



JÖNKÖPING UNIVERSITY  
*School of Engineering*

# **Identifying specific line balancing criteria for an efficient line balancing software**

**A case Study**

**PAPER WITHIN** *Production Development and Management*

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Shravan Dhanpal Harinath



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## **Abstract**

For any business, surviving in a competitive market while maintaining all the operational performance indices up to mark is very crucial. There are several theories and techniques to improve the efficiency of the operational performances. Line balancing is one of those well practiced techniques used daily in most of the industries. Line balancing helps balance the assembly lines with regards to man, machine, takt times, etc.

This thesis research was done with Electrolux laundry systems, Ljungby in Sweden. With the varying customer demands the case company was balancing its line manually using basic methods. As a part of lean development schemes, Electrolux Ljungby, wanted to transform the line balancing techniques from manual to a fully automated software.

The purpose of this research is to determine the company-specific line balancing criteria which should be considered before performing line balancing. This research furthermore lays out a guideline to follow a smooth transition from the manual system of LB to an automated software by concluding the features the software must handle to perform the LB according to required objectives.

A case study approach was utilized to collect all the required data to achieve the results. Initially with the literature review few generic algorithms which can solve the multi model single sided straight-line balancing problems with an objective to balance the work load are suggested. Later using other data collection techniques such as interviews, observations and historical analysis we arrived at the data required to design the guidelines with regards to line balancing software features.

The findings suggest that the desired line balancing constraints which are very important in the multi model single sided straight-line balancing problems are flow of materials, assembly precedence, physical constraints, product demand, bill of materials, restricted processes, man power and desired line balancing objectives. Keeping these constraints into consideration the features which are desired in an onlooking line balancing software are the Integration of data and documents/ maximum control, mixed model and option intelligence and analysis, multiple resources, smart variant management, scenario management, yamazumi chart, constraints and reporting tabs.

The findings of this thesis can be used as guidelines by any manufacturing industry while they consider buying a new software which can handle Line balancing problems. This research is one of its kind which talks purely about the constraints and desired features only in a specific line balancing scenario. Practitioners can use this as a base for conducting further research on constraints and features pertaining to it, for different line balancing scenarios.

## **Keywords**

Multi model line balancing, line balancing constraints, assembly line balancing, multi model, single sided, work load distribution

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# 1 Introduction

*This chapter gives a fair insight into what this research is about. Information is divided into different sections background, problem description, purpose and research questions and limitations of this thesis.*

## 1.1 Background

After agricultural revolution, industrial revolution of 18th-19th centuries triggered world's second largest expansion in economic productivity. Together with his team at Highland-Park Assembly Plant, Henry Ford introduced a manufacturing process which substantially reduced the assembly time and cost. For the first time in a history, automobiles became affordable to public. Creation of the assembly line made one of the greatest impacts on the world's history not only by developing manufacturing industry, but also by improving working and living conditions, rising urbanization, life expectancy and public wealth.

The principle that was followed by Ford was moving of the work from one worker to another until it becomes a complete unit, this followed by arranging of this units at the right place and right time to form an assembly line from which the finished product comes out. Assembly line typically consists of a series of tasks that are performed on a product at consecutive work stations. Each station is manned by a worker and this worker performs a series of tasks on the product while it's in that station. When the task is completed the product moves on the next station where next set of tasks awaits it. Since the times of Ford, a lot of transitions have taken place in the manufacturing and assembly methods. Due to the constantly-increasing customer demand the fast mass-producing lines have taken shape as multi-model assembly lines, flexible systems and customized lines. These changes in the assembly lines also include parallel work stations or tasks in the same assembly line, customized mixed models and multi-model lines, U-shaped lines and un-paced lines with buffer (Becker & Scholl, 2006).

Assembly lines were mostly seen in those industries which typically produces high-quality standardized products. Recently, assembly lines have also gained an importance in the customized low-volume productions (Becker & Scholl, 2006). It is eminently important for any industry to continuously increase its productivity considering changing customer demand in order to maintain its competitive advantage. According to Schmenner (2001), productivity can be achieved if the production systems are efficient and effective. Assembly line balancing plays a key role while managing the assembly systems (Becker & Scholl, 2006).

Installing a new assembly line is a tedious and long-term decision which requires extensive investments. Hence, line balancing (LB) plays a vital task in the medium-term production planning. These assembly lines should be designed and balanced in an optimum way to work effectively and efficiently. LB is a process of distributing the assembly task equally between the available work stations. LB is not only done to newly-installed lines, instead it is also implemented on the existing lines when the production processes are being altered and to maintain them regularly. The balancing decisions



have a long-term effect on the assembly lines which makes it highly important for the companies to align them with the strategic goals of the organization.

A traditional assembly line consists of definite set of tasks which are associated with a processing time. Each of the tasks comes with a set of precedence relations, which specify the order of tasks to be carried out (Ghoush & Gagnon, 1989).

The basic function of LB is to assign the tasks in a defined sequence of stations. Helgeson was the first one to formulate analytical solution for LB in 1954 (Ghoush & Gagnon, 1989). After that in Salveson (1995) introduced a mathematical form and suggested a linear programming solution. Since then the assembly line balancing has become a topic of interest for numerous researchers.

In an intermixed sequence, the mixed model assembly lines produce range of products with varying attributes such as colors, components, size etc. Due to this, such elements as precedence, takt time, operator skills and equipment must be constantly adjusted, and these adjustments must be taken into consideration while balancing the line. Finding a perfect balance between all the changing attributes is highly unlikely. Hence, there is a need for a mixed model line to be flexible regarding precedence, takt times, operator skills and equipment (Becker & Scholl, 2004).

### 1.1.1 Company background

Electrolux strives every day to achieve its vision “To be the best professional laundry factory in the world” in terms of its customers, employees, shareholders and other stakeholders. The production techniques of Electrolux have been evolving over the years and currently the company is a complete lean production site aiming to eliminate the wastes and getting efficient in resources daily. Electrolux has also introduced its defined production system, called EPS temple.

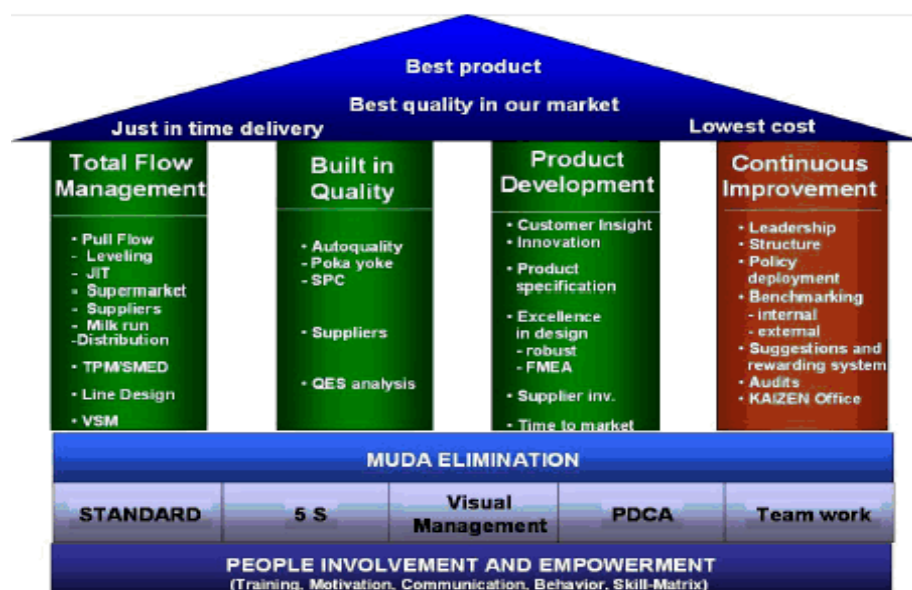


Figure 1 EPS temple

The base of the company is substantially built by valuing the people involvement and empowerment in regards with standards, 5S, Visual management, PDCA and Team work. To achieve certain goals such as “Just in time and lowest cost which in return benefit the company with Best quality product in the market”, Electrolux has designed four pillars which stand tall such as Total flow management, Built in quality, Product development and Continuous improvement.

Electrolux laundry systems in Ljungby concentrate on three distinct types of delivery time codes for distinct product types which are listed below:

Class A products are ready for delivery and are always kept ready to ship in the inventory as the customer is guaranteed to receive a product within 24 hours.

Class B products are made for market, the lead time is 5 days from the date of order while they have only 3 days to finish the product and send it to the warehouse.

Class C products are delivered on demand, the lead time can vary from 1 day up to several weeks.

Class B products which have only 3 days in the plant are called TR3. They were optimized from higher lead times such as TR7, TR8 etc. meaning that Electrolux has been able to achieve immense optimization with the lean production techniques.

## 1.2 Problem description

Electrolux laundry systems at Ljungby have a vast variety of Laundry systems to be manufactured daily as per the customer demand. It is a global company delivering to a large customer base all over the world. To keep up with this level of variety there is a need for making assembly line balancing faster and more efficient. At present the company performs line balancing using the tool MS Excel where they must deal with a wide range of calculations to be done manually daily, making it hard to understand and change the values as per the changing customer demand. Electrolux also considers changing current way of dealing with line balancing problems by changing the existing system from working on a manual MS Excel sheets to a line balancing software which is more accurate and time efficient considering the applicable line balancing criteria of the company.

## 1.3 Purpose and research questions

The purpose of this research is to determine the company-specific line balancing criteria which should be considered before performing line balancing. This research furthermore lays out a guideline to follow a smooth transition from the manual system of LB to an automated software by concluding the features the software must handle to perform the LB according to required objectives.

The research questions according to the purpose of the thesis are categorized into two.

RQ 1: What are the different criteria which should be met for ideal Line balancing in the context of Electrolux Ljungby?

RQ 2: How can these criteria be transformed to required specifications for a Line balancing software?

#### 1.4 Delimitations

This research is confined to a specific case company and a specific line balancing scenario. Hence, the results may not be generalized unless the new line balancing scenario is very similar to the case company. Moreover, the research mainly concentrates on the LB problems of assembly lines, excluding the sub-assembly lines.

#### 1.5 Outline

This section describes all the important chapters of the thesis report in a very short note.

##### Chapter - 2

##### Theoretical background

In this section various terms and their definitions collected from the literature are given which is crucial to know before further thesis content.

##### Chapter - 3

##### Method and implementation

In this section the research methodology is thoroughly explained while giving an insight on the data collection techniques used and the data analysis methods.

##### Chapter - 4

##### Findings and analysis

This section is further divided into two sub sections called as Theoretical findings and the Empirical findings. All the data required to answer both research questions is presented in this section.

##### Chapter - 5

##### Discussion and conclusion

In this section the research methodology and the findings are discussed in order to arrive at a conclusion. Moreover, visual representation of the whole research is provided. To conclude, suggestions for further research are presented.

## 2 Theoretical background

*In this chapter, Definition of the terms and theories regarding the LB are explained, which are important to be known before going on to the core of this research.*

### 2.1 Assembly line design

Assembly line design is a result of the continuous evolution of manufacturing technologies over time. Henry Ford was one of the firsts to invent the assembly line. Which in turn changed the way the cars are manufactured in terms of cost and the pace as they are manufactured. Henry Ford was also the first one to introduce the conveyor belts. Conveyor belts were helpful in implementing the principle of “Division of labor”. Division of labor made it easier for the employees to concentrate on one piece of a product at once instead of concentrating on the whole product all at once (Brahim et.al, 2006).

