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Distribution of time in complex assembly

A simulation approach to assess balanced and unbalanced time

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Abstract

A higher demand on flexibility and efficiency at the assembly line has led to a more complex environment with increased need for supporting activities in order to enable the assembly to produce cars in the required takt. In such an environment, the supporting departments have to increasingly spend time on daily operations and to prepare changes that take place in the factory.

This has led to the initiation of this master's thesis, which is aimed to investigate how the complexity at the final assembly affects the time the supporting departments needs to spend on daily operation and to implement changes.

The purpose was to identify and analyze the activities that are performed by the supporting departments, both the daily operations and the time spent to prepare changes. The analysis of the activities was then used to develop a simulation model that can calculate and visualize the distribution between balanced and unbalanced time for different degrees of complexity.

The work resulted in a current state analysis, where the supporting activities performed at the factory are explained, both the daily operations and the administrative tasks performed when a change occurs. Functional structures were created, visualizing the flow of administrative tasks when changes are introduced. A model was developed, simulating how changes affect the time spent on the daily operations and how much administrative time that is required implementing the changes.

The study concluded that complexity at the final assembly increases the time required by the supporting activities and that the distribution of time can be simulated.

Keywords: Complexity, Distribution, Mixed model assembly, Simulation, Indirect time

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We also hope the information from the work will be of use for VCC and can help them to improve their great organization even further.

Thanks is also sent to the "Complex project" group for their aid throughout the master's thesis.

Mattias Karlsson,Tommy Schoug, Gothenburg 15/6/12

Nomenclature

Balanced time – The balanced time is a term used in this report for the time spent by the assembly worker.
CompleXity Index (CXI) – A method to measure the complexity at an assembly station or line.
Equipment Card (EC) – An equipment card is a form that is made when new equipment is needed at the stations.
Facility, Tooling & Equipment Engineering (FTEE) – Is the department that handles all changes to the facilities, tools or equipments.
Full Time Employee (FTE) – Is the working time of a fulltime employee.
Integrated Computer-Aided Manufacturing (ICAM) – Is a US Air Force program that developed tools and processes for manufacturing, the IDEF method was developed in this program.
Integrated DEFinition (IDEF) – Is a family of modeling languages.
Integration Definition for Function Modeling (IDEF0) – IDEF0 is a modelling language focused on function modelling.
Material Handling Vehicle (MHV) – A collective name for the material handling vehicles used at VCT, which include forklift and forklift-free trucks.
Methods-Time Measurement (MTM) – A method used to optimize time with a pre-determined time system. MTM uses TMU the time-unit.
Process Inspection Instruction (PII) - Is an instruction describing changes made to a station. The PIIs are made by the Manufacturing engineering department. A PII describes the required time for the assembly of a part.
Sekvensbaserad Aktivitets- och Metodanalys (SAM) - A method used to optimize time using a pre-determined time system. SAM uses TMU as time-unit.
Tillstånd till Särskild Utgift (TSU) – Used at Volvo to request funding when needed for new equipment to a workstation.
Time Measurement Unit (TMU) – A time unit used in MTM and SAM. 1 TMU equals 0.036 seconds.
Unbalanced time – The unbalanced time is a term used in this report for the time spent by the employees other than the assembly workers.
Volvo Cars Torslanda (VCT) – VCT is the name of the factory in Gothenburg, Sweden called Torslandaverken. This is where the cars XC70, V70, V60, XC90 and S80 are produced.
Volvo Cars Cooperation (VCC) – VCC is the international name for Volvo personvagnar, which includes both factories in Ghent, Belgium and Gothenburg, Sweden.

Contents

1

Introduction

This is the introduction of the master's thesis ”Distribution of time in complex assembly” conducted at VCC in their factory in Gothenburg, Sweden. The introduction presents the background to the project followed by the purpose, objectives and limitations.

1.1 Background

There is an increasing demand from the market to deliver cars with an increasing ability for the customer to choose among several car types and built-in functions depending on the customer desire. In order to be able to follow this demand, the automotive industry has adopted mixed-model production, meaning several types of cars and functions are assembled on the same assembly line. This approach makes it possible for the customer to choose from a range of functions and options on the product while the manufacturer is able to produce these options at the same production facility [1, 2].

The mixed-model production approach has led to an increased complexity, in the final assembly it has the form of more parts and variants together with an increased need for tools to assemble these parts. This has led to an increased need for supporting activities such as logistic handling, maintenance and equipment engineering, in order to ease the work at the assembly. To avoid overloading the assembly worker with variants and options that can be assembled. The production environment is constantly changing, with new variants and models being added at a regular basis, which further increases the complexity in the factory. Furthermore, more integrated support functions has led to the situation that the time to handle changes in the factory has increased [3].

