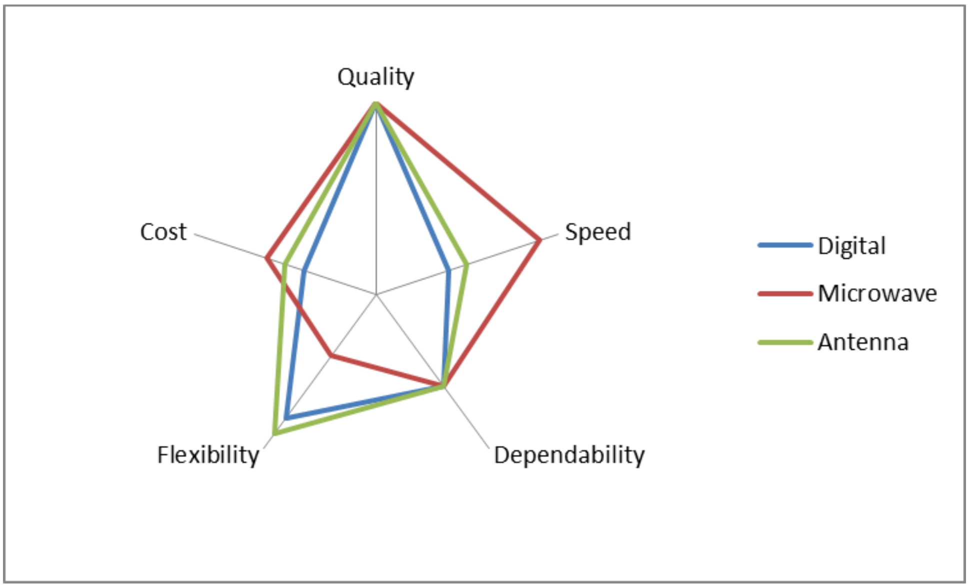

Figure 4-1 Polar representation of the relative priority of the performance objectives for Antenna, Digital and Microwave product families.

Through interviews it was revealed that all the three product families had a great requirement on quality. There is no room for errors in the space industry. This requirement is heavily reflected in the production operations where many tests and inspections are performed to secure the demand on quality. The dependability was perceived as the same relative medium level of importance for all product families since late deliveries could end up with hefty fines. Cost was considered intermediate priority, with slightly higher priority to Microwave since they have been experiencing rising levels of competition in recent years. The greatest relative difference in performance objectives could be found in the Speed and Flexibility performance objective. For the Antenna and Digital flexibility was considered to have a high relative priority of both volume and variety. For Microwave, flexibility was more restricted to changes in volume and less in variety. However the speed were prioritized considerably more important for the Microwave, were customer demanded shorter lead times.

4.2 Production processes

The production processes for RUAG Space's product families are first described and then positioned on a volume-variety chart. According to Slack et al. (2007), the positioning of processes in the volume-variety chart serves as a first guidance when choosing a feasible production layout type. The positioning of the processes will narrow down the feasible layout types to one or two layout alternatives.

The *Digital* product family has processes dealing with high variety and low volumes. There is a mixture of one-offs projects together with products produced in shorter series. Furthermore, the Digital products have a high degree of variations in terms of product structure, number of produced products, production lead time and the resources needed to produce the products. The manufacturing operations needed to produce the digital products include many operations and can be rather complex.

The *Antenna* products are, similar to the Digital products, produced in smaller series with a high degree of variety (low volume-high variety characteristic). The antennas vary in both size, shapes and operations needed. However, the antenna products have fewer process steps involved and requires less resources in relation to the Microwave and Digital product families.

The *Microwave* production, unlike the Digital and Antenna production, has processes with relatively lower degree of variety. Even if the volume can vary greatly over time the product structure, ingoing operations and resources needed to produce Microwave products varies considerably less than both the Antenna and Digital productions. Furthermore, production volume is greater than for Antenna and Digital production.

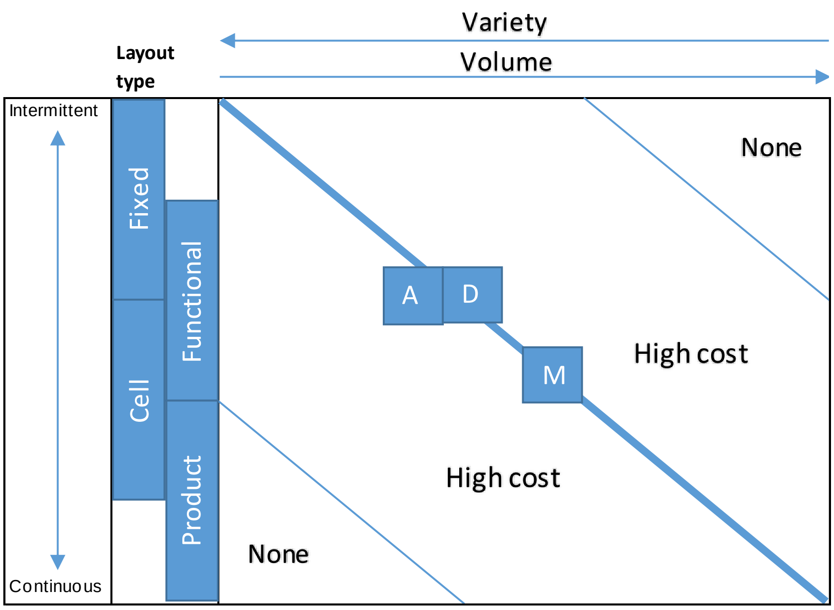

Figure 4-2 Positioning of the process characteristics in a volume-variety chart for Antenna (A), Digital (D) and Microwave (M). Based on the chart, feasible layout types are considered to be either functional or cell layout for all three product families.

If the process characteristics for Antenna, Microwave and Digital described above are positioned on the volume variety chart, the feasible production layout types will be narrowed down to one or two feasible production layouts. As illustrated in figure 4-2 above, all three product families fit with both a *functional* layout and a *cell* layout. In order to decide more precisely which of the two layout types that is suitable for each of the product families, the preferable layouts are further analysed in chapter 4.5 on page 23.

4.3 Current production layout

Figure 4-3 below and Figure 4-4 on page 20 show the current layout of the production system at RUAG Space separated into sub-areas. Figure 4-3 show the layout separated into functions as RUAG Space currently sees it and Figure 4-4 on page 20 shows the layout separated according to the production families.

Figure 4-3 Production areas split into functions

The layout in the above picture is separated into functions such as assembly, inspection and test. In these areas all the equipment needed to perform certain tasks has been gathered. In the testing area for example all the testing equipment and operations have been gathered with no regard to what type of tests will be carried out or on what type of product. This functional approach was very present in the old company organization and the current layout is very likely a direct product of that way of thinking.

The areas in this picture are separated according to the production families Microwave, Digital and Antenna, as well as the common utilities such as Surface Mounted Technology department (SMT), kitting and the sub-assemblies from Multi Chip Module department (MCM). The coloured areas illustrate who use the equipment in the area and is based on information both from line supervisors and from operators. As can be seen from the picture the green, orange and yellow areas are located close to each other while the purple, red and blue areas are scattered throughout the facility. The latter areas are also many times cutting each other off. These characteristics mean that transportation and handling times are going to increase as personnel and products are transported between the areas. It also means that communications between the areas get harder and that personnel and products will travel through areas that do not belong to them which can generate both disturbances and annoyance.

Figure 4-4 Production areas split into families

Another problem with having the areas scattered like this is problems with coordination when handing over the product to a new area. When the products are transported to testing for example they are taken from the assembly area and put into a locker at the test area with very few visual cues to the testing personnel. The testing personnel then have their own priorities separate from the assembly personnel and this in tandem with the limited visibility often result in long waiting times when products are handed over to new areas. It is not uncommon to have a sub-assembly change hands 10-15 times before the final assembly and the waiting times during these changes of hands range from a few hours to two weeks depending on the circumstances.

The reason why the red and blue areas are scattered like this is very likely due to the very functional way the layout is set up, as can be seen in Figure 4-3 on page 19. This does not fit into the new production flow oriented company organization.

4.4 Current production flow

The mapped production flow is shown in Figure 4-5 on page 22. The flow show how a product moves throughout the facility and do not take personnel movement into account. It is important to note that these mappings are very general and only show when a product leaves a room. Movements within a function, such as different assembly steps in the antenna workshops for example, are not illustrated. This is because those movements were small compared to the movements between functions and because the pictures would get clogged by lines which would limit their visual usefulness. The flow in Figure 4-5 show the flow in its entirety. The individual production flows can be seen in Appendix A.

Figure 4-5 Production flow for Microwave (red), Digital (blue), Antenna (green) and MCM (yellow). Arrival, kitting, vibration, photo and MIP are purple.

As can be seen in Figure 4-5 there is a lot of long transports involved inside the production facility which not only increases all the risks associated with transporting the products but also risk disturbing the production processes that they pass. Since a lot of the lines are crisscrossing each other this risk is greatly enhanced and creates what the operators have named a "runny environment". Interesting to note here is that the green and yellow flows, being the Antenna and MCM productions respectively, mainly keep to themselves and only leave their areas on occasion, making them somewhat closed systems. The red and blue flows, being the Microwave and Digital productions, look to be very connected to each other as they move along very similar lines. This is not necessarily the case however but could instead be a result of having grouped functions such as "test" and "assembly" together, as can be seen in Figure 4-3 on page 19. All in all, this flow is very functional for all families, which as can be remembered from chapter 4.2 on page 18 is not necessarily the preferable scenario.

4.5 Suitable production layout types

In chapter 4.2 on page 18, the feasible production layout types for Antenna, Digital and Microwave were narrowed down to either *functional* or *cell* layouts. In order to more precisely decide what layout type is feasible, the relative advantages and disadvantages of the layout types (see chapter 2.2 on page 6) need to be compared with the requirements of the product families(Slack et al., 2007). In this chapter the suitable layout types are identified and then compared with the RUAG Space current layout type. In chapter 4.1 on page 17 the requirements of the product families were analysed in terms of performance objectives. The Digital and Antenna prioritized high *flexibility*. According to Slack et al. (2007), a functional layout provides a high mix and product flexibility and is relatively robust to disruptions. Therefore, a *functional* layout was considered suitable layout type for Digital and Antenna product family.

Microwave on the other hand, emphasized *speed* in terms of fast throughput time and good flow as important (see chapter 4.1 on page 17). Since a functional layout can have long throughput times (Bellgran and Säfsten, 2010) with complex flow pattern (Slack et al., 2007) this layout type was not considered suitable for Microwave. Cell layout on the other hand, have an increased flow orientation and can contribute to faster throughput times (Slack et al., 2007) which is in line with Microwave's performance objectives. For those reasons, *cell* layout is considered suitable for the Microwave product family.