The basic assembly line is that there are several numbers of workstations positioned along a moving conveyor belt. Every station performs either one or more tasks while every station performs a value-added task. These tasks are performed by workers and with the use of appropriate machines and robots. The conveyor belts move according to a time termed as Cycle time. By repeating this process for several times, the final product is obtained at the last workstation. It is also possible that these tasks are associated with the precedence relationships (Brahim et.al, 2006). By using the principles of specialization and work division, high productivity of mass production system can be achieved (Bukchin et.al, 2002).

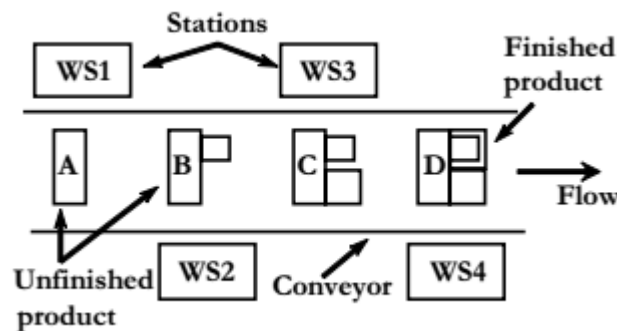


Figure 2 Assembly line design

### 2.2 Characteristics of Assembly lines

Since industrial manufacturing systems are different in each case, assembly line balancing problems corresponding to each assembly line are also different. (Rekiek et al., 2002b) and (Rekiek and Delchambre, 2001) provide a detailed classification of assembly line balancing issues (Becker et al., 2004). In every assembly line the time every product spends in each station is limited to the cycle time ‘c’. This is the maximum value of each product. Since tasks performed on the product are inseparable work

elements, the minimum value of  $c$  is always equal to the largest task time. Each assembly line has a fixed production rate, this is due to fixed cycle time. This fixed production rate is referred to as takt time.

In the absence of a predetermined cycle time, each station operates at its own individual speed. This causes uneven flow of product in the assembly line and the product may have to wait before it enters the next work station. This puts the current work station in the state of idleness when they have wait for the next product. This situation is partially overcome by introducing a buffer. In case of an assembly line that has buffers, assembly line problems are accompanied by additional decision problem of dimensioning and positioning the different buffers (Dolgui et al., 2002a)

If the assembly product is of only one type, then all the tasks that must be performed are identical and this assembly line is termed as ‘(A)Single-model assembly line’. If the manufactured products have several models on the same line the assembly line balancing problems are now connected to a sequencing problem. These sequencing problems must decide the sequence of assembly of different model units (Merengo et al., 1999). To have higher efficiency of the line this sequencing is important because various products may have considerable different task times. Based on the type of sequencing two categories of products arise.

- Single model assembly line: single model is assembled repeatedly, or one assembly line is complicated to a single model.
- Mixed-model assembly line: Where in the assembly line produces units of various models in an arbitrarily intermediate sequence (Bukchin et al., 2002).
- Multi-model assembly line: Where in the assembly line produces a sequence of batches of each model. Each batch contains a unit of only one model or a group of very similar models.

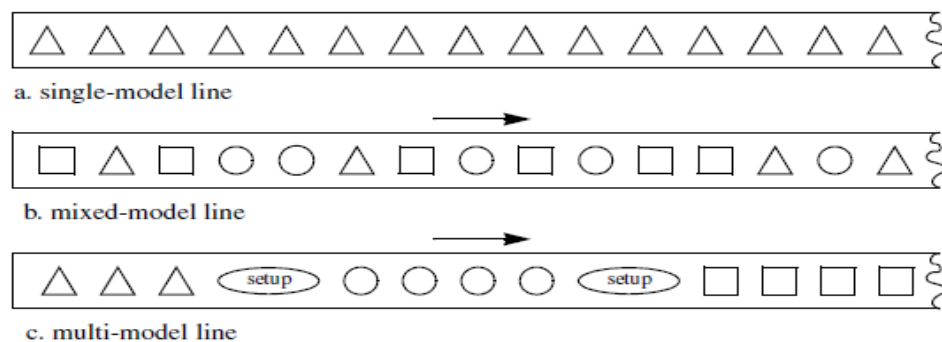


Figure 3 Assembly line for single and multiple models, (Bukchin et al., 2002).

## 2.3 Assembly line balancing problems

The researchers who have been researching on this topic of assembly line balancing are dated to be as from past 40 years. Many of the research carried out throughout these years are on the simple single model and without considering the constraints such as

precedence relations. It is very recently that the mixed model assembly lines came into the topic of interest for researchers as most of the industries now a day run on a mixed model line due to the pressures of sustaining in the market by satisfying the customers with more variety of products (Gocken, 1997). Mixed model assembly lines became the topic of interest as a result of market competition to satisfy varied customer demands (Gocken, 1997).

### 2.3.1 Desired line balancing objectives

In assembly line balancing various objectives are considered. The goal is to optimize one or more objective without exploiting the assembly line restrictions (Ghosh et.al, 1989). The most common objectives that are widely investigated are as follows

- Minimizing cycle time
- Reduction of number of workstations
- Maximizing work relatedness
- Maximizing workload smoothness
- A combination of maximization of work relatedness or workload smoothness (Kim et al., 1996)

## 2.4 Theoretical line balancing criteria

### 2.4.1 Assembly precedence

Precedence is the order in which the tasks must be carried forward while performing the assembly process of any product. These constraints are because of the technological restrictions. The nodes in the diagram are termed as the tasks which should be carried out and the arrows represent the precedence directions which indicates which task must be completed before the other. (Brahim et al., 2006)

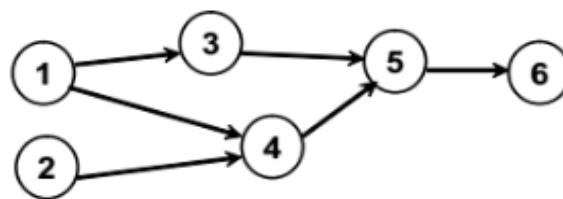


Figure 4 Illustration of precedence diagram (Brahim et.al, 2006)

Traditionally an assembly line comprises of limited set of tasks, each of these tasks has a predetermined fixed processing times. This fixed processing time occurs within the precedence network, this precedence network indicates the permitted order of the tasks. Assembly Line Balancing problem (ALBP) assigns tasks to workstations in a systematic way so as the precedence relationships are not violated. ALBP also ensures that some effective measures are optimized such as line efficiency, number of workstations (Boysen et al., 2008). All these factors make balancing assembly line have significant effect on performance and productivity of the manufacturing system (Hamta et al.,

2011). Assembly lines comprises of series of workstations in which the product enters the assemble line through a particular station and a set of predefined operations are executed on it. This happens in a straight line and the product finally reaches the end of the assembly line. The time duration between the entry of the product into a particular station and the exit of the product from the same station is referred to as cycle time. Simple assembly line balancing problems (SALBPs) is where the focus lies widely till now.

There are two types of SALBPs (Boysen et al., 2007)

1. SALBP type 1: This type of problems aims at reducing the number of workstations for a predetermined cycle time. This situation generally arises when the company decides to design new assembly line.
2. SALBP type 2: This type of problem is usually intended for already available assembly systems and focuses on improving their line efficiency. The goal is to minimize the cycle time or to maximize the production rate for a specific station.

To bridge the gap between real problems and academic studies, more realistic relevant features have been considered such as U-shaped lines, parallel stations, equipment selection and other processing alternatives. These types of problems are called as General assembly line balancing problems (GALBPs) (Becker et al., 2006)

Time always plays a key role in real industrial situations. When considering new machines that shortens the processing time, we must account for the factors that will reduce the lifetime of the machine, such as wear, corrosion, and fatigue. In most assembly lines, reducing the cycle time will increase the production rate. By using new machines with flexible operation time, we can reduce the processing time which might shorten the cycle time and increases the production rate. Cost and Operating time vary with the working and use of machines, but for simpler calculations a linear function between the two is considered. The problem is to reach a trade-off point between the cost of reducing the task time and the value of the cycle time. For straight assembly lines the problem is commonly known as Flexible task time assembly line balancing problem (FTALBP) (Hamta et al., 2011). Assembly lines problems can be categorized into different domains and researchers have focused on each of these fields. Straight assembly lines, U shaped assembly lines and parallel assembly lines are the most considered assembly lines (Hamta et al., 2011). Various algorithms are developed to obtain optimal balancing in reasonable time. Numerous algorithms are developed and can be classified into genetic algorithms (Chen et al., 2002), tabu search (Lapierre et al., 2006), ant colony optimization (Simaria et al., 2009), simulated annealing (Özcan, 2010), petri-net heuristic algorithms (Kilinci et al., 2010), Computer Method of Sequencing Operations for Assembly Line (COMSOAL) method (Toksarı et al., 2010) and Graphical Representation of Algorithms, Structures and Processes (GRASP) algorithms (Andres et al., 2008).

#### 2.4.2 Physical work load constraints

Physical work load (PWL) is the cost that is related to an individual when performing a task with specific demands while considering their capacity of achieving that level of performance (DiDomenico, 2003). The PWL considers several factors that are related to work and environment. The factors related to work include repetitive movements, awkward posture, vibrations, lifting, and prolonged sitting or standing, and those related to the environment include lighting, temperature, and humidity. Not considering these factors may lead to an excess of workload.

PWL is a necessary part of designing a job, as excess of workload leads to injuries, such as musculoskeletal disorders (MSD) (Fredriksson et al., 2001), (Marras et al., 2009). MSDs are muscle injuries that affect the ligaments, nerve and tendons. MSD affect many employees and constitutes of about one-third of all injuries reported each year. The economy and the businesses also pay heavily, because of its effect on the workers. The Factors such as awkward or static postures, repetitive activities, lifting or moving and vibrations are the main cause of MSD. The frequency, intensity and duration of exposure to these factors determine the level of risk. Such factors are always found in assembly lines, and hence assembly workers are most exposed to MSD (Moreau 2003, Landau et al., 2008). Hence it is important to consider PWL when designing the work-stations so that the risk of injuries, such as MSD, are minimized.

It is important to ensure that the employees are not overworked to reduce the risk of MSD. Hence the assembly line should be designed to limit the workload at every station. Most of the assembly line problems only consider duration and task precedence when it comes to minimizing cycle time. PWL is a vast concept considering many dimensions. When talking of the physical work the following factors should be considered (Mutlu et al., 2012).

- The requirements of the job like, repetition, work posture, duration etc.
- Workplace conditions like floor, seating arrangement, the height of the workspace etc.
- Conditions of the workspace environment like temperature etc.
- Psychological factors like stress etc.

PWL can be assessed in diverse ways which are subjective methods, direct methods, psychophysiological methods and observational methods (Li and Buckle, 1999). The subjective method uses different tool, like rating scales, interviews, questionnaires etc., to collect data directly from the workers. Workload can also be calculated using the Fuzzy set theory. The simplicity and the validity of the subjective approach makes it the most frequently used (Li et al., 1999). The direct method accounts for the physical factors, like heart rate, blood pressure, electromyogram (EMG), oxygen consumption, electrocardiogram (ECG), respiratory rate etc., while determining the PWL. Considering such factors requires the use of software and devices that are tailored for each factor. (Mutlu et.al, 2012). The method of observation determines the position of the body, like trunk, head, lower and upper arms etc., when the workers are observed while they perform a task. Deviation from the observed data, in terms of neutral position, repetition



and force required for an action, is observed and scores are assigned for each body part based (Mutlu et.al, 2012).