Currently at VCT, the time required for the assembly workers to assemble a car is measured and standardized, this time is called the balanced time in this report. When changes are introduced to the assembly line, the consequences for the assembly workers are investigated. This could be rebalancing or new tools to handle the limited time the assembly worker has to assemble the part. However, the time required by the support functions, the unbalanced time, is not controlled to the same degree but instead the focus is on getting the assembly line to work as efficiently as possible. The unbalance work however, has a major part in the cost of a product, only the logistic stands for 20-30 percent of the cost of a product [4]. Currently, the unbalanced work is approximated by using a factor of the balanced time. Therefore, it could be beneficial to examine this area further to get more knowledge about how this time is distributed.

This problem has led to the initiation of this master's thesis ”Distribution of time in complex assembly”, which aims to give VCC a deeper understanding of the unbalanced activities and the time that is required in different scenarios.

This master's thesis was made as a part in the ”Complex project”, which is a cooperation between Swerea IVF, Chalmers, VCC, Stoneridge Electronics AB, Electrolux AB and AB Volvo to get a broader understanding of complexity in manufacturing.

1.2 Purpose

The purpose of this master's thesis is to give VCC a deeper understanding of how the complexity at the final assembly affect the unbalanced time in the daily operations and how this complexity affected the time required to perform changes.

1.3 Objectives

This master's thesis work has three objectives, which are presented below.

- Identify the unbalanced activities at the assembly shop in VCT.
- Present a functional structure of the administrative work performed when changes occurs.
- Develop a general simulation model that can calculate and visualize the distribution between balanced and unbalanced time at VCT.

1.4 Limitations

Due to the size of the company and the limited time of the project, the following limitations have been made.

This report will only include the final assembly shop at VCT plant. The report will only include the activities that are performed internally and for the final assembly at VCT. The work will only look at the time that the activities take and not consider the cost of these activities. Additionally, administrative time caused by lack of floor space will not be included.

The project will not examine how changes on assembly stations affect operations performed outside VCT. The actual time spent on repairing products because of quality or equipment errors in the factory will not be included in the simulation model.

It is expected that data in databases at VCT are continuously updated.

2

Methodology

This chapter presents the methodology that was used to complete this project. It presents the activities that were performed and the order in which they were done. An overview of the project work order can be seen in Figure 2.1.

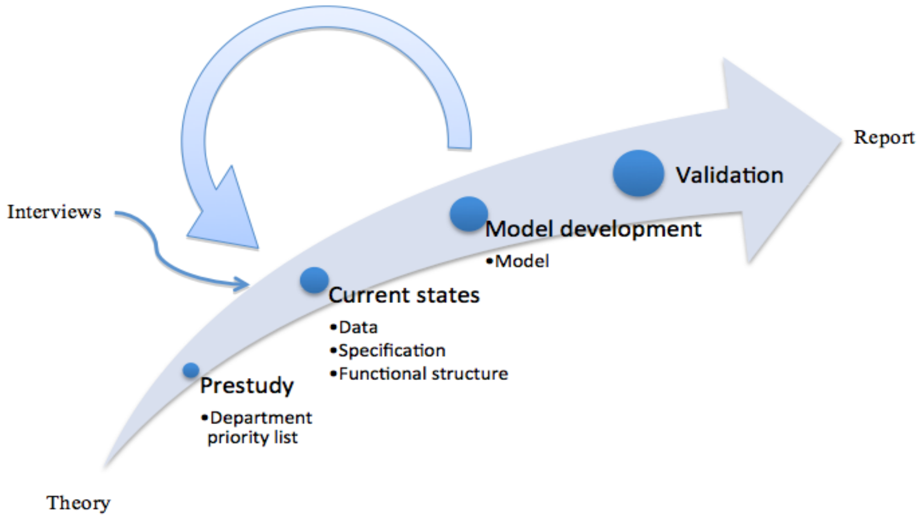

Figure 2.1: A visualization of the activities performed in this project.

2.1 Pre-study

This project started with a pre-study where the concept complexity in mixed-model assembly and the definitions about balanced and unbalanced time were studied.

This was done to get an updated frame of references about the subjects.

The Chalmers library databases were the main source for collecting the theory used in this project. When searching the database, the keywords ”complexity” and ”indirect- and direct-time” were used. Literature, from previous courses at Chalmers with focus on manufacturing and management was also used.

In parallel to the theoretical study, information was gathered about how tasks currently were handled at VCT and how the organizational structure is built up. This gave information on how the work in the support functions are performed, what activities and why these activities are performed. This made it possible to sort the departments that are the most critical for the simulation model, in terms of unbalanced time required at different levels of complexity.