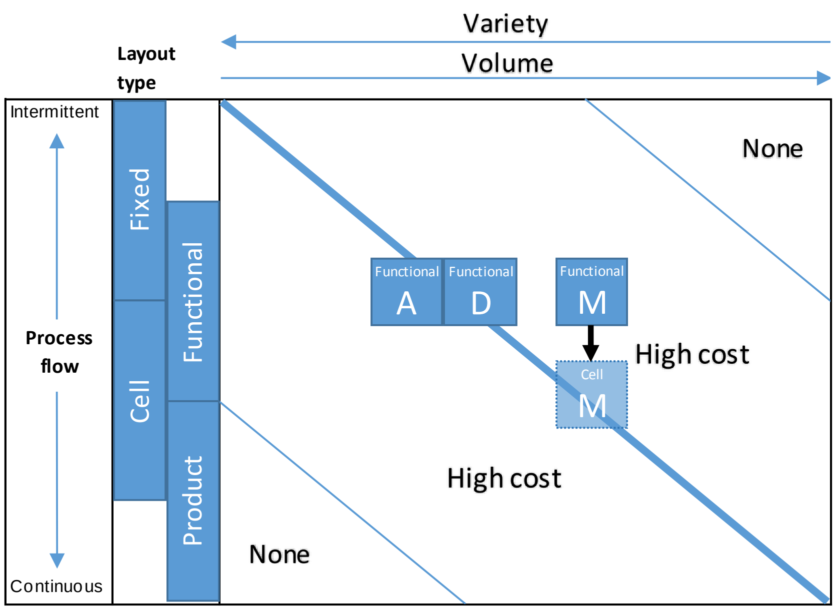

Figure 4-6 Volume variety chart illustrating a gap between suitable production layout types

As stated above, Microwave has a volume-variety characteristic together with requirement priorities that suggests a Cell layout with an enhanced process flow. However, in chapter 4.3 on page 19 it was concluded that all three product families, including Microwave, have a functional layout. Furthermore, in chapter 4.4 on page 21 it was shown that the process flow of Microwave are far more intermittent than the feasible process flow suggested above. This mismatch in relative priority of performance objectives and current layout type are illustrated in Figure 4-6 above. According to Slack et al. (2007), if processes are positioned to the right side of the natural diagonal as in the case of Microwave, there is a potential for standardization of the processes that are not taking advantage of. Being more flexible than needed (positioned on the right hand side of diagonal) is thus likely to result in unnecessary high costs(Slack et al., 2007). It would therefore be suitable to address this issue.

5 Generate future concept

In order to generate a future concept that meets the requirements for the product families, the suitable production layout types identified in the current state analysis (see chapter 4.5 on page 23) was acting as guidance throughout the development of the future concept. A top-down approach in three stages was used to generate the new concept:

1: Factory Flow Analysis
2: Overall layout design
3: Detailed layout design

Figure 5-1 below shows an overview of the involved steps together with the objectives and the method used for each step.

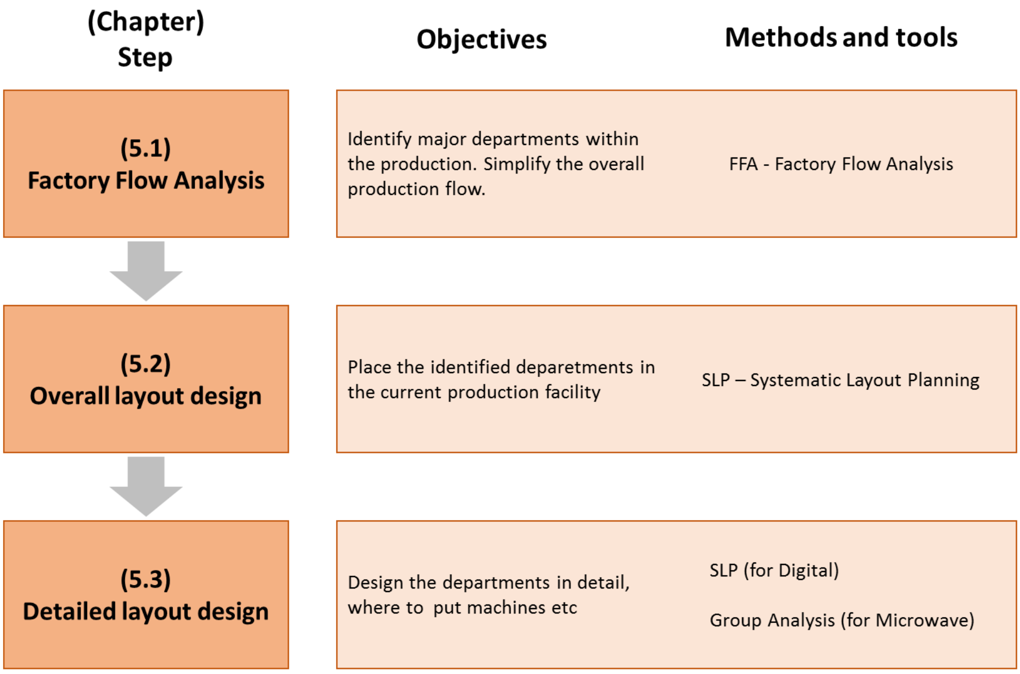

Figure 5-1 Overview of the involved steps together with the objectives and method used for each step during future concept generation.

The approach shown in Figure 5-1 is followed schematically from top to bottom and will be lain out in detail in the chapters associated with each step. Lastly an evaluation of the generated concept based on the research questions (flow oriented production that meets the requirements of the product families) is presented.

5.1 Factory Flow Analysis - FFA

A Factory Flow Analysis (FFA) was performed in order to identify and separate the production into major departments. The aim was to define the departments in such way that the sub-components were fully processed in each department and no material flow was backtracked. The FFA starts with mapping the current process flows for the components and by gradually simplify the network, major departments can be identified. The first sub-chapter (chapter 5.1.1) describes the identification of the departments. For simplicity, only the identification of the Microwave and Digital department are here presented. The second sub-chapter (chapter 5.1.2 on page 28) describes the final result of the FFA, including all the identified departments and their simplified network.

5.1.1 Identification of Microwave and Digital department

In this sub-chapter a closer presentation of how two of the departments, the Microwave and Digital department, were identified using the FFA method.

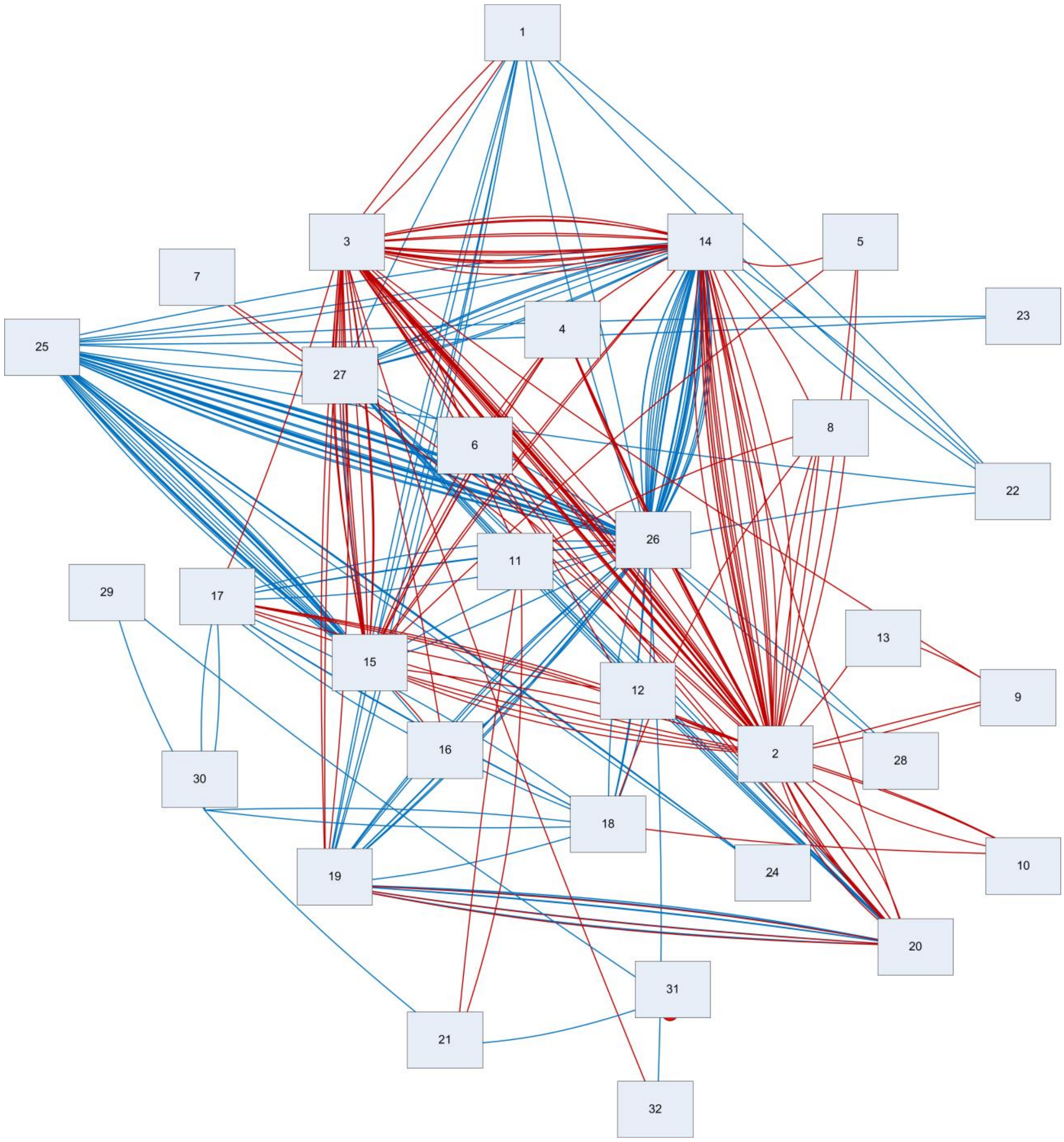

Figure 5-2 Basic flow network chart

The boxes with numbers in them represent functions and operations. For example, number 1 at the top represents the SMT which distributes material to the manual assembly and number 32 represents the shipping of the final products. The absolute values of the numbers are not significant in any way. The red and blue lines, being once again the Microwave and Digital flow respectively, represents the product and sub-assemblies moving between functions and operations. These lines are based on the lines in Figure 4-5 on page 22. These flows look to be much intertwined but some areas were identified as separable. These and the interlinked processes were separated in order to isolate the departments and simplify the process flow, which is presented in Figure 5-3 below.