Another problem derived from the assembly line are those related to ergonomics. The human factor was considered by Chen et al., (1994) while constructing a model that calculates the degree workload after determining the several reasons that increase the workload. Moreover, Hagberg et.al., (1995) concluded that excluding factors other than processing time when balancing an assembly line would result in an increase in the number of workers which might lead to physical injuries to the workers (Choi, 2009). To avoid such situations, Carnahan et al., (2001) realized that physical factors play a key role in designing an assembly line and derived a formula to reduce the cycle time of a single model which considered grasping power to be the physical factor. The workers performance is affected by their workload level, so Jung et al., (2001) analyzed the several reasons that affect the workload and established a scale to determine the level of workload for the workers. Landau et al., (2008), Kumar et al., (2008), and Newell et al., (2008) further researched the problem of physical work and found several areas where a solution could be implemented. (Choi, 2009)

Many researchers have been working to determine a solution to both the single and mixed-models balancing problem (Gagnon et al., 1991). A detailed literature review has been presented by Matanachai and Yano (2001) documenting 1980-1990 development. Becker and Scholl (2006), Boysen, Flidner, and Scholl (2007, 2008) have best addressed the balancing problem by providing a structured classification and analysis of concerns related to the single and mixed models (Choi, 2009).

The research that has largely impacted the balancing problem of traditional mixed model are listed below. The first approach, by Roberts and Villa (1970), was to ensure continuous operation by using an integer program model that constraints the number of work stations. The approach was implemented in real life and further improved by Macaskill (1972), Raouf et al., (1983), Berger et al., (1992), and von Zante-de et al., (1997). Erelbacher et al., (1991) recommended integrating the different work categories at each station and using that data to determine the best way to assign the job. Hsu (1992) introduced a way to refine an existing workstation to cut down the rate of overload and to curtail the cost. The shortest path model was introduced by Erel et al., (1999) which aims at ensuring a continuous work flow. Matanachai et al., (2001) established a way to account for the change in model combination while determining and assigning the processing time. Resource constraints was addressed by Agpak et al., (2005) who proposed the use of 0-1 integer formulation. (Choi, 2009)

After extensive research Scholl et al., (2006) introduced a survey about the algorithms that are used to design a stable assembly line. A few of the main algorithms are listed below. Branch-and-bound algorithm was introduced by Berger et al., (1992), which constrained the fixed cycle time to reduce the number of workstations. The Branch-and-bound algorithm gained prominence when Bukchin et al., (2006), Miralles et al., (2008) recommended its use. Using goal programming, Gokcen et al., (1997) were able to eliminate imbalances in the assembly line, furthermore, the fuzzy goal programming

formulae were introduced by Özcan et al., (2008). Simaria et al., (2004) suggested the use of genetic algorithm for a heuristic approach.

### 2.4.3 Material supply

Material supply is a salient, but critical part of an assembly line. In recent times automated vehicles are used to transport materials directly to the station, but a traditional method it to use containers that are transported alongside the product. Implementing the traditional approach of transport requires answers to many questions such as the size of the container, quantity of material, the system to connect different stations, the number of stations to be connected, the distance between the container and the operator (Bukchin et al., 2005). A decision must be made for each of the factors before implementing the transport system. To simplify the decision-making process, it is always recommended to consider the material supply problem while balancing an assembly line (Boysen et al., 2008)

### 2.4.4 Product demand

Manufacturing of products requires accomplishment of diverse types of tasks and this task assignment is done by assembly line balancing (ALB). The problems associated with this ALB are called simple assembly line balancing problems (SALBP) (Scholl, 2006). SALBP basically considers two constraints while assigning tasks to the workstations, which are precedence constraints and cycle time constraints. Bautista et al., (2007) proposed a more realistic ALB problem which is an extension of SALBP. The authors considered an additional space constraint which is much closer to real world situations. This gave birth to the term “time and space assembly line balancing problem” -(TSALBP) (Chica et al., 2013). TSALBP is a more realistic multi objective version of industrial problems associated with line balancing which also takes into consideration of the area of the working stations.

However, in a real industrial situation these are not the only important constraints, fluctuation of product/customer demand must also be considered. Chica et al., (2013) considered TSALBP and introduced a real scenario which comprised of mixed products with fluctuating demands. The authors suggested a novel robustness functions which measures the robustness of the assembly line configuration when demand changes the production plan. The robustness value is graphically represented which forms a generic model and in turn gives a better picture of the effect of demand.

### 2.4.5 Cost synergies

A cost synergy is observed when different tasks demand the use of a constant set of resources. The synergy presents an opportunity of reducing the capital cost by assigning the set of resources to a particular station. Zoning constraints are also implemented for the task performance. Using cost synergies, the resources are conserved, but the line balancing is pared down which add to the cost. An explicit cost synergy model is used to determine if minimizing resources could compensate for reduced line balancing. During a theoretical calculation the cost synergies are usually included with the station and process costs, although in actual practice cost synergies are incurred when resources

are either used, or when the stock is replenished. Therefore, the cost of resources should be separated from the rest (Boysen et.al 2007).

### 3 Method and implementation

#### 3.1 Research approach

It is said that the three major checkpoints in any research start from formulating a problem, then the collection of empirical data through observation of various sources of information regarding the problem formulated and connecting the collected data with the available problem-specific research papers which are already published (Jacobsen, 2002).

The the end results of this research work are expected to be qualitative and hence the flexible design of the qualitative approach is implemented.

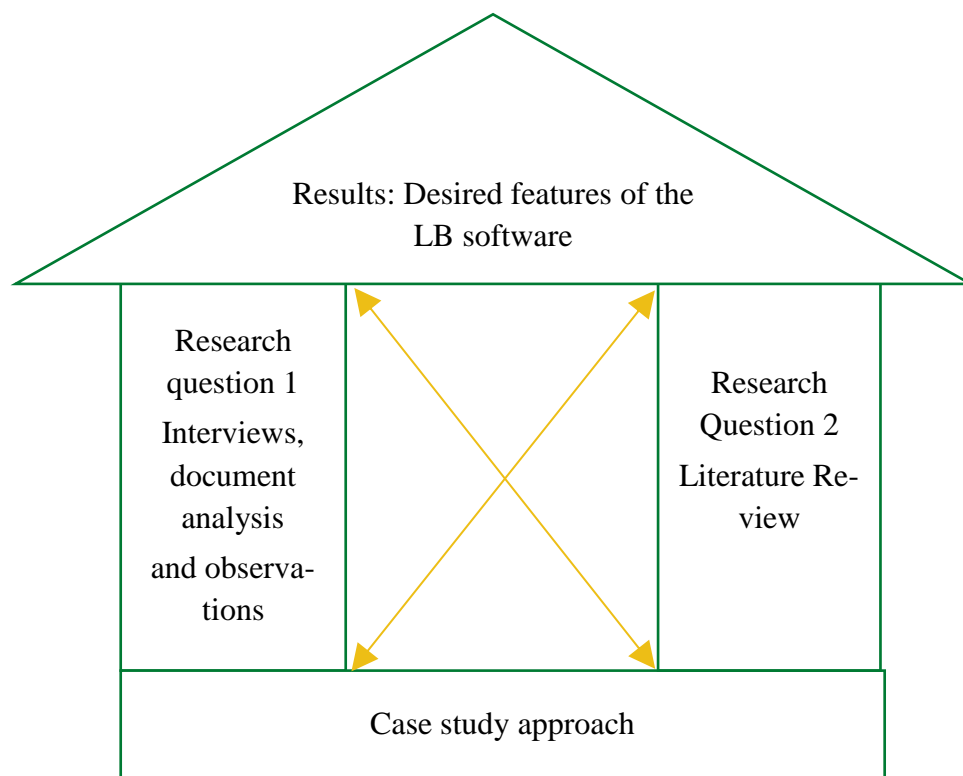


Figure 5 Research Design

The figure above depicts the research approach followed, using the case study approach. All the empirical data is collected from the case company regarding the LB criteria which set up the firm base to the structure of this research work. To collect the empirical data from the case company, interviews were adapted as the best option as it was necessary to have a deeper knowledge about the problem. Semi-structured interviews were conducted with a specific set of questions which led to discussions. The company's historical documents such as demand trends, company structure, plant layout was

analyzed using document analysis as the secondary source of empirical data for (RQ1). Another data collection technique which was used are observations. Observations was chosen to validate the line balancing criteria which were collected through interviews and document analysis, it was made sure through the observations that all the LB criteria are seen on the assembly line in real time.

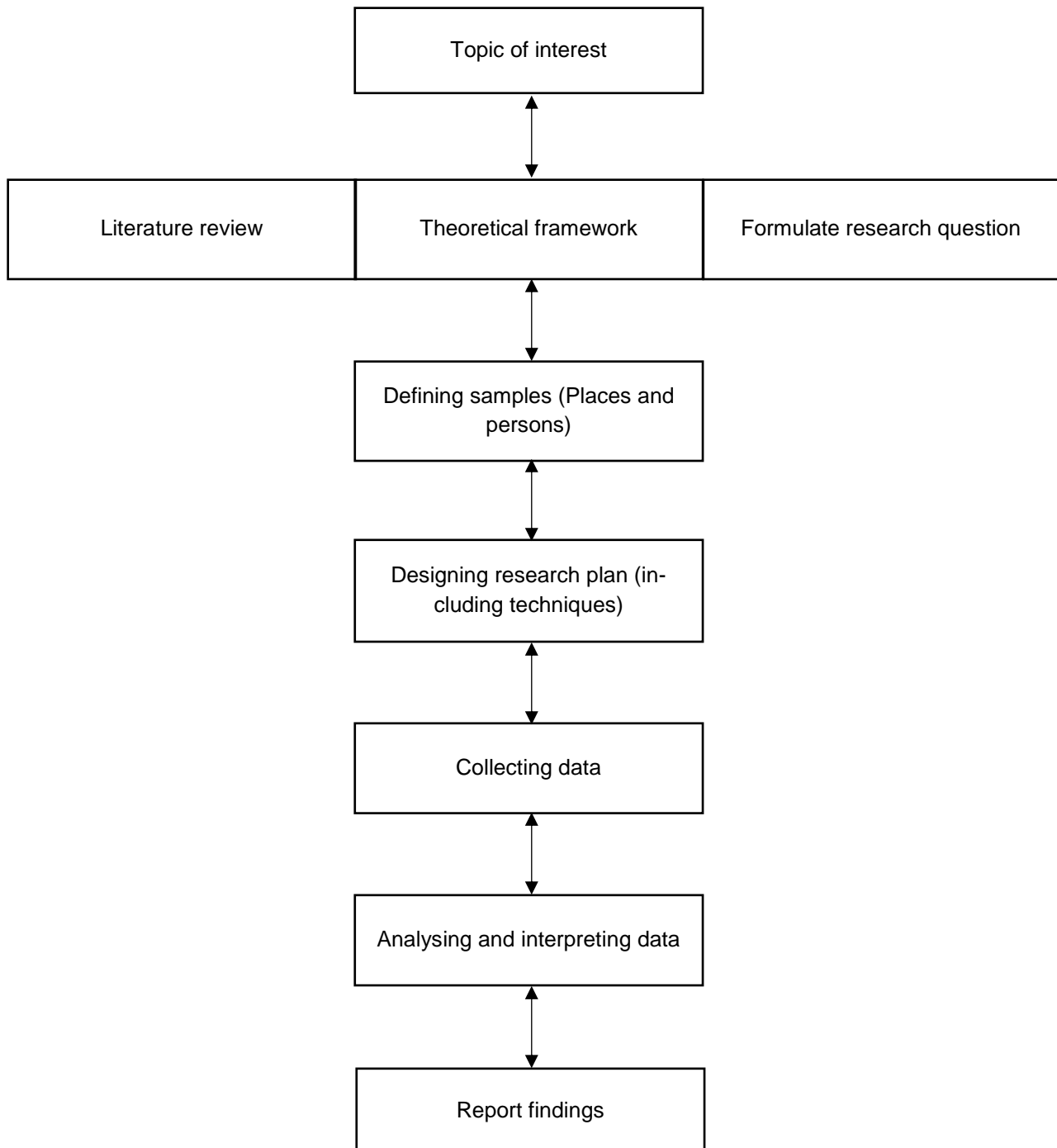


Figure 6 Qualitative research design (Williamson, 2002)