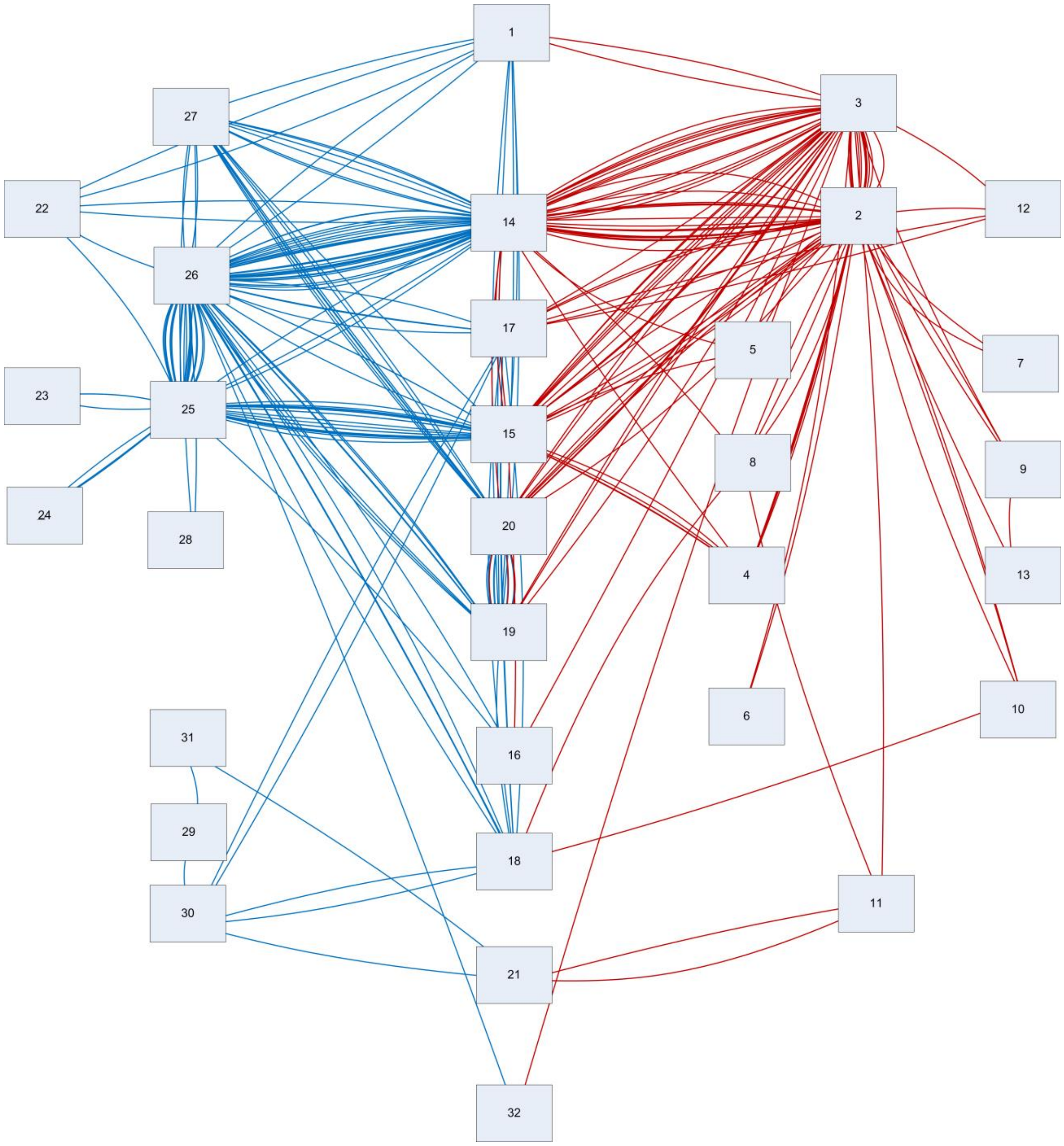

Figure 5-3 Simplified network chart

A separation of the Microwave and Digital dedicated areas with shared resources in the middle confirmed the fact that these are very separate flows. The left hand side has the dedicated resources needed for Digital production and the right hand side has all the dedicated resources needed for Microwave production. In the middle are resources that are used by both families such as tinning and bonding. The lines are the same lines as in Figure 5-3 on page 27, only moved. This shows that, except from a few shared resources such as tinning and bonding, the Microwave and Digital production are very distinct from each other. It would therefore be possible to split these two with decisions taken on individual shared resources whether they should keep sharing them or if it is possible to split them. Separating and isolating these flows would have several advantages including shorter distances, minimizing the risk of disturbing others and a more flexible workspace. These separated flows could then be further divided into cell structures where for example everything needed for the Microwave sub-assemblies were located next to each other within the Microwave area.

5.1.2 Identified departments

Using the same method illustrated in the previous sub-chapter, six natural departments were found; SMT, MCM, Microwave, Digital, Vibration and Antenna. The Antenna and MCM departments was largely already treated and separated into natural departments whereas the Microwave and Digital departments had several interlinked processes (see chapter 5.1.1 on page 26). The interlinked processes were separated in order to isolate the departments and simplify the process flow, see figure 5-3 on page 27. It was considered impossible to give each family its own vibration equipment because it requires a special foundation in the building to be able to operate. Therefore it is treated as one shared resource at the end. The simplified network process chart can be seen Figure 5-4 below.

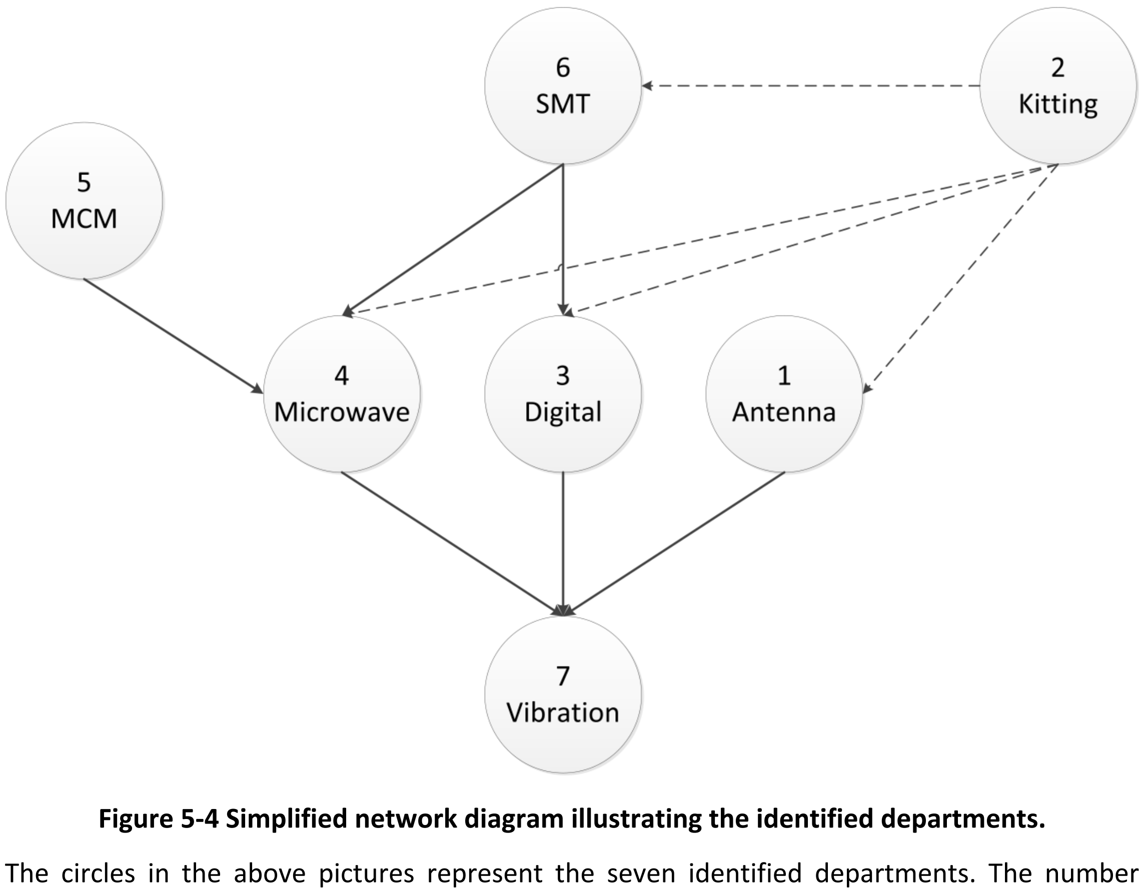

Figure 5-4 Simplified network diagram illustrating the identified departments.

The circles in the above pictures represent the seven identified departments. The number associated with each department is simply an identification number and the absolute values of the numbers have no bearing. The dashed arrows represents kitting supplying the connected departments with materials and components and the full arrows represents assemblies and subassemblies moving between departments.

5.2 Overall layout design

This chapter presents the overall layout design of the departments identified in the previous chapter. The aim was to allocate the identified departments in the current production facility. The relationships between the identified departments were mapped in a relationship-chart as can be seen on the left in Figure 5-5 below. Since the production flow between the departments was not available from production logs or documentation, the desirability of departments being close to each other were gathered through interviews with operators and managers. Five ratings of desired closeness were used; A=Absolutely necessary, I=Important, O=Ordinary closeness, U=Unnecessary and X=Not desirable. The required spaces for each department are stated in square meters and were obtained simply by manually measuring and adding the subareas together. The relative importance of closeness as well as the space required for each department can also be viewed in the relationship-chart in figure 5-5 below.

Based on the relationship chart a relationship diagram was constructed in order to visualize an ideal arrangement of the departments. This diagram can be seen in the middle of figure 5-5 below. The lines between the circles represent the needed closeness between the departments with more lines indicating a higher need. The relationship diagram was combined with the space requirements from the relationship-chart to form a space relationship diagram, seen on the right hand side off figure 5-5 below.

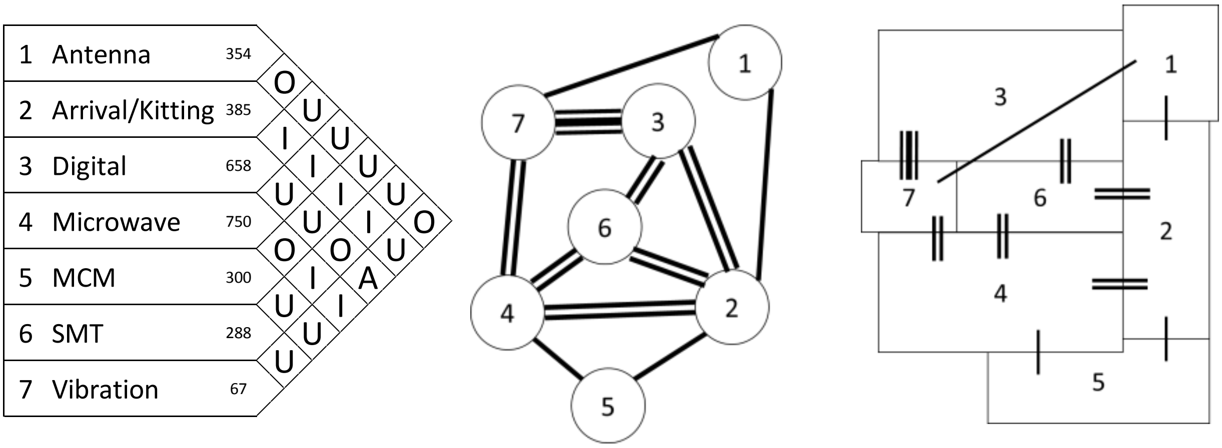

Figure 5-5 The relationship-chart (left) for the identified departments together with relationship diagram (middle). By combining space requirements and the relationship diagram a space relationship diagram was constructed (right).