The literature review was done to build the theoretical base of this report which includes various definitions and concepts needed to be known before going deeper into the subject area. Literature review is also done to narrow down the knowledge gap regarding the multi model line balancing techniques which the company are unaware. The arrows in the Figure 5 represent the flexible nature of this research design. It is said to be flexible because there were a lot of iterations in the very beginning of this research where based on the literature knowledge obtained the aim and research questions were modified a few times, meanwhile the literature search took us back and forth throughout the process. The top most part of the diagram which is called as roof represents the results of this research, which is strongly supported by all the other sections of this report.

This research started by understanding a specific theory by conducting the literature review and then choosing the topic of research and framing the research questions. Later suitable data was collected from the case company and analyzed the data in the last section to get to the conclusions. Hence this design becomes iterative and nonlinear in nature. The figure above depicts the qualitative and iterative research design where one can see that there is a two-way arrow marks between every step which is the nature of it (Williamson, 2002).

## 3.2 Research methods

### 3.2.1 Case study approach

The case study is a method which investigates a phenomenon in a real-life context (Yin, 1994). The case study approach was chosen for this research because it was very appropriate to the Electrolux context where there was a need to examine and understand a specific context.

It is a single-case study as this research heads to solve a problem which is specific to a single company. Anyhow the results can be generalized to the manufacturing industries with a similar environment as Electrolux such as multi model straight assembly lines with batch production.

## 3.3 Research techniques

### 3.3.1 Literature review

Literature review is nothing but gathering all the available theories and research papers regarding the topic of interest, which enhances the knowledge we have with respect to the research topic and gives the knowledge which is required to carry out the topic of research. (Jesson et al., 2011). This research has a two-step approach in doing the literature review, where the first step is the traditional review and the second step is the systematic review. In the traditional review process, papers were searched based on a set of keywords with all possible combinations such as Line balancing, Mixed model, Line optimizing, Customization, workload balancing, Precedence constraints etc. (Jesson et al., 2011).

Later the systematic approach of the literature review was implemented where the papers which were very close to the research topic and those which were helpful to build the research were chosen after reading the abstract and content of the paper.

Literature review in this research was used to build a theoretical base to understand the concept of Line balancing and for defining a few terms which are largely used in the concept of Line balancing. Literature review was also used to search for the research papers which deal with the Line balancing techniques which closely match to the line balancing scenario of the case study company which is Multi model single sided straight type. The papers which deal with the Multi model single sided straight type with its objective to balance the work load across the assembly lines are summarized in the theoretical findings sections.

The literature search was done using the three search engines Primo, Scopus and Science Direct, these three searching sites are relevant to articles related to technology. Because most of the advancements in line balancing are recent, time line filter was set between 1985 to 2017. With the term “Assembly line balancing” a total of 216205 hits in Primo, as little as 2632 hits in Scopus and 599829 hits in Science Direct were found. Since these are vast number of papers and the probability of having papers which are not relevant to this research was high, the combination of keywords such as Multi model line balancing, Line balancing constraints, Multi model, Single sided, Work load distribution were added for the filter. Then the number of papers reduced to around 800 to 900. Further, the titles and abstracts were read to check if the papers can contribute to the aim and research questions of this research. For the papers which were in ambiguity with its content, the problem descriptions and the conclusions were read. Finally, 10 papers which were useful for this research were found. Later using the snowball technique, few more papers were found which helped to build the whole report.

### 3.3.2 Interviews

Interviews are the most used data collection techniques for a case study, it is a technique which is used when you are planning to extract qualitative data and when it is hard to arrive at the desired information just with simple survey questions. With the interviews, a deeper knowledge is obtained on a specific case (Williamson, 2002). There are three distinct types of interview techniques which are structured, semi structured and unstructured. The type of interviews adopted in this research was semi-structured where there was a scope to divert from the topic to a certain extent while giving knowledge on other topics which could be useful. There were definite set of questions designed in the interview guide, the interview guide can be seen in the “appendix 2”. The interview questions were direct while the list of LB criteria listed from the literature review was given to the interviewees and asked for their relevance in the Electrolux context. Care was taken according to the interview guide to design the questions. These questions led to informal discussions about diverse topics while giving insight and deeper understanding about the company problem. Purposive sampling was done to pick the interviewee candidates who had key information of the subject and could contribute to the purpose.

### 3.3.3 Observations

Observations fall under ethnographic techniques. Observation is the most flexible data collection technique which is available. There is no proper defined way to perform observations, they can be designed according to the context. There are a few ways in which the researcher can do the observations. The different types of observations are best explained by (Glense and Peshkin, 1992) in their research.

For this research, the entire process was observed standing next to the participants in the participants point of view. This helped to identify some patterns of line balancing criteria and to observe rare failures which resulted in the stoppage of a whole line for one complete day (Williamson, 2002).

### 3.3.4 Document analysis

The historical documents are a collection of data. Relevant documents when observed and analyzed for over a period shall give a lot of information which might be helpful for the present research work being carried out (Williamson, 2002). In this research various documents from the case company were analyzed to find out if there is some information regarding the LB criteria. The documents which were analyzed include customer demand sheets, operator work instructions, product variation sheets, plant and line layout.

### 3.3.5 Data analysis

As this research is qualitative in nature, there is no proposed theory or a method by any of the researcher's which can be followed to carry out the data analysis. There is liberty to perform the data analysis in one's own way. Anyways, pertaining to this thesis the data analysis is done by taking the points into consideration mentioned in the research paper written by (Williamson, 2002). Firstly, all the data collected through observations, semi structured interviews and historical research were transcribed onto paper. It was clear what to look out for in the transcribed data because the literature review was done well before. For example, the patterns such as yearly variations in products 520 and 595 were observed in the transcribed data. Once these data were found, they were categorized into different line balancing criteria. This helped in completing the analysis and concluding the report. Qualitative data is something which gives you a meaning or views of the researcher regarding a specific topic, and hence it is dealt with the qualitative data in this research, a deductive approach was followed which allows to confine and group the collected data according to the research questions.

## 4 Findings and analysis

*In the findings, authors arrive at the theoretical line balancing criteria from literature review, and the company-specific LB criteria through document analysis and interviews. These data were compared and evaluated for its significance in the context of Electrolux. Also, the findings regarding LB theories with workload balancing and number of workstations as its objective are shown and analyzed. Using all these above data the research questions are answered accordingly.*

### 4.1 Theoretical findings RQ 1

Theoretical potential line balancing criteria:

The literature review was done to figure out the various Line balancing criteria which researchers have given importance and applicable to the present case specific Line balancing situation. After reviewing the literature, a list of criteria was found evident which are shown in the table below.

Table 1 Potential line balancing criteria found in literature

Theoretical Line Balancing criteria	Author	Literature
<b>Assembly precedence</b>	(Hamta & Ghomi & Jolai & Bahalke, 2011)	Bi-criteria assembly line balancing by considering flexible operation times.
	(Pallavi & Thakur & Gupta, 2014)	Evaluation of multi criteria assembly line balancing by MCDM approaches: a conceptual review
<b>Physical work load constraints</b>	(Mutlu & Ozgormus, 2012)	A fuzzy assembly line balancing problem with physical workload constraints
	(Carnahan & Norman & Redfern, 2001)	Incorporating physical demand criteria into assembly line balancing
	(Ozgormus, 2007)	Ergonomik faktorler altnda montaj hatt{ dengeleme [Assembly line balancing problem under ergonomic factors



	(Choi, 2009)	A goal programming mixed-model line balancing for processing time and physical workload
<b>Takt time</b>	(Hamta & Ghomi & Jolai & Bahalke, 2011)	Bi-criteria assembly line balancing by considering flexible operation times.
<b>Processes, Resource, Station restricted</b>	<p>(Tuncel &amp; Topaloglu, 2012)</p> <p>(Boysen &amp; Fliedner &amp; Scholl, 2007)</p> <p>(Scholl &amp; Klein, 1999)</p> <p>(Dar &amp; Rubinovitch, 1979)</p> <p>(Kim &amp; Park, 1995)</p> <p>(Pastor &amp; Andres &amp; Duran &amp; Perez, 2002)</p> <p>(Sawik, 2002)</p> <p>(Bautista &amp; Pereira, 2007)</p>	<p>Assembly line balancing with positional constraints, task assignment restrictions and station paralleling: A case in an electronics company</p> <p>A classification of assembly line balancing problems</p> <p>Balancing assembly lines effectively – A computational comparison</p> <p>MUST – A multiple solutions technique for balancing single model assembly lines</p> <p>A strong cutting plane algorithm for the robotic assembly line balancing problem</p> <p>Tabu search algorithms for an industrial multi product and multi objective assembly line balancing problem, with reduction of the task dispersion</p> <p>Monolithic vs. hierarchical balancing and scheduling of a flexible assembly line</p> <p>Ant algorithms for a time and space constrained assembly line balancing problem</p> <p>Incorporating physical demand criteria into assembly line balancing</p>

	(Carnahan & Norman & Redfern, 2001)	A branch and bound algorithm for assembly line balancing problems with formulation irregularities
	(Johnson, 1983)	Balancing assembly lines. An industrial case-study
	(Lapierre & Ruiz, 2004)	
<b>Product demand</b>	(Manuel & Chica & Óscar & Córdón & Sergio & Damas & Joaquín & Bautista, 2003)	A robustness information and visualization model for time and space assembly line balancing under uncertain demand
<b>Man power</b>	(Iskander & Chou, 1990)	Unbalanced production line scheduling with partial job specialization.
<b>Desired LB objective</b>	(Yong & Yeo & Yongkyun, 1998)	A Heuristic Based Genetic Algorithm for Workload Smoothing in Assembly Lines
	(Bautista & Jaime, 2008)	Minimizing work overload in mixed-model assembly lines.
	(Chen & Lu & Yu, 2002)	A hybrid genetic algorithm approach on multi-objective of assembly planning problem

## 4.2 Empirical findings

### 4.2.1 Company overview

Electrolux Ljungby consists of four major assembly lines which are established in parallel. These lines are called as Lean A, B, C, and D respectively. The products assembled on this line include washing machines and dryers. Complete assembly is not done on these lines, there are other lines which does the sub-assemblies, then these sub-assemblies are assembled in the assembly lines A, B, C and D. The product mix on these lines are categorized based on the product family and the part commonality which makes it easier for balancing the line and since most parts are common between the product mix, no special training is required for the lay men. The busiest line among all these is Lean B and the focus of our thesis is on Lean B for the same reason.

The Lean B assembles washing machines with model numbers 520 and 595. This Lean B runs at different takt times depending on the demand variations. Mostly this line works on 75% takt. Lean B has no room for buffers, the products move from one station to the other at the same instance, if there is a delay even in one of the stations then the whole line stops which is why it is very important to balance the lines in such a way that there are no stoppages. Lean B has 12 stations all together, assembly takes place between stations 1 and 7, 8 and 9 are testing stations and stations 10, 11 and 12 is where the packing is done. Whenever an assembly exceeds the takt time with a great margin on the line, the product is removed from the line and is sent to a separate area called as testing area where the remaining part of the assembly is completed and tested at the same station. Later the product is reintroduced at station 10 where the packing is done. Since the products produced on these lines 520 and 595 are same product family and the only difference is in the size of drums. Assembly precedence's cannot be combined for two models because of the difference in the part sizes. These products are assembled in batches with batch sizes according to the demand.

#### 4.2.2 Findings regarding RQ 1

When the term LB criteria is used, it means that these are the constraints which should be considered in balancing the line without fail.

In this section findings through interviews and document analysis are shown. Five semi structured interviews with four persons belonging to various levels of organization on the same assembly line. were conducted separately with the same set of questions. All the findings are shown below.

Table 2 Line balancing criteria stated during the empirical research

<b>Empirical LB criteria</b>	<b>Data collection method</b>
Flow of materials	Interview
Assembly precedence	Interview
Physical constraints	Interview
Bill of materials(BOM)	Document analysis
Restricted processes	Interview
Product demand	Document analysis
Man power	Interview
Desired line balancing objectives	Interview

All the listed LB criteria in the case study are explained in detail as told by the interviewees at the case company and gathered through observations and document analysis. Supporting documents regarding the same are placed in Appendix.

## **Flow of materials**

Some interesting information regarding flow of materials were obtained in the empirical study, this information helps us to draw some conclusions on how it affects the LB. The points below are a summary of the information gathered.

- All the raw materials are always refilled at the line (By a material handler)
- Refilling the raw material on the line follows milk run concept.
- Production is planned on the available material in the super market. Hence there is no stoppage on the line once the assembly process is started.
- Daily production is planned by the planning department
- Material handler has all the information regarding the takt's so that he knows how to refill the material in a right order and right place at the right time.

Keeping track of the material flow inside the plant is of utmost importance for the assembly process to keep running without any interruptions. Case company has realized through various incidents that not keeping track of the material consumed daily, might lead to poor replenishing of the raw material which in turn lead to lack of material on time to continue the production. Hence the need for a system which records the material consumption, quality of material, material loss in rework etc. is important.

During the first day of the observations, it was observed that an entire assembly line (Lean A) had no production for the entire day and probably till the material arrives, due to the lack of material. In this case it was a single part which was crucial for the production while rest of the parts were available. Unavailability of even a small part can prove fatal to the company's productivity. When asked about the same who was responsible for that line, the operator said that keeping track of the material flow plays a key role in balancing the line, which helps to the assembly scheduling and product mix based on the available material in the master storage.

## **Assembly precedence**

This constraint was observed in the work instructions available on assembly line, few important points are listed down

- All the processes in Electrolux follow assembly precedence.
- The work instruction provided for the operators on line were studied for the precedence.
- Since, Lean B is multi model assembly line and the two different models are manufactured in specific batch sizes, the precedence's cannot be combined.

There is a set of precedence's attached with every individual product. Sequence of procedures were observed for a few products through the documents such as work instructions available on assembly line, which signifies the importance of precedence constraints

Regarding the assembly precedence at Electrolux Ljungby, the products which were studied in this research (models 520 & 595) are bound with a set of precedence constraints. This can also be generalized to all the models at the case company. These precedence constraints play a role in deciding the assembly process of each model

separately which also helps in fixing the cycle times. As the lines in the case company are multi model and not mixed model the models are produced in batches. Hence, there is no need to consider combining the assembly precedence of the different models on the same line. This empirical information regarding the assembly precedence was collected through document analysis and interviews. The interview question and the information deferred from it can be seen in the appendix. The type of document which was analyzed are the work instructions which are present on the assembly line for workers. As these work instructions documents were confidential it was not able to retrieve them.

### **Restricted processes**

In the assembly line there can be few processes which are restricted with respect to the assembly process, precedence, man, equipment, positioning etc. This particular constraint was not found prominently on Lean B but this was generally found on other lines in the company. Electrolux have a few products which are assembled on an assembly line because they have the right equipment to assemble that product only on that line. One such example comes from the model 590 which was assembled on Lean A, where the drum of the washing machine was huge and complicated to handle, it needs a special fixture to be fixed on. This assembly cannot be done on any other assembly lines available. Hence, it becomes very important to make sure that product is assigned on the same line and station while balancing the line.

### **BOM**

The BOM is associated with the flow of materials. The usage of materials should be updated in the BOM as soon as they are consumed in the assembly line. This entry should be made either manually or by a software. In case if the BOM consumption is not updated, it could result in unanticipated stoppage of the assembly line. This was seen during observations at the company, where an assembly line (Lean A) had stopped due to shortage of materials. Hence BOM is one of the main constraints which indirectly affects the line balancing process.

### **Product demand**

After analyzing the documents related to the demand variations for past few years a few conclusions can be drawn. After reading the documents available from the case company regarding the demand fluctuations from 2010 till 2017. It is evident that there are no prominent fluctuations in the demand over the period observed. The demand graphs are drawn using the data available from the document which is analyzed (Graphs can be seen in appendix). Very few instances are seen with unexpected fluctuations like 2014-12-04 where only model 595 had 100% while model 520 had 0% demands. In 2010-04-15 again model 595 had 100% while model 520 had 0% demand. Observing the demand trend, it is evident that the demand is deterministic. Product demand is also an important constraint to be considered as the production is planned prior in three days to meet to-day's demand. This planning before three days is termed as TR3 technique in the company. For unplanned demand variations, there is a finished products inventory with approximately 1500 finished products. (capacity 2500)

Table 3 Average product demand for models 520 & 595 (Yearly)

Year	Average demand	
	Model 520	Model 595
2009	88 %	12 %
2010	85 %	15 %
2011	84 %	16 %
2012	83 %	17 %
2013	83 %	17 %
2014	82 %	18 %
2015	83 %	17 %
2016	84 %	16 %
2017	83 %	17 %
<b>Total Average</b>	84 %	16 %

Table 4 Standard deviation in product demand for products 520 & 595 (yearly)

Year	Standard Deviation(520 and 595)
2009	0,079
2010	0,093
2011	0,083
2012	0,107
2013	0,108
2014	0,105
2015	0,082
2016	0,080
2017	0,075
Average Standard Deviation	0,090

The average demand and the average standard deviation for the two models (520 and 595) through the years 2009 to 2017 is shown in the tables 4 and 5 respectively. This indicates that the early demand is stable and hence predictable. This information can also be used determine the emergency stock needed and in turn help to create a more efficient line balancing.

### Man power

The case company have man power who are skilled equally to work on various models across the assembly line. These men work with different takt's based on the possibility and the man power available. For example, laymen work with 75% takt and 50% takt which simply means that 3 men working on 4 machines or 2 men working on 4 machines respectively. This was discussed during the interviews and it was also observed

at the assembly line where the men were working at 50 % takt while 2 of them were managing 4 machines.

The expectation of the case company through Line balancing is to vary this takt percentage to the least possible and efficient way. Right now, the case company does a lot of man power balancing in various occasions. The company also like to continue to do the man power balancing along with the line balancing with other objectives such as work smoothening and work station reduction in future. Hence, man power is considered as one of the criteria of LB.

### **Desired line balancing objectives**

The line balancing is performed with various desired outputs. It can be to achieve lesser number of work stations, lesser lay men, lesser cycle times, balancing work load etc. The interviews conducted suggest that the product cycle time audits are done very frequently on the assembly line and hence they are not very keen to achieve optimized cycle times through LB. They also suggest that the workers are equally skilled in all the areas of production and hence they can put them on different jobs whenever desired which is not a problem again. But the company is very keen in balancing the work load equally as they face work over loads and idleness very often.

#### **4.2.3 Findings regarding RQ 2**

Theoretical general features of a LB software:

It was quite difficult to find the relevant literature regarding the features of different LB software, however a brief study of the user manuals and web pages of different competitive LB software's such as Proplanner and Avix have helped establish a list of general features of a LB software and are listed below.

##### **1. Integration of data and documents/ maximum control**

Each balancing operation comes with its specific data and when such an operation is moved in the balancing sequence so does the data. Engineering changes will be easily reconciled in the balancing process.

##### **2. Mixed model and option intelligence and analysis**

When establishing a task assignment line balancing for all the products it is not enough to consider a few product variants when there are thousands of product variations in the line. This mixed model and option intelligence and analysis feature will identify common tasks and unique tasks between the product modules. The data in the form of charts and report provide a detailed analysis of the different labour times that each module requires.

##### **3. Multiple resources**

Multiple resources tab allows several operators to work on different tasks simultaneously, simple handling of various resources helps analyse setups with multiple machines. Easy determination of time spent on different tasks and actual time necessary for different tasks.

#### **4. Smart variant management**

This LB feature makes it easy to see how different product variations will affect the workload on different stations and show the effect of different product mixes to the balancing.

#### **5. Scenario management**

Whenever a change is made in the balancing process, it creates a new scenario. Changes made in takt time, takt assignment, models etc create new scenarios and these scenarios will be saved and is assessable for further use.

#### **6. Yamazumi chart**

Yamazumi in Japanese means “stack” or “pile”. The Yamazumi chart is used to visualize the passive wastes, it is a lean management tool used to highlight workload between and within processes (Pieńkowski M, 2014). This feature will generate mixed model Yamazumi charts which are easy to read and reassign tasks as required.

#### **7. Virtual assembly**

Visual confirmation of the balancing sequence eliminates errors in the actual assembly process. It helps engineers anticipate issues with their task assignment by viewing the progression of the assembly process.

#### **8. Value added analysis**

Charts that display value added, non-value added and supporting work are generated using this feature. This data will be extracted from initial time studies done on the different activities of assembly lines.

#### **9. Constraints**

Physical and other type of constraints such as precedence, tools that are required for certain tasks, work zone, task groups that must be performed in the same station, inspection or other tasks that cannot be performed at the same station etc will be considered in the balancing process.

#### **10. Reporting**

Balancing summaries and comparison, standard work documents, parts and tool summaries etc will be available when required.