The ideal arrangement from the space relationship diagram was then fit into the actual area available in the production facility. Some adjustments had to be made from the ideal relationships in order to fit all the areas. The final adjusted layout can be viewed in figure 5-6 on page 30.

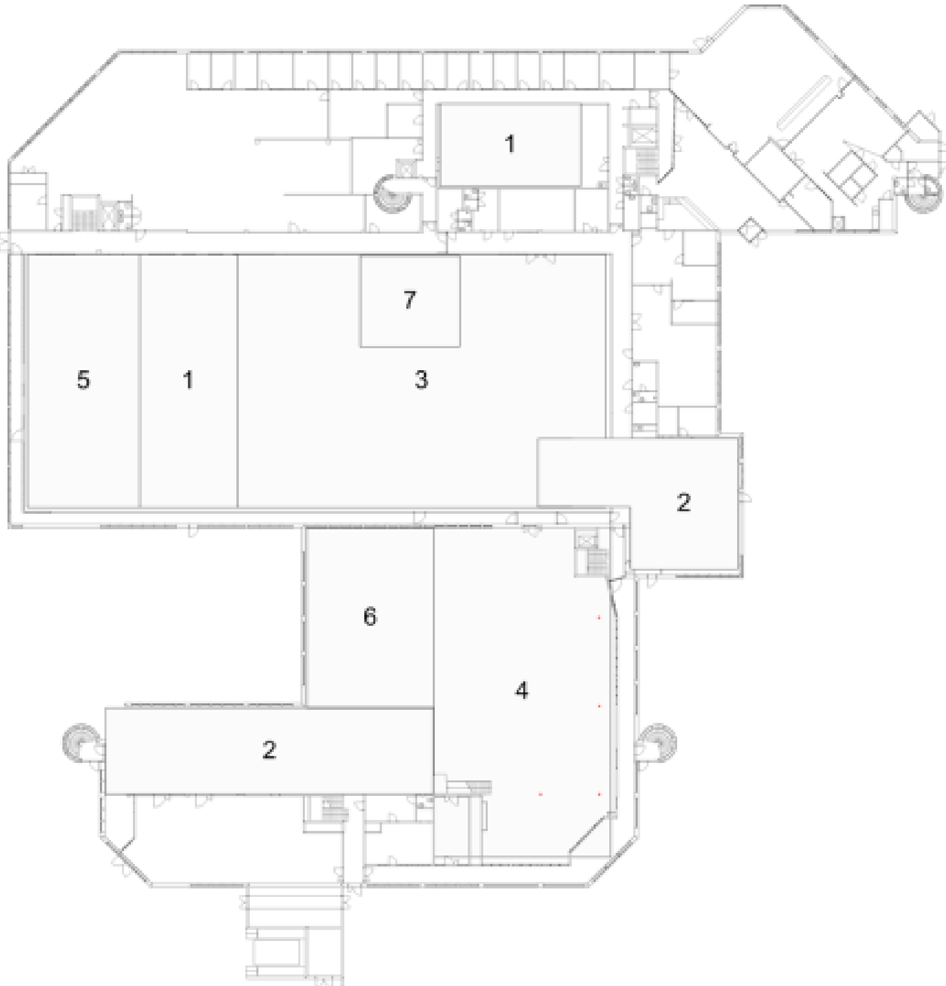

Figure 5-6 The departments fitted into the current production facility area.

Figure 5-6 shows an overview of the suggested layout in its entirety. The numbers denote the department that is located within the designated area. The numbers and the area sizes are gathered from the relationship-chart in figure 5-5 on page 29. Interesting point to note is that the Antenna workshop has been moved outside the clean room and is represented by the area with the number one at the very top. The operations performed in the Antenna workshop does not require clean rooms and can thus be moved outside to an ordinary production environment. The MCM, arrival, kitting and Antenna assembly remain more or less entirely where they are located now since they currently function as closed systems. Where they are located does not matter all that much since most of their process steps are internal and have their resources located close by. Therefore the most gains could be had by focusing on the larger, currently more scattered Digital and Microwave areas.

5.3 Detailed layout design

This subchapter addresses the construction of the detailed layout design for the Digital (chapter 5.3.1) and Microwave (chapter 5.3.2 on page 33) departments.

5.3.1 Digital detailed layout design

The arrangement for the digital production was designed using the SLP method. The same procedure and classification used when designing the overall layout (see chapter 5.2 on page 29) was used for the Digital layout area. The relationships between the departments were mapped in a relationship-chart as can be seen on the left in Figure 5-7 below. However, the relative importance of closeness in this design was based on the production flow in Figure 4-5 in chapter 4.3 on page 22. The relationship chart can be viewed in figure 5-7 below.

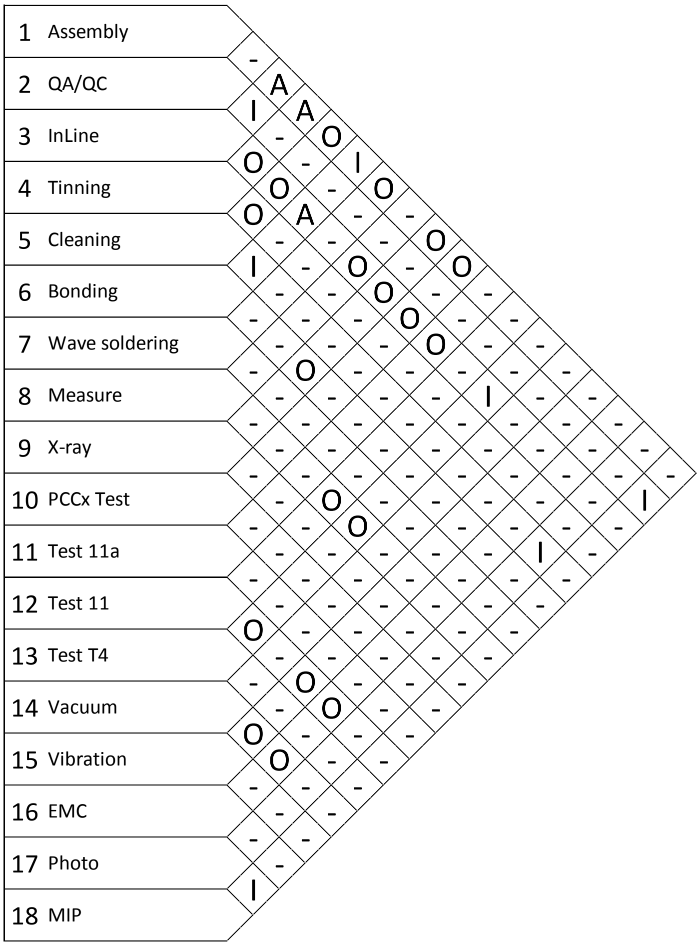

Figure 5-7 Relationship chart for Digital product family. A=Absolutely necessary, I=Important, O=Ordinary closeness, U=Unnecessary and X=Not desirable.

The required spaces for each process were obtained by manually measuring and adding the subareas together. Based on the relationship chart a relationship diagram was constructed in order to visualize an ideal arrangement of the Digital processes. This diagram can be seen in figure 5-8 on page 32.

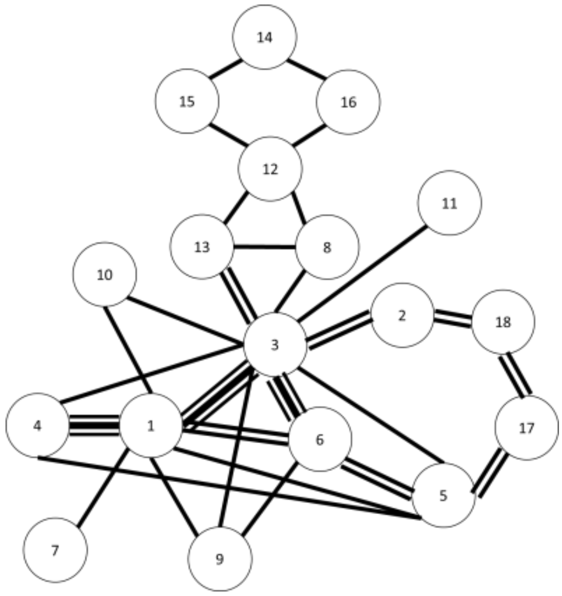

Figure 5-8 Relationship diagram for the Digital product family

The circles represent the processes listed in figure 5-7 on page 31. The lines between the circles represent the needed closeness between the departments with more lines indicating a higher need. The relationship diagram was combined with the space requirements from the relationship-chart to form a space relationship diagram, seen in figure 5-9 below.

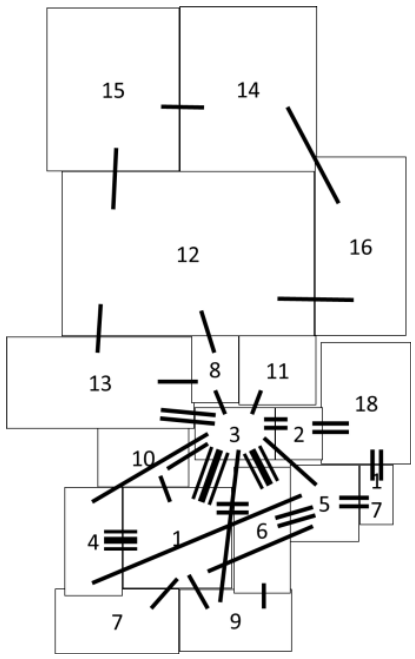

Figure 5-9 Space relationship diagram for the Digital product family

The ideal arrangement from the space relationship diagram was then fit into the designated Digital area in the production facility. Some adjustments had to be made from the ideal relationships in order to fit all the areas. The final adjusted layout can be viewed in figure 5-10 on the following page.

Figure 5-10 The final suggested layout for Digital production

Figure 5-10 shows an overview of the suggested layout for the Digital production. The numbers denote the processes listed in figure 5-7 on page 31. Note that processes 1 through 6 except 5 have been placed along the bottom centre. This is because these are activities which require long manual work and has therefore been placed close to the windows to allow for exposure to natural daylight. The reason why number 5 is located at the right hand side is because those activities require a fire safe room which is very costly to move from its current location.

5.3.2 Microwave detailed layout design

In chapter 4.5 on page 23 it was concluded that Microwave should have a cell production layout type. The Microwave production was then consequently further divided into cells using the GA method in three steps.

Step 1 – Grouping into cells
Step 2 – Classification and decision on duplication of machines
Step 3 – Allocation of machines

Each step is closer described below together with the final result of the cell design phase.

Step 1 – Grouping into cells

Initially, components and machines were grouped together in clusters using the machine-component matrix, see Table 5-1 on page 34. When the cells were identified, the Microwave product structure was used as a guidance to ensure a flow oriented production flow. Three cells were identified, Cell 1, Cell 2 and Cell 3, by identifying and grouping assemblies that required the same resources, see Table 5-1 on page 34.

Table 5-1 Machine-component matrix

Sub-part \ Resource	Test (Vacuum)	Test M1, M2	Weighing	Test T4, Bonding	Test D, M1, M2	Test B, C	EMC	Vibration	Measure	MIP	Arrival	LO/Temp	LOTrim	Photo	Assembly	Bonding	QA/QC	InLine inspection	Tinning, Soldering	Cleaning	PCCx Test	Test Filter
Classification	D	D	D	D	D	D	D	D	S	S	D	D	D	S	C	S	S	C	C	S	D	D
Final assembly	●	●	●	●	●	●	●	●	●	●				●	●	●	●	●				
Sub assembly 1									●	●	●			●	●	●	●	●	●			
Sub assembly 2												●	●	●	●	●	●	●				
Sub assembly 3												●	●	●	●	●		●		●		
Card 1														●	●	●	●	●	●	●	●	
Card 2														●		●	●	●	●	●		
Card 3															●	●	●	●	●	●		●
Card 4																		●	●	●		
Card 5																		●	●	●		
Card 6																		●	●	●		
Card 7																		●	●	●		
Card 8																●		●	●			

Cell 3

Cell 2

Cell 1

The assemblies required for a finished product are listed on the left hand side under *Sub-part* and the resources needed are listed horizontally at the top under *Resources*. The numbers denote how many times a specific resource is used during an assembly. The letters in the *Classification* row are further explained in Step 2 below.

Step 2 – Classification and decision on duplication of machines

The machines were classified in three different categories based on the number of equipment available and the number of cells that the equipment is represented in. The three categories were defined as:

- **Dedicated equipment (D)** – few or single equipment used to process a specific component represented in one cell.
- **Common equipment (C)** – equipment in multiple copies used to process components represented from many cells
- **Shared equipment (S)** – few or single equipment used to process components represented from many cells

Some of the machines were found represented in more cells than there were machines available (the S-equipment). The S-equipment had to be further investigated whether it should be duplicated (investing in more equipment) in order to be represented in each cell or treated as a general function outside the cells. Whether an S-equipment was a candidate for duplication was evaluated based on the cost for investing in new equipment, the space requirements for the equipment and how often it was used. The cost aspects were estimated based on interviews, the usage frequencies were based on production logs and space requirements were measured in the production. A high cost, seldom usage and bulky machine favoured a machine to be put outside the cells as a support function whereas the opposite favoured the machine to be duplicated and distributed to the concerned cells. The result can be viewed in figure 5-11 on page 35. Two resources were considered necessary to treat as a general function outside the cells; the measurement device and the Mandatory Inspection Point(MIP) resources.

Function	Cost	Area	Usage	Decision
MIP	S	L	S	Share
Measuring	M/L	S	S	Share
Photo	S	S	S	Split
QA/QC	S	S	M	Split
Cleaning	M	S	M	Split
Bonding	M	S	M	Split

Figure 5-11 Decision on whether to split (invest in new equipment) or shared (treated as general support resource outside the cells). The resources have been classed as Small(S), Medium(M) or Large(L) in relation to three categories serving as base for the decision.

The only functions that were to be shared in the suggested layout are the MIP and measuring functions because of the space requirements of building another MIP room and the cost of investing in new measuring equipment. The other functions could all be split and divided into each cell.

Step 3 – Allocation of resources
The last step of the cell design phase was to decide how many of each resource to include in the respective cell. By investigating the number of operations performed by the various resources in each cell, an estimation of how to allocate resources could be made.

The final result of the Microwave cell design can be viewed in figure 5-12 below. The cells are allocated to the area identified in chapter 5.2, figure 5-6 on page 30. The cells were adjusted to fit into the current production facility.

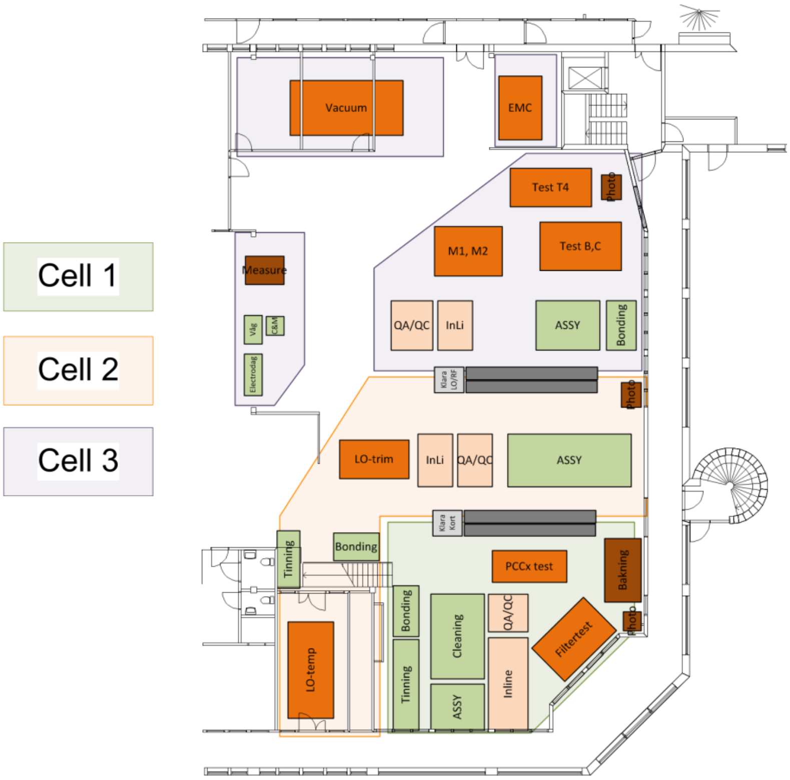

Figure 5-12 Final detailed design of the Microwave cells

Figure 5-12 above shows the design of the Microwave cells. The cells are denoted by a given coloured area and the attached colours are seen on the left hand side of the figure. The flow of the products starts in Cell 1 and continues to Cell 3 through Cell 2. The green boxes represents desks used for assembly, tinning or bonding operations, the beige boxes represents desks used for inspection, the orange boxes represents desks and machines used for testing operations, the brown boxes represents larger machines and equipment such as ovens and the grey boxes represents shelves used for stock and other inventory. Most of the shelves in the figure are placed between the cells which allow for easier placement of assemblies leaving a cell for the next one as well as serving to create a movable wall separating the cells.

5.4 Evaluation of generated concept

The generated concept was evaluated in accordance with the purpose of the thesis (to suggest a flow oriented production layout that meets the requirements of the product families). In chapter 5.4.1, the production flow is evaluated and in chapter 5.4.2 the fulfilment of the product families' requirements are evaluated.

5.4.1 Production flow orientation

Generating a production layout that is production flow oriented is one of the main research questions for this thesis but it is also one that is very hard to quantify. Nevertheless we can see a number of potential gains with the new generated concept with regards to the production flow. The differences in the production flow between the suggested and the old layout can be seen in Figure 5-13 below.

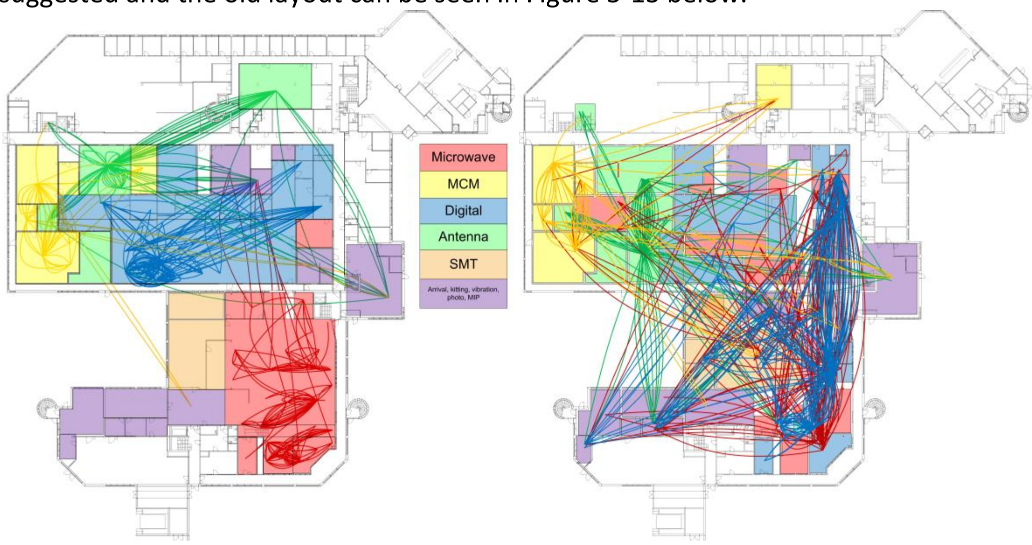

Figure 5-13 Comparison between the new flow and the old flow

The flow for the suggested layout can be seen on the left and the flow of the old layout can be seen on the right. First and foremost the main gain will be done by separating the Digital and Microwave flows. Since they do not interconnect with each other but on a few occasions there is much to be gained by separating them and locate the equipment that they need close to them. By doing this these two flows will not crisscross each other and the transportation times will be drastically reduced. For the Microwave flow we can also see further separation into smaller flows with the cellular structure which further enhances a lot of elements that affect the production flow such as planning potential, visibility, reduced transportation distances and dedicated storages and equipment.

5.4.2 Fulfilment of individual requirements

The fulfilment of the product families individual requirements are here evaluated in terms of how the generated future concept influences each of the five generic performance objectives.