Assembly planner user manual. (2015) and Assembly planner website. (2018) and Avix PLM software website. (2018)

### **4.3 Analysis**

#### **4.3.1 Regarding RQ 1**

In this part of the chapter the credibility and the importance of the line balancing criteria which were observed by the company are compared and analyzed. The interviews conducted in the company and line balancing criteria in the literature are also analyzed. All the criteria found through literature and case study are represented in a table and they are marked according to who has mentioned about it in the interview and literatures.



This gives a clear idea about which criteria are most important and should be considered before any line balancing problem.

I 1 – I 4 in Table 5 are the interviewees who all belong to the case company designated at various levels.

I 1 is EPS manager

I 2 is Project manager

I 3 is Line leader

I 4 is laymen on the production line

Table 5 Analysis by comparing the theoretical and empirical LB criteria

<b>LB Criteria</b>	<b>I 1</b>	<b>I2</b>	<b>I 3</b>	<b>I 4</b>	<b>Literature</b>	<b>Observations</b>	<b>Ranking based on number of occurrences in the findings</b>
Flow of materials		x	x			x	3
Assembly precedence	x	x	x	x	x	x	1
Physical constraints		x	x	x	x	x	2
BOM	x		x				4
Restricted processes	x	x	x	x	x	x	1
Product demand	x	x	x				3
Man power	x	x	x		x	x	2

According to the number of times the occurrence of LB criteria in various occasions such as literature studies, interviews and observations, they can be ranked with their priority levels.

Assembly precedence, restricted processes, desired line balancing objectives fall under the most valued line balancing criteria according to the analysis. Followed by physical constraints and the man power in the ranking as these were not talked by two interviewees when interviewed. Flow of material and BOM are the two criteria which are of less priority, but these should still be considered as these were said by the key members of the organization who are working very close to this research work.

As the company is now in the transition phase from manual way of working to an automated software which deals with their line balancing problem, while considering a software which can handle line balancing problem which perfectly fits into the case study situation, the software should be able to consider all these constraints while defining the LB problem on software.

In addition to the constraints observed through literature and case study there are few more general criteria which are very important. These general criteria be the software should be economical and affordable when compared to other available line balancing software's while not compromising on the features, the software should have to deal with the line balancing problem pertaining to Electrolux scenario (Multi model single straight-line assembly line balancing problems). Also, the software should be able to perform simulation which gives a fair idea of the results only after which the solution can be implemented on lines. By doing this a lot of time and resources are saved.

#### 4.3.2 Regarding RQ 2

The analysis related to the RQ 1 decides the different LB criteria which a LB software should consider in the Electrolux context. The next step in the analysis section would be to connect the findings related to RQ 2 with the analysis part of RQ1. As listed down in the findings for RQ 2 in the findings section of this chapter there are a list of general LB features. By reading the general features thoroughly from the user manuals of both Proplanner and Avix, it is understood that a few of these software features deal with the LB constraints related to the Electrolux context.

Considering the Electrolux LB criteria, it is not required for a software to possess all the features listed down in the first box of Figure 7. The criteria flow of materials, and bill of materials is considered in integration of data and documents/ maximum control. All the data regarding assembly precedence, physical constraints and restricted processes are entered, manipulated and executed using the constraints feature of the software. Product demand is the main variable input without which there is no question of LB, this very important data is taken care with mixed model and option intelligence and analysis section of the software. Assembly planner user manual. (2015) and Assembly planner website. (2018) and Avix PLM software website. (2018)

The next LB constraint Man power is taken into consideration in constraints and multiple resources features of the software. The type of LB, the desired objective of the LB, the different scenarios of LB all the data relating to these are handled in the Mixed model and option intelligence and analysis, Integration of data and documents/ maximum control, Smart variant management and Scenario management tabs. The Yamazumi charts feature shows a pictorial representation of different stations and its takt time variance, which makes it easy to balance the line accordingly either by increasing or decreasing the work load which will balance the line. And finally, the reporting tab in the software stores all the data changes which is happening over time and keeps it safe for feature references.

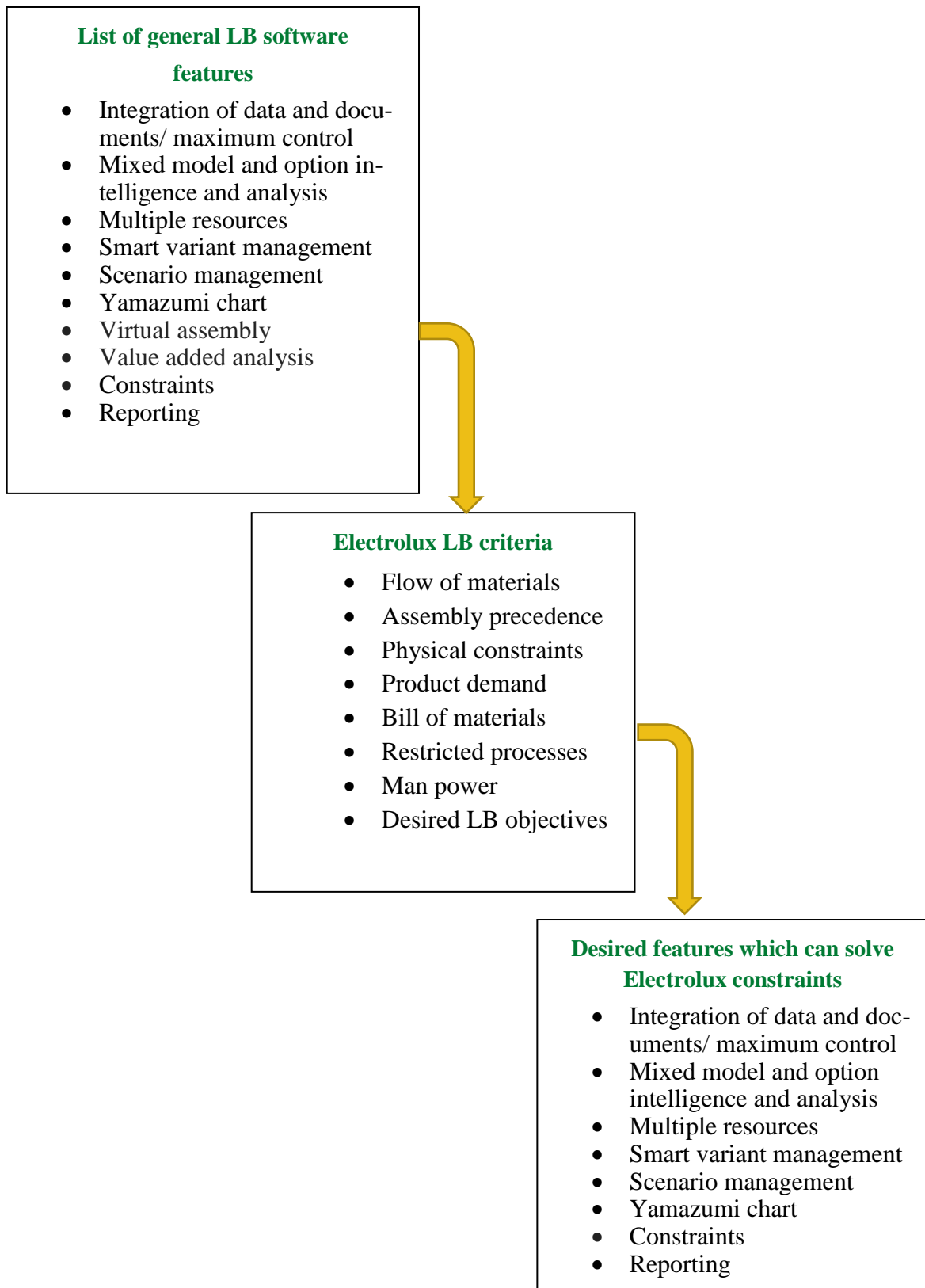


Figure 7 Desired features in a LB software

## 5 Discussion and conclusions

*This section will brief about how and why the chosen research methods were used to arrive at the end results, content validity and reliabilities are discussed. This chapter also answers the purpose and research questions of this research (Desired features of the LB software). Later part of this section also reflects the authors views on the results.*

### 5.1 Discussion of method

This research was carried out in a case study approach. Case study approach was chosen as the problem was company specific and a problem which is specific to a company setting in real time was solved. This research follows a flexible design as there were a lot of iterations between the literature review and the data collected through the data collection methods.

Interviews, literature reviews, document analysis and observations were done at various stages of the research process to arrive at the literature. Since there are four different data collecting sources, this research is source triangulated. Semi structured interviews were chosen as this demands deeper understanding to look for constraints, also observations as “observer as a participant” while seeing at the problems in a participant view were conducted. Complete historic analysis of the company documents related to this thesis were studied. Systematic two stage literature review approach was done to arrive at the expected research data. This increases the validity of the research. For the analysis of the qualitative data involved, an analysis scheme was designed, and the analysis was done as can be seen in the “findings and analysis” chapter.

#### 5.1.1 Reliability and validity

It can be said that great care was taken throughout the research with the research methods and techniques to make this research more valid. All the data collection techniques were chosen considering the validity and reliability. Since, there are four different data collection techniques this thesis is source triangulated which increases the validity of this report.

Although this research is a single - case study approach, the methodology, data collection techniques, analysis process are well explained and motivated. By doing this it is made sure that the reader understands the report easily, which helps any researcher to follow the same research approach as it is mentioned in this paper. When the research with same aim and research question is performed repeatedly in a similar setup following the same research methods and techniques as mentioned in the discussion of methods, it is most likely to reproduce the same results.

### 5.2 Discussion of findings

This research was intended to find out the required specifications of the Line balancing software which can take into consideration all the line balancing constraints listed down based on the literature review and the case study conducted. The findings were analyzed to conclude on the desired features of the Line balancing software.

### 5.2.1 Answering research question 1

RQ 1: What are the different criteria which should be met for ideal Line balancing in the context of Electrolux Ljungby?

The results regarding the desired LB criteria obtained theoretically and empirically were compared with the interviews conducted. This made it evident that the criteria with Electrolux were same as the theoretical and empirically obtained LB criteria.

It is evident that the following LB criteria are the most important of all the other LB criteria which can be found in literature review. The list is as follows:

- Flow of materials
- Assembly precedence
- Physical constraints
- Product demand
- Bill of materials,
- Restricted processes
- Man power
- Desired LB objectives

### 5.2.2 Answering research question 2

RQ 2: How can the criteria of Electrolux Ljungby be transformed as required specifications in a Line balancing software?

It was very hard to get any source from literature which gives some knowledge about the general features of any LB software's. After a lot of research, the user manual published by the Assembly planner software team, and the websites of Proplanner and Avix which talk about the features of their products were found. Few of the sections were read thoroughly in this user manual to depict the required information on the desired features in a LB software with regards to Electrolux scenario.

While talking in context with the software all the listed important criteria are taken care by these desired feature's in a Line balancing software as follows.

Desired feature's:

- Should be able to consider the part precedence in the assembly process
- Should be able to record the BOM consumption as soon as the part is consumed in any of the assembly lines
- Should be able to enter the data regarding demand and the time available so that it can perform the Line balancing
- Should be able to consider the line preferences (If there is any specific line only in which the assembly process can be carried out)
- Should also be able to consider the Ergonomic issues connected to the assembly line
- Should also be able to take in information regarding the resources available like man and machine
- Should be able to run the simulation already showing the results on the software even before implementing on the line

## Discussion and conclusions

- Should be easy and simple to implement during the transition phase
- Should be economical and worth the investment.