Flexibility

In the current state analysis (chapter 4.1, page 17) it was pointed out that the Antenna and Digital department had a greater need to be flexible in terms of the capability to handle different products and variation in volume. When the basic layout type was chosen for the product families, Digital and Antenna were given a functional layout in order to meet the requirements of a flexible production. In the current state production layout (chapter 4.3., page 19) it was shown that the Digital and Microwave production to a great extent shares the same production area despite having mainly separate production processes. By separating the Microwave and Digital production families, the digital production gives a greater room to change, reduce or expand its production without affecting the Microwave production. In this way the Digital production is given a greater flexibility and at the same time gives Microwave the possibility to change its production towards flow oriented layout.

Speed

Speed in terms of fast throughput times and shorter lead times were considered a high priority performance objective for the Microwave production, see chapter 4.1 on page 17. As seen in previous chapter, the travelled distance is considerably shorter in the generated future concept. This has a direct contribution to shorter leadtimes since less time is spent on transportations. The basic layout type for Microwave was chosen to be cell layout (see chapter 4.5 on page 23). According to Slack et al. (2007) cell layouts have the advantages of having a fast through put time compared to functional layout, which is current layout for Microwave (see chapter 4.3 on page 19). For Antenna and Digital product families, speed was considered less important relative to Microwave (see chapter 4.1, page 17). Since the Digital and Antenna layout type was chosen to remain functional, the layout type will not change the influence on the speed. However, as seen in figure 5-13 on page 36, the distance for material transportations is shorter for Antenna and Digital, which contributes to shorter lead times in the same manner as to Microwave.

Quality

Quality was identified as high priority requirements for all three product families (chapter 4.1 on page 17). In interviews with managers it was revealed that material transportations were regarded as a risky operation and therefore wished to be minimized. For instance, all items, despite being very small and light weight, had to be transported on trolleys in order to reduce the risk that the expensive components would mistakenly be dropped to the floor. The generated future concept has a considerably less material transportation distance as illustrated in figure 5-13 on page 36. Thus, the relative importance of high quality is supported by the suggested future concept.

Dependability

The relative priority of dependability was perceived as intermediate importance compared to the other performance objectives (see chapter 4.1 on page 17). The suggested layout does not directly contribute to more dependable processes within RUAG Space. However, as stated above, the quality was considered improved for all three product families. According to Slack et al. (2007), an improved quality increases the dependability since there will be less disruption and less time spent on correcting unplanned quality deviations.

Cost

Implementing the generated future layout is associated with an initial cost. Since many of the larger equipment and machines are left in their current places (see chapter 5.2 on page 29), the cost for implementing the future concept were considered to be relatively limited. Furthermore, the processes are not altered and the level of personnel was considered to be constant, which means that the running costs should remain the same. In the long term perspective the other four performance objectives are likely to lead to a lower unit cost due to for example shorter production lead times.

6 Suggested future layout

This chapter summarizes and presents the suggested new layout with regards to the layout types, the new layout, both as an overview and in closer detail, and the resulting process flows.

6.1 Production layout type

Based on the volume-variety characteristics together with the main performance objectives, the basic production layout types were decided to be *functional layout* for the Antenna and Digital product family whereas *cell-layout* was chosen for the Microwave product family, see chapter 4.5, on page 23.

6.2 Layout

In this sub-chapter the future production layout is presented, both as an overview and in detail. An overview of the future state is presented in Figure 6-1 below.

Figure 6-1 Overview of future state

As is illustrated in Figure 6-1 and as has been discussed in previous chapters, the main changes are the separation of Microwave and Digital and the relocation of the Antenna workshop to outside the clean room environment. The new location of the Antenna workshop is the green rectangle in the upper right. The MCM, arrival, kitting and SMT areas are left as they were with the exception of moving the MCM ovens inside the clean room.

The layout for the Microwave production is split into three work cells and is presented in Figure 6-2 below.

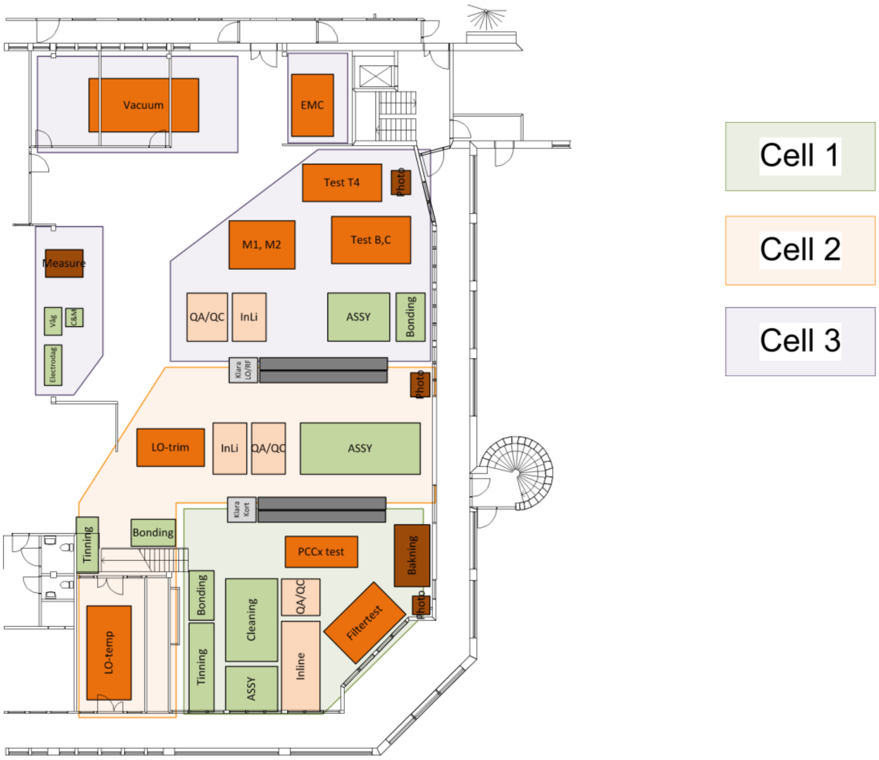

Figure 6-2 Microwave layout

As can be seen from the above picture the cells are clearly defined with the first cell located in the bottom right corner, the second cell located above it and the third cell located up top. The first cell produces material used by the second cell and so forth.

The digital layout is not split into cells the same way as the Microwave layout is. This layout is more functional and is presented in Figure 6-3 on page 41.

Figure 6-3 Digital layout

Each process in the digital production has been given a box representing the area it needs as well as an identification number. Areas 1-6 are activities that take a long time to perform, such as bonding and assembly, and have therefore been placed along the windows to allow for natural daylight.

6.3 Process flows

The resulting process flows from the suggested layout can be found here in Figure 6-4 through Figure 6-6. The first figure is an overview of the entire production area and following figures denote the Digital and Microwave flows close up.

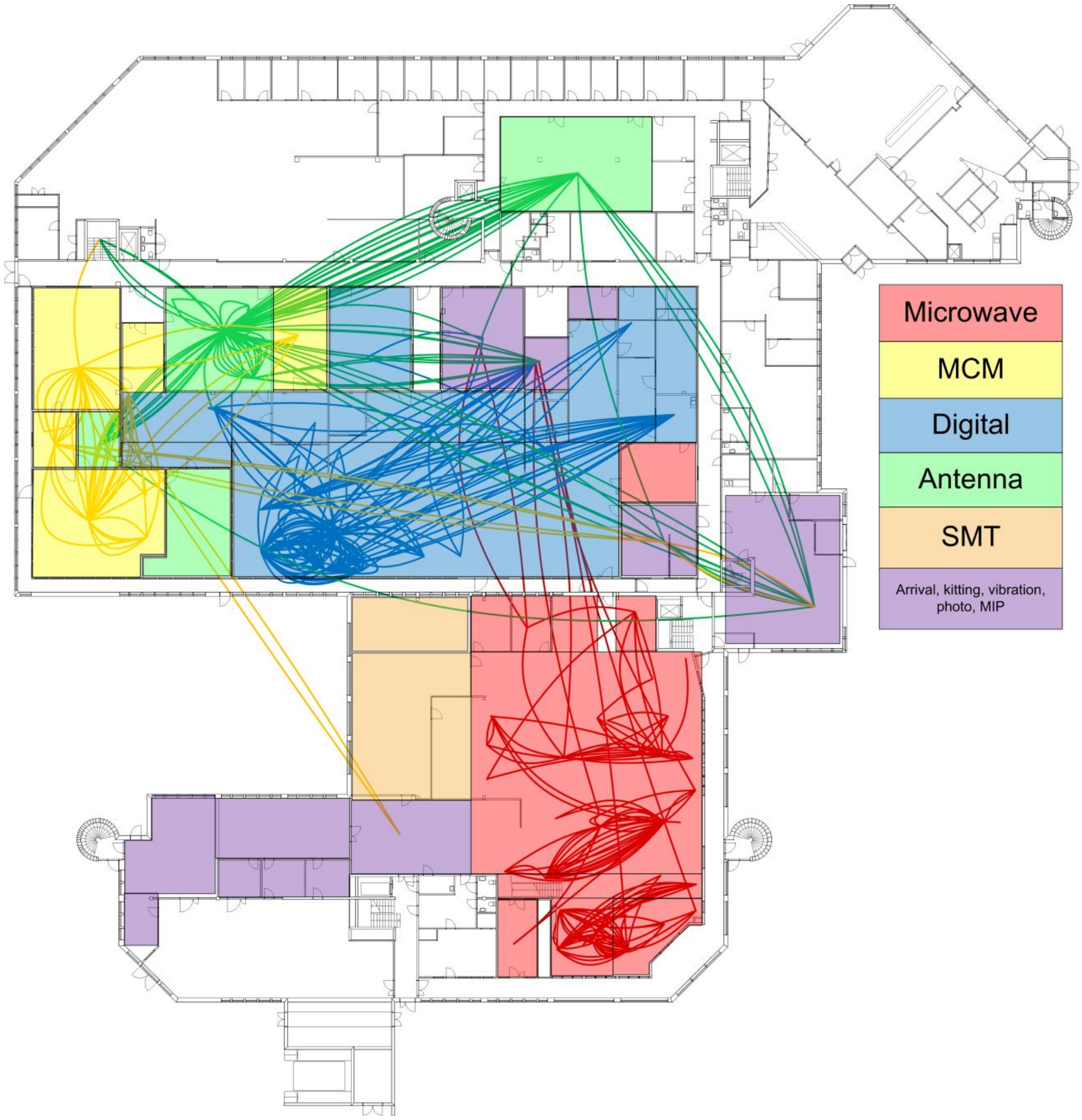

Figure 6-4 Overview of future state with process flows

Most of the transports between the families have been eliminated and the distances have been greatly reduced overall, resulting in short transportation times, lower handling times, reduced risks and improved communications within a family.

Figure 6-5 Microwave future flow

The Microwave flow has been separated into three clear cells which in addition to the benefits mentioned above serves to localize needed equipment and provides a foundation for, improved flow, easier planning and a more visual production.