In the exact terminology the software's use these desired features of the LB software are termed as:

- Integration of data and documents/ maximum control
- Mixed model and option intelligence and analysis
- Multiple resources
- Smart variant management
- Scenario management
- Yamazumi chart
- Constraints
- Reporting

### 5.3 Conclusions

The purpose of this study was to provide an overview of the LB criteria to Electrolux which in turn acts as a guideline for choosing a suitable LB software at the company. After studying the company's existing LB techniques, it was evident that there needs to be an adoption of a more sophisticated technology that can help with the LB.

The first research question was answered by collecting information about LB the company and qualitative literature data was used to support the argument. It was evident that the LB criteria at Electrolux falls under to the previous conducted research in this field and hence can be linked to the general LB criteria.

Answer for the second research question provide insight in to the features that are required in the LB software to support the LB criteria at Electrolux. Referring to the user manual published by assembly planner software team, the different sections in the manuals tells about what the different features of the software can do. So, when verified with the LB criteria which were listed down with the research question 1, the features which can solve these problems are the Integration of data and documents/ maximum control, mixed model and option intelligence and analysis, multiple resources, smart variant management, scenario management, yamazumi chart, constraints and reporting tabs.

This research work is useful at both industry and academia. The literature provides insight in to the different criteria that need to be considered while balancing an assembly line. This combined with the situation at Electrolux form a link between the theory and real-time application. The result of this thesis is suitable for medium management who interact directly with the workforce and are responsible for its smooth functioning of the assembly process at the plant.

### 5.4 Future works

This thesis can be performed again in several other companies with a similar setup and verify from the case studies if the same line balancing criteria are desired in the new setup's too. This will also increase the validity and reliability of the research work.

A complete set of line balancing criteria can be listed under one research for different line balancing scenarios such as the combinations of Mixed model, Single model, Single sided, double sided, straight type, U-type.

Due to the lack of time, to evaluate various line balancing software's with the required features was not possible. Software evaluation can be performed based on the decided features in a line balancing software

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## 7 Appendices

Here the data which act as a proof of evidence for our analysis are added, this section includes the interview guide, transcribed data from the interviews, set of documents analyzed from the company etc.

### 7.1 Appendix 1 Interview guide used to design the interview questions:

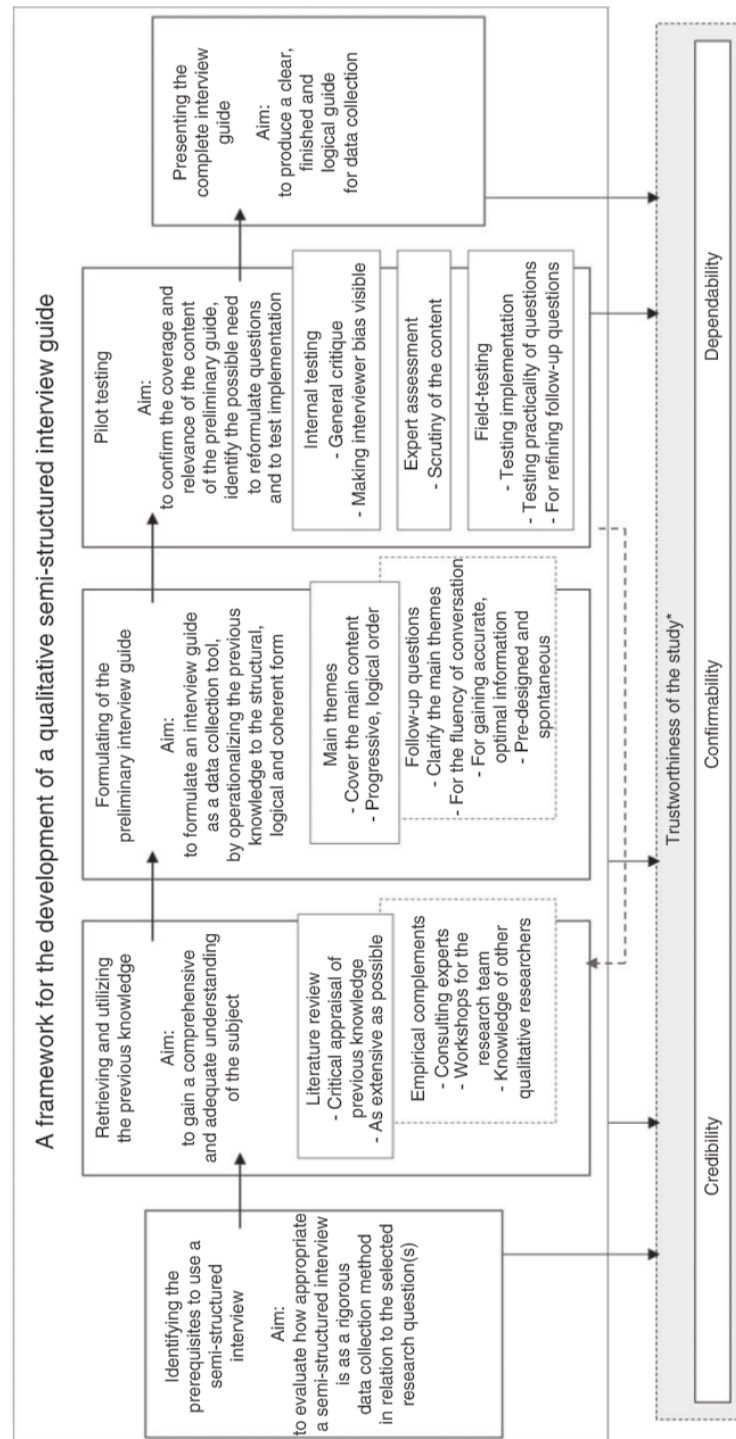


Figure 8 Interview guide (Kallio et al., 2016)

*This frame work from* (Kallio et al., 2016) tells what all should be kept in mind while designing the questions. By using this frame work it is ensured that the information gathered through the semi structured interviews are credible, confirmable and dependable.

## 7.2 Appendix 2 Semi structured Interview Questions:

1: What is your role in the company and also mention about the number of years you have been working here?

2: What are the challenges you face within the assembly lines on a daily basis?

3: How often is the line balancing performed and which departments involve in performing the line balancing?

4: Why is it important for Electrolux to move from a manually operating line balancing technique to an automated software?

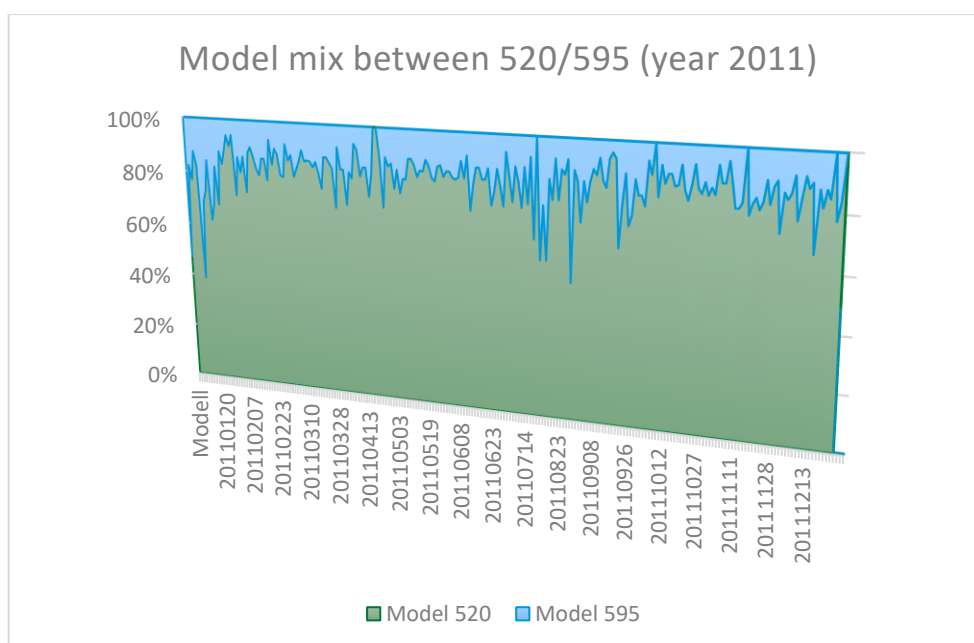
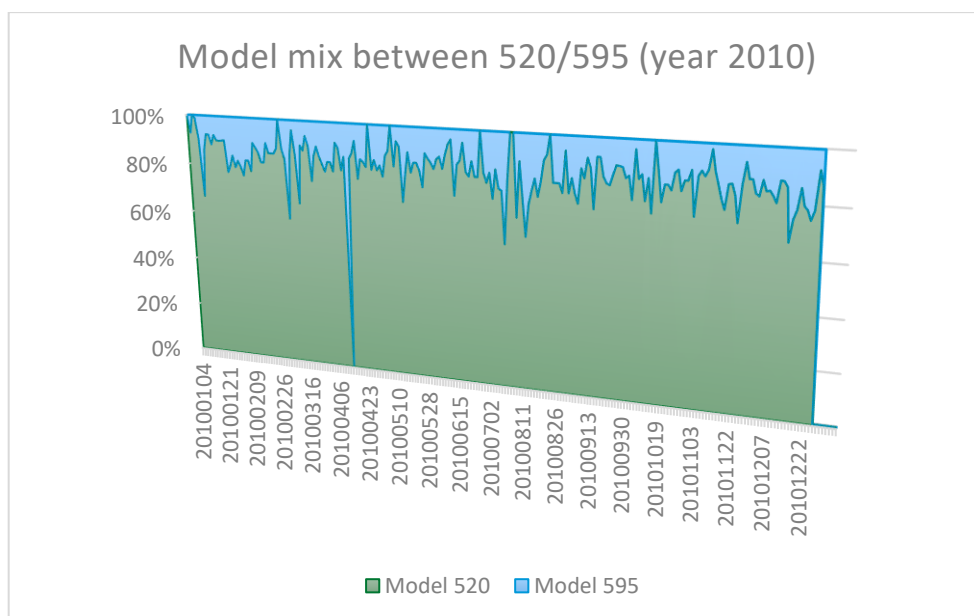
5: As there are different form of results which can be obtained by performing LB. what are your desired LB objectives with this research work?

6: What are the different LB criteria which you believe are important before performing the LB for the assembly line?

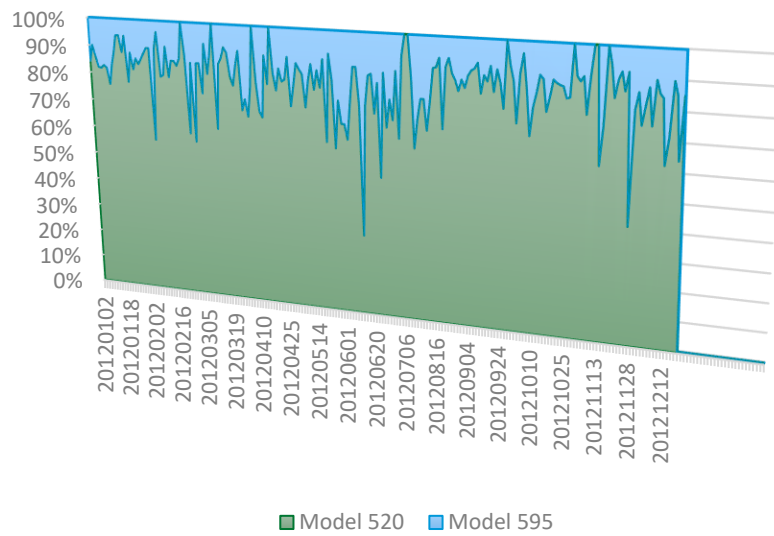
7: According to the literature review done we have listed down a few LB criteria, could you please talk about these a little and say if these LB criteria play any role in Electrolux scenario?