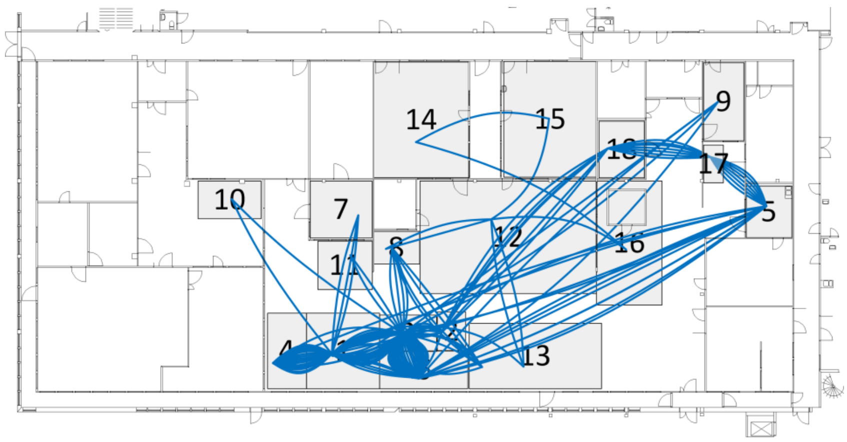

Figure 6-6 Digital future flow

The Digital flow is not as clearly separated as the Microwave flow but has the most commonly used equipment placed together in the bottom centre with a small loop for washing and photo up in the top right corner. This provides for a more flexible environment since the structure isn't locked into work cells like the Microwave production is but with large improvements to the old layout.

7 Discussion

7.1 Data gathering:

There is a lack of documented data regarding the products and the production, such as what is done when and where, aside from direct work orders and unstructured production logs. The result of this is that the vast majority of the collected data about the processes and product structure is based on interviews with line managers and operators. There are many possible uncertainties from this kind of data base but to mitigate these uncertainties the authors made sure to collect data from a large amount of sources and from different levels in the organization. Another way to deal with possible uncertainties was to double check all information that was either delivered in a vague way or critical to the quality of the results. Examples of this are the products that were studied when making the process flows in chapter 4.4 on page 21. These products were suggested by the line managers as representative of the whole production flow and this information was directly confirmed by the production personnel. There is of course still a risk that this data could be incorrect but that risk was assumed to be miniscule. Another example is during the design of the cells in chapter 5.3.2 on page 33 where interviews with production personnel revealed that there were some uncertainties where some of the operations were performed. These ambiguities were cleared up after some discussions and confirmation by other operators but still remain as a possible uncertainty. In the future the authors would recommend RUAG Space to document their production and its processes in detail in order to both aid future improvement projects and to aid with creating a full understanding of their production for both managers and production personnel. Such documentation would also serve to create a feeling of quality and competence which could be used as a marketing tool in order to secure future orders.

7.2 Methods

The SLP was used when arranging the departments and equipment into the current facility (see chapter 5.2, page 29). The input data for the SLP method were based on interviews together with production logs. As discussed above, the uncertainties related to this type of gathered data was mitigated by collecting data from a large number of sources. To optimize the arrangement of the equipment in a plant there are computer aided systems available with the advantages of having the possibility to process a large amount of data. However, computer aided systems were not used mainly due to the insufficient quantitative data available for the production processes. Furthermore, the input data needed for the SLP were relatively limited and thus relatively easy to handle manually.

GA was used to identify and design the cells for Microwave production. During the implementation of the GA it was revealed that some of the equipment had to be duplicated in order to form the cells. Since the input data for the cell design was based on interviews there is a risk that some of the equipment are not possible to duplicate, or more expensive than estimated to duplicate. However, since the cell-design allows placing some shared equipment outside the cells as support functions, the cell design is still possible to implement.

Process mapping was used both to analyse the current state as well as evaluate the generated future concept. The process maps were based on one product alone for the Microwave and Digital product family. Deviations could occur if other products were mapped, especially for the Digital product family where the product structure can vary significantly more between different products. However, a functional layout was chosen for the Digital production which is capable of handling large variations. Before implementing the detailed layout it is recommended to confirm the viability of the generated concept by complementing the analysis with additional process maps from a larger number of products.

7.3 Result Future concept

The level of detail on the suggested layout differs a bit between the product families. Detailed suggestions for the Antenna, MCM and SMT families weren't presented because they were considered closed, and relatively small, systems already. This has resulted in a solution where focus has been on detailing the Microwave and Digital flows while at the same time keeping the smaller closed systems intact and coherent. The effects of this decision are considered to be relatively minor on the final outcome of the thesis because at most this would have changed the internal look of these systems. The overall suggested solution would still remain the same regardless of the internal structure of the Antenna family, for example. Additionally, these smaller closed systems already have the resources that they need close by or even inside their systems, which is the modification that has generated the greatest benefits for the larger Microwave and Digital families.

The level of detail on the suggested layout also differs a bit between the Microwave and Digital families. The layout for the Microwave family is more detailed than the layout for the Digital family and that is because the Microwave products are more standardized than the Digital products. This higher degree of standardized products therefore allow for a more rigid, standardized production while the Digital layout remains less rigid with a higher focus on flexibility.

The question of costs for implementing the suggested layout is not formally handled in this thesis but is still an interesting question for discussion. While an exact calculation will need the aid of appropriate experts it can still be argued that a lot of items that would generate large costs to move or change have been left as is. Examples of this could be the SMT area, with its large machines and ovens, and the vibration which requires a special foundation in the building to operate. The most expensive estimated cost in the suggested layout would probably be moving the Antenna workshop or moving some of the Microwave vacuum machines. These costs are estimated to be much lower than moving the SMT area or the vibration equipment in the examples above. It is therefore argued that the suggested layout will keep within reasonable bounds as expected by RUAG Space regarding costs.

7.4 Suggestion for future studies:

The authors believe that much can be gained by developing a production planning system that fit the suggested layout. For example the cellular structure of the Microwave flow provides a solid base for capacity planning and perhaps even a system for a constant amount of work in progress. With the suggested layout and the new organization it is also recommended that RUAG Space develop new performance measurements for their production that they can use both to measure their current production and to compare it to any changes that they make.

Further work on the design of the production layout could eventually use 3D scanning and point clouds. This would require an investigation into the benefits of 3D scanning and how it could be used to benefit RUAG Space.

8 Conclusion

The current state analysis shows that the present layout is organized in a functional layout type, which is in contrast to the new product oriented organization. This functional layout result in complex process flows for each of the product families. Furthermore, the analysis shows that the product families have different performance objectives that the current layout does not support. The Antenna and Digital department requires relatively high flexibility whereas the Microwave product family requires a more flow oriented production to support faster throughput times.

The suggested flow has been improved mainly by separating the Digital and Microwave production flows and giving them dedicated areas. This change allows the Digital production to focus on their need for flexibility while at the same time allowing the Microwave production to focus on their need to be more flow oriented by introducing a cell layout. This change will make it easier to cater to the individual requirements of the product families and is fully in line with the new organizational structure.

9 References

Andersen, H., Liungman, C. and Mårtensson, B. (1994).*Vetenskapsteori och metodlära*. 1st ed. Lund: Studentlitteratur.

Bergman, B. and Klefsjö, B. (2010). *Quality from customer Needs to Customer Satisfaction.* Lund: Studentlitteratur.

Bellgran, M. and Säfsten, K. (2010). *Production development*. 1st ed. London: Springer.

Burbidge, J. (1971). Production flow analysis.*Production Engineer,* 50(4.5), pp.139-152.

Creswell, J. (2003).*Research design*. 1st ed. Thousand Oaks, Calif.: Sage Publications.

Dale, B., Burbidge, J. and Cottam, M. (1984). Planning the introduction of group technology.*International Journal of Operations \& Production Management,* 4(1), pp.34-47.

Damelio, R. 2010. *The Basics of process mapping*. New York: Productivity Press/Taylor & Francis Group.

Kalman, H. K. 2002. Process mapping: Tools, techniques, & critical success factors. *Performance Improvement Quarterly,*15 (4), pp. 57-73.

Liker, J. and Meier, D. (2006).*The Toyota way fieldbook.*1st ed. New York: McGraw-Hill.

Maynard, H. and Zandin, K. (2001). *Maynard's industrial engineering handbook.*1st ed. New York: McGraw-Hill

Muther, R. 1973.*Systematic layout planning.*Boston: Cahners Books

Neely, A. (2002).*Business performance measurement*. 1st ed. Cambridge: Cambridge University Press.

Skinner, W. 1969. Manufacturing-Missing Link in the Corporate Strategy. *Harvard Business Review,* 47 (3): 136-145.

Slack, N. and Lewis, M. (2011).*Operations strategy*. 1st ed. Harlow, Essex: Pearson/Prentice Hall.

Slack, N. and Chambers, S. (2007).*Operations management*. 5th ed. New York: Prentice Hall/Financial Times.

Tompkins, J. A. (1996). *Facilities planning* (2nd ed.). New York: Wiley.

Vance, D. (2009).*Corporate restructuring*. 1st ed. Heidelberg: Springer.

Watanapa, A. and Wiyaratn, W. (2012). Systematic layout planning to assist plant layout: case study pulley factory.*Applied Mechanics and Materials,*110, pp.3952-3956.

Appendix A

Figure A-1 MCM flow

Figure A-1 shows the production flow of sub-assemblies from the MCM unit. The equipment in the SMT area that MCM uses has been moved into one of the 10k rooms since this picture was made. The one line going into the stairs on the top left shows the products being transported to tests on other floors.

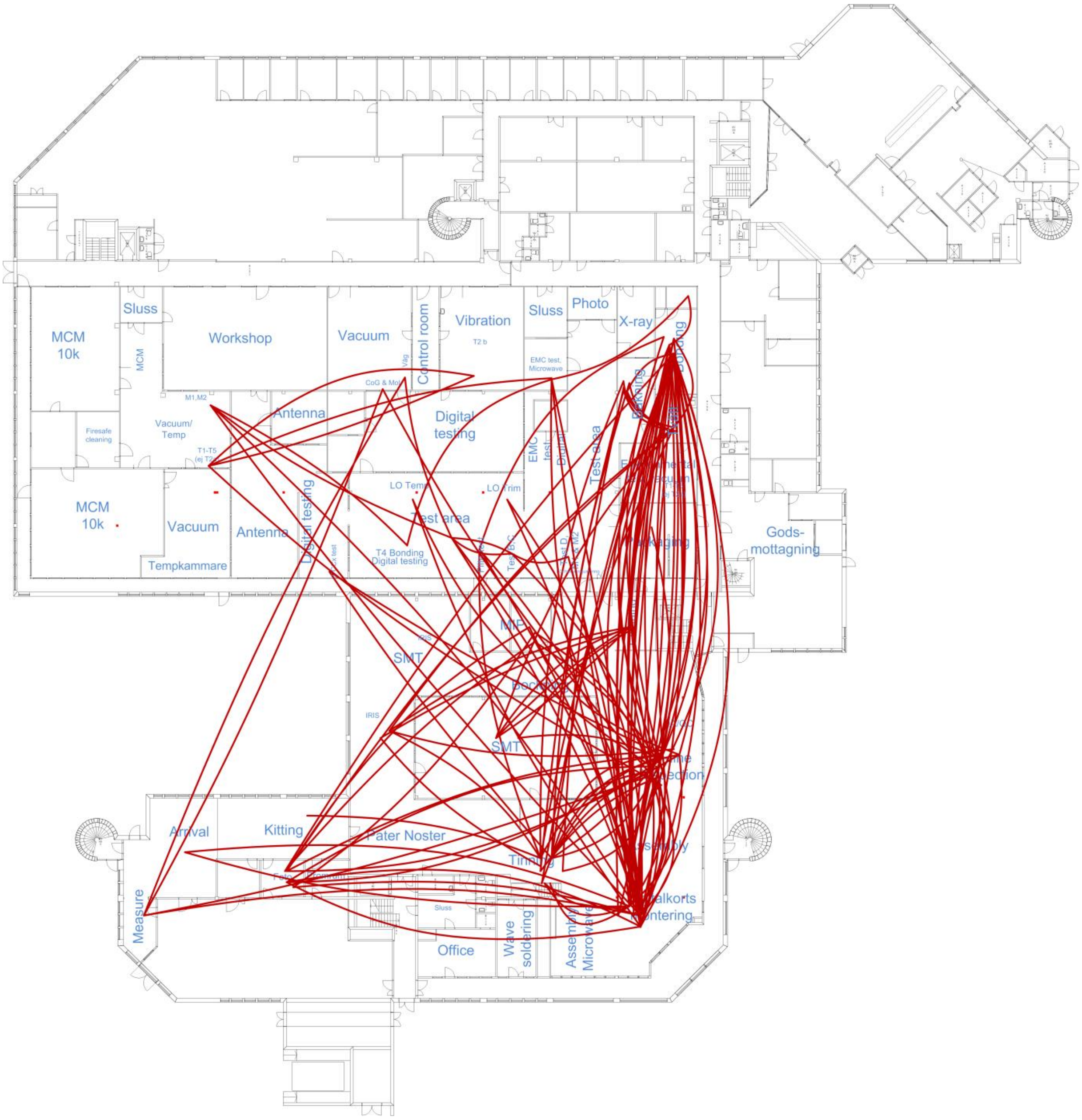

Figure A-2 Microwave flow

Figure A-2 shows the total production flow of a converter including all the sub-assemblies except the subassemblies from MCM.

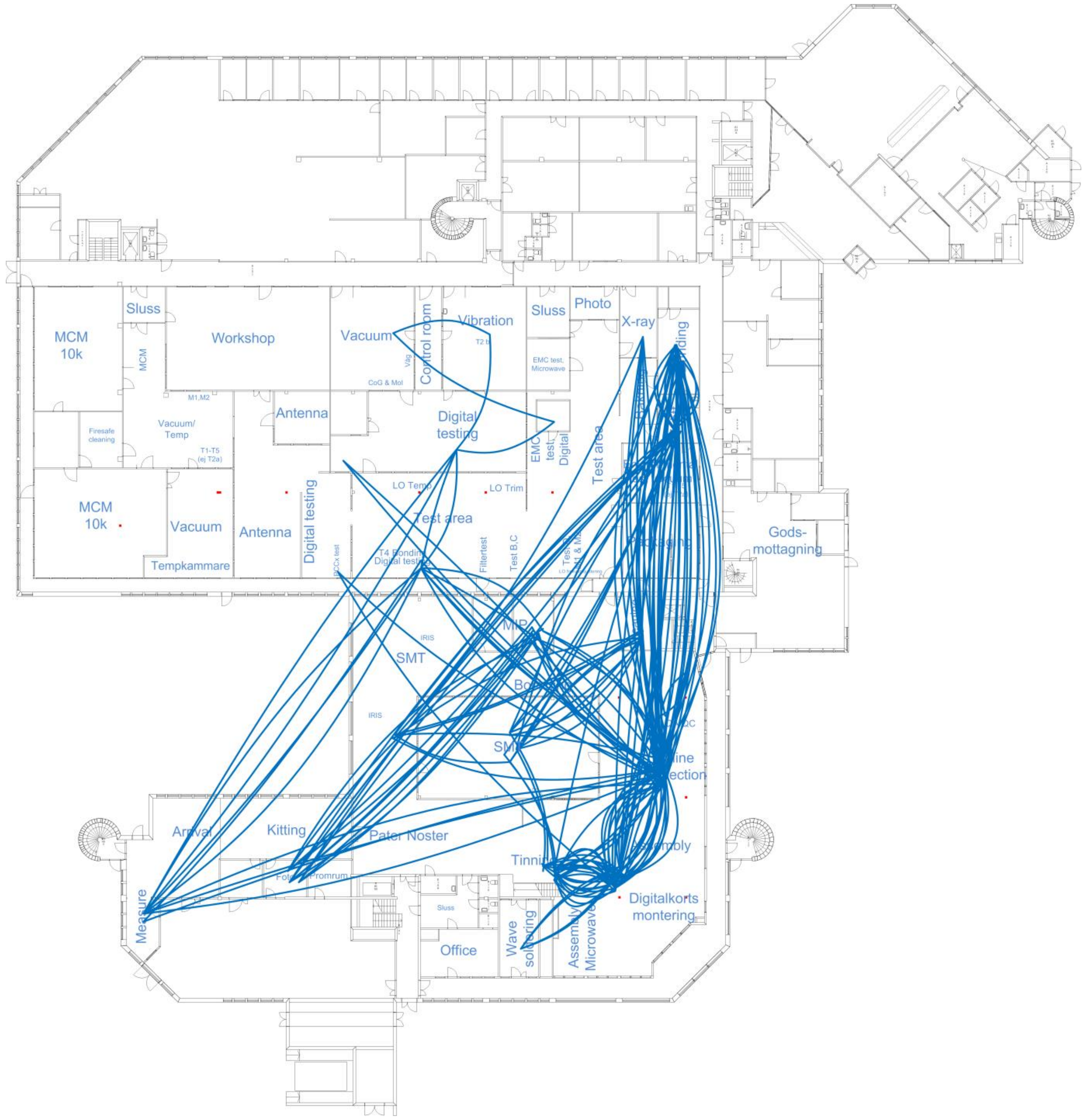

Figure A-3 Digital flow

Figure A-3 shows the total production flow of a Digital product including all of the sub-assemblies.

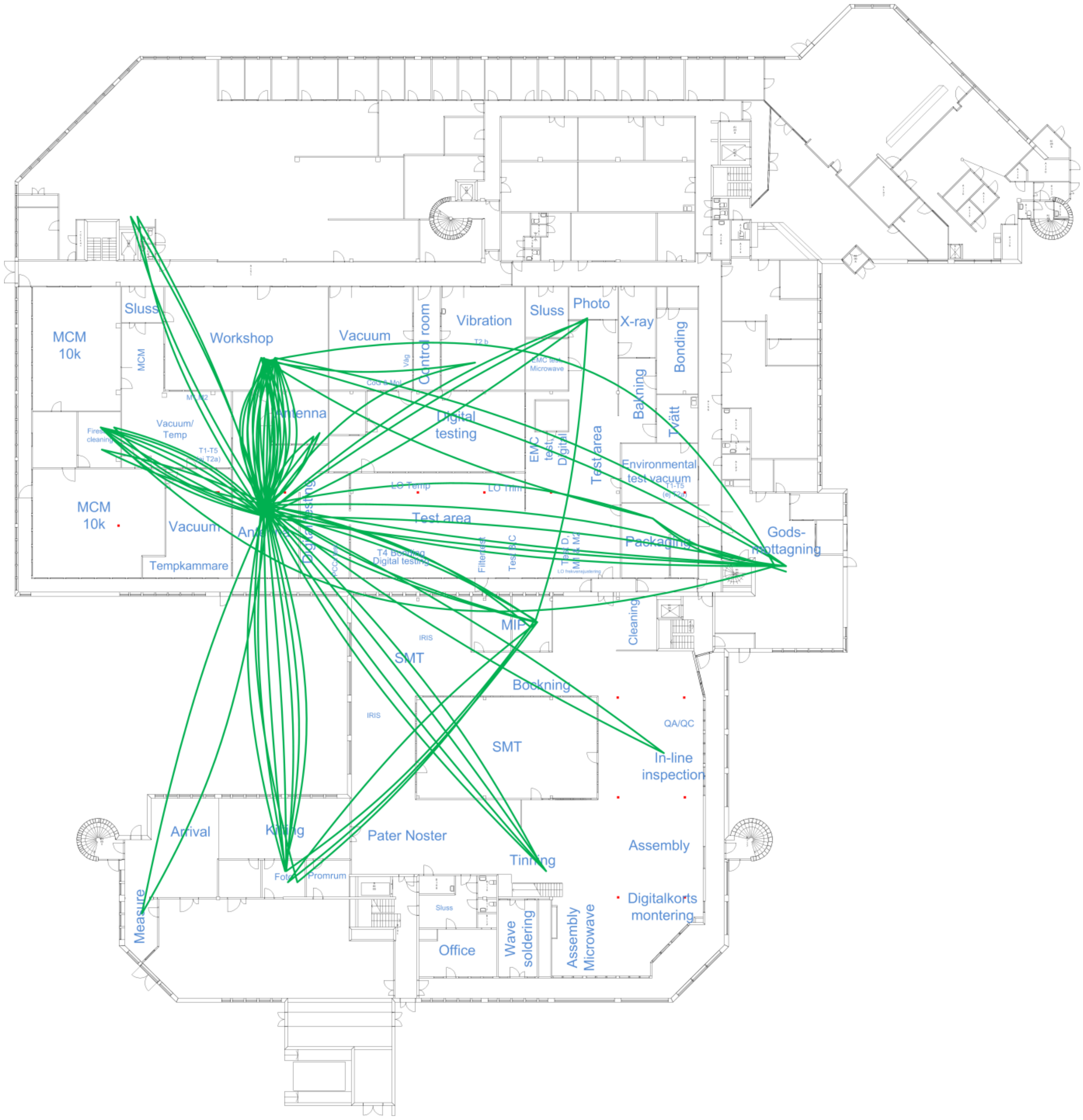

Figure A-4 Antenna flow

Figure A-4 illustrates the production flow of four different types of antennas. The lines going into the stairs on the top left represents the antennas going into test chambers on other floors.