- Assembly precedence
- Physical work load constraints
- Takt time
- Processes, Resource, Station restricted
- Product demand
- Man power
- Desired LB objective

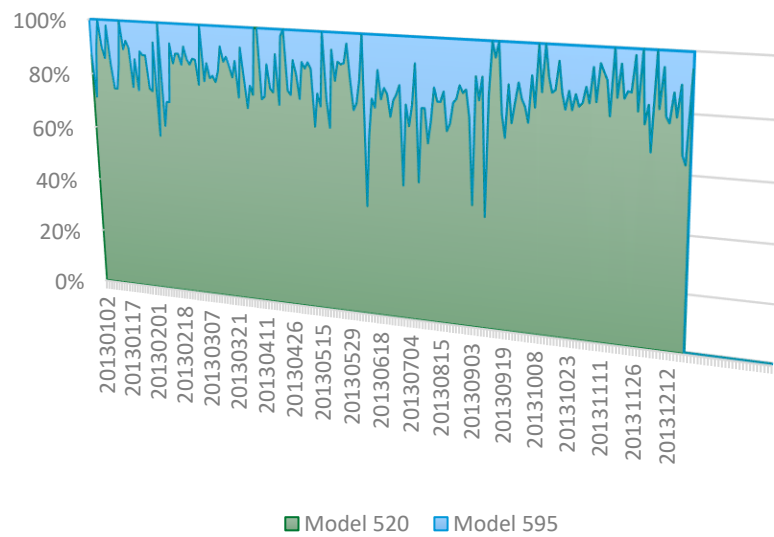
### 7.3 Appendix 3 Demand for the fast-moving models 520 and 595 for the washing machines from the year (2010-2017)



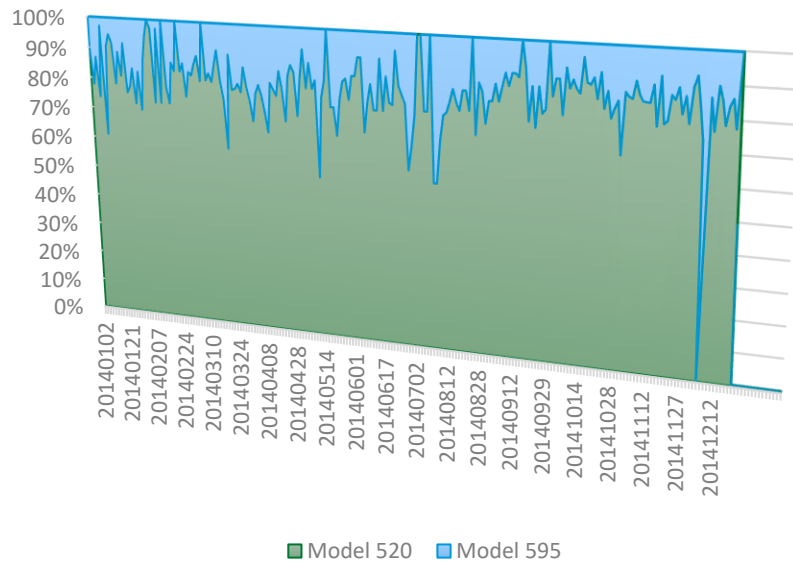
Model mix between 520/595 (year 2012)



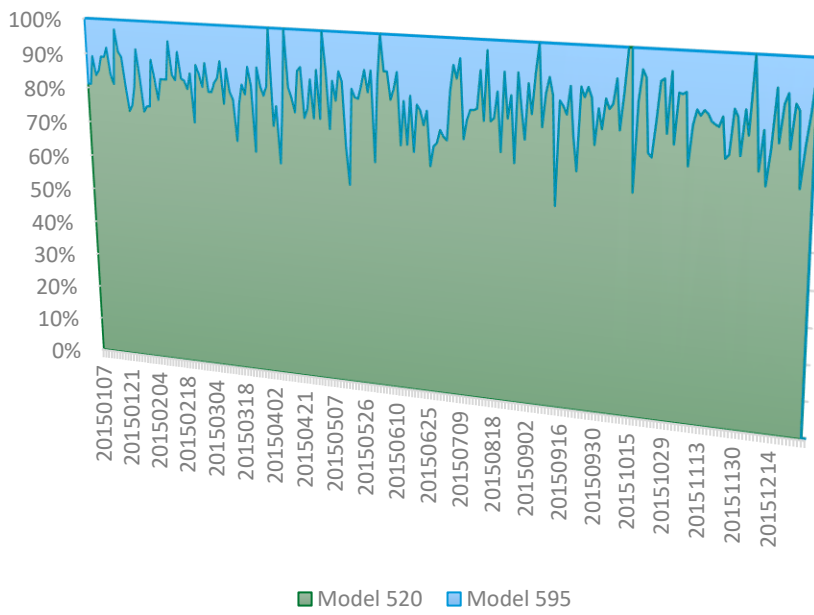
Model mix between 520/595 (year 2013)



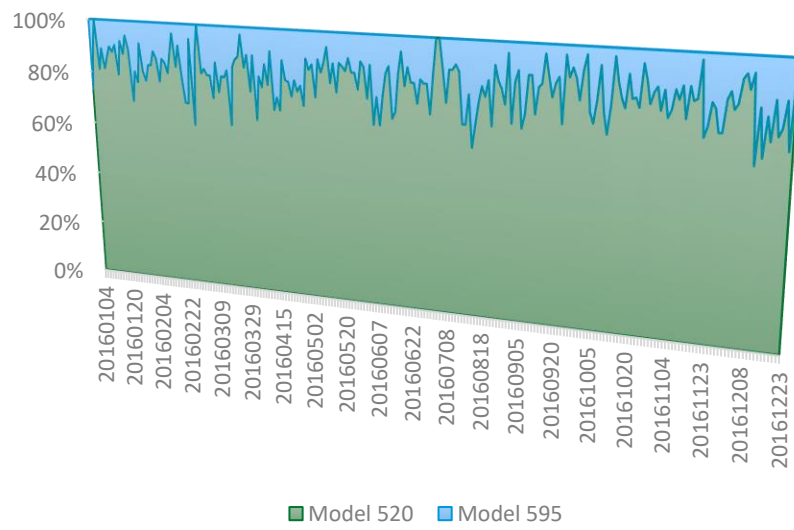
Model mix between 520/595 (year 2014)



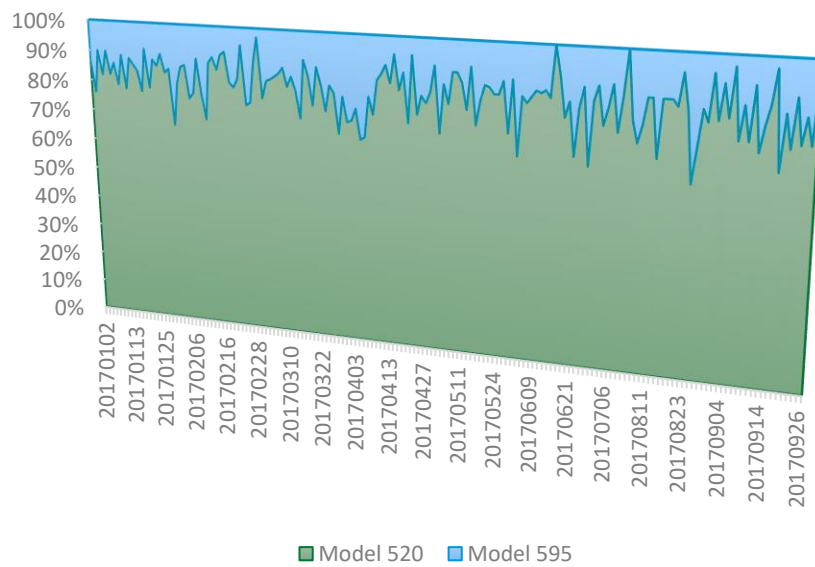
Model mix between 520/595 (year 2015)



Model mix between 520/595 (year 2016)



Model mix between 520/595 (year 2017)



## 7.4 Appendix 4 Plant I

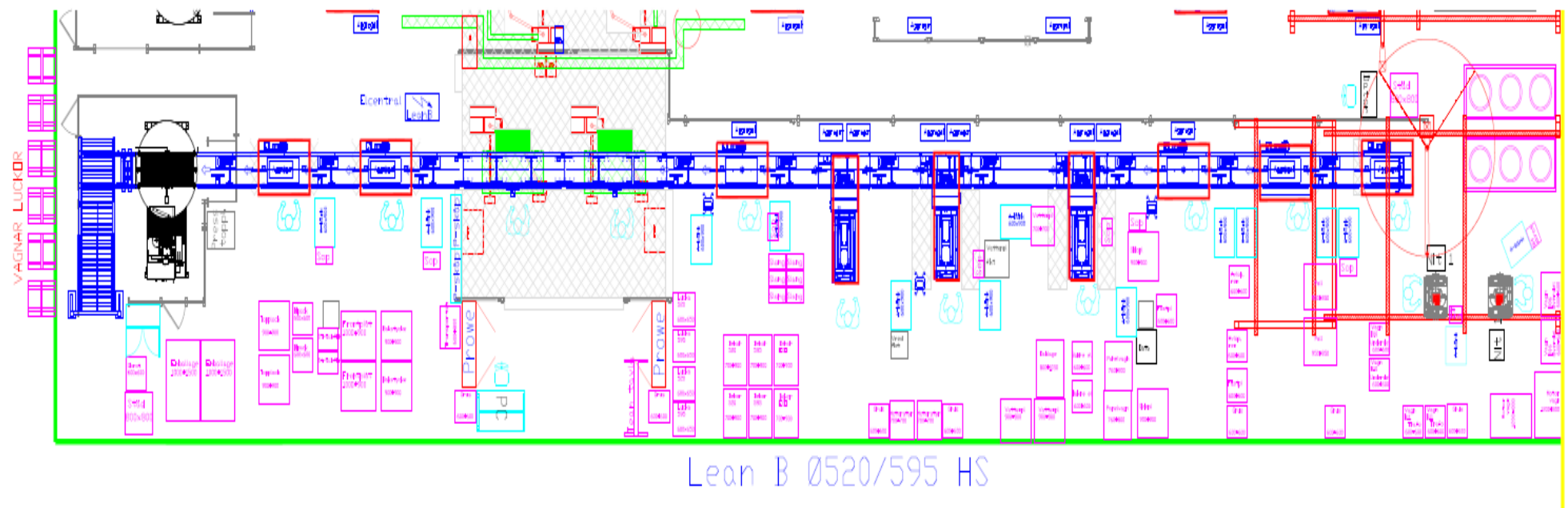


Figure 9 Electrolux Ljungby plant layout- Lean B