There are two kinds of tasks performed by the departments, the daily operations tasks and administrative tasks performed when a change occurs. The daily operations are tasks that are preformed repeatedly in the production, tasks that are required to receive the output. The administrative tasks are the actions performed when changes need to be made to the production. This division is described in the Lean philosophy as ”white-collar”, employees that performs the administrative work and ”blue-collar”, performing the daily work [5].

The pre-study resulted in a priority list, listing the priority of the departments that will be included. This list was used to collect data for the model and later build the model.

2.1.1 Time distribution

When working with a complex manufacturing environment, there are different activities that need to be performed to run the production. Different ways are used to categorize these activities, what activities are necessary and what activities need to be minimized. One way of categorizing is using value-adding work.

Value-adding work was defined in the Lean philosophy for the automotive industry to distinguish waste and value. To find the value-adding tasks a value-stream mapping is performed, which tracks both how information and products travel through a company. It has been proven by Womack (1996) that the Lean philosophy can be utilized in almost any kind of manufacturing system [6]. An example is the health care industry that started to identify the value-adding steps to improve their business by reducing waste [7]. The value-adding tasks are when a human or machine performs actions that gives a product a higher value, an action that results in something the customer is willing to pay for [5]. The effect of this is that all supporting activities are categorized as non-value-adding. Activities such as logistic handling and maintenance of equipment do not produce value to the customer but they are necessary to have a working production flow [8]. Even actions performed by the assembly worker, such as walking to fetch parts or tools are considered non-value adding.

To avoid having a mixed interpretation of the time distribution, this project uses the terms balanced and unbalanced work. The balanced work is the tasks performed by the assembly worker. The unbalanced work is the tasks performed by employees other than the assembly workers, but still required to have the production running.

2.2 Current state analysis

With the priority list of the departments as an aid, a current state was made for each of the listed departments. The current states were made to get information about the tasks and activities performed at a department, both daily operations and administrative tasks performed when changes occur. Additionally, information on how the changes are managed by the organization will be gathered and compiled into a functional structure using IDEF0. The structure will describe what activities that are executed during different types of changes and how the departments trigger activities in other departments.

The result from the current states was extensive information about the activities and time for the various tasks. This result was then used to develop a model for calculating the unbalanced time. The gathered information was about both the daily operations and the time required by the administration to implement various changes that affect the department.

2.2.1 Information gathering

Information for the current state and the model was mainly gathered from interviews and databases.

Interivews

An interview can be structured or unstructured, meaning that there can be prepared questions or the interview can be a discussion within the subject without questions. There is also a step between structured and unstructured, where the interview is a discussion following open questions, this is called an "open-ended interviews". A common way to do interviews is by having "face-to-face" interviews, which is when the interviewer and the subject are meeting in the same room. The benefits of face-to-face interviews are that a discussion around the questions can be held, there are lesser risks of misunderstandings and one get the ability to perform follow-up questions as the interview progress. However, physically meeting people is time-consuming for both parties and it is required that both persons can meet at the same time. If the subject is located far away geographically, this will add travel cost and time. Another way is to prepare a questioner and send to the persons, this is more time effective and useful if input from a large amount of persons is necessary. However, this will only give answers on the questions and there is no possibility to do follow-up questions. There is also a risk that the interview subjects interpret the question differently [9].

The project used face-to-face and open-ended interviews at VCT. The use of interviews was done because the people were located in a close proximity of the project work area. Open-ended questions were used since the employees often had more extensive knowledge about the subject and were given opportunities to mention areas they thought were important. Face-to-face interviews were possible because mainly there is only one person that is responsible for a certain task in the department.

The interviews were performed by contacting the manager of the departments and got referred to suitable subjects within each area. The interviewed employees can be seen in Appendix A.

Databases

Data about activities can be extracted from databases where possible, however in some cases the data needed to be processed to get the required information by filtering out the data needed to the model. Filtering can be done either manually or automatically. Automatic filtering can be used when data is stored in an enterprise resource program. However, if this is not the case the manual, more time-consuming, approach can be used [10].

Information about many of the activities performed at VCT is stored in databases mainly made up by spreadsheets with time data. In this case the automatic filtering was not possible and the manual approach was used. Additionally, the databases at the departments are not linked together.

2.2.2 Functional structure

A functional structure is used to visualize how different functions depend on each other and what kind of work that is required to achieve a task. There are different tools that can be used to model functional structures, an example is a functional flowchart that show how a process travels through an organization [11].

In this project, the method IDEF0 was used to create the functional structure. IDEF0 is the functional modeling method of the IDEF family. IDEF was developed by the United States Air force to visualize the information flow and manufacturing functions for ICAM projects. IDEF contains several different modeling methods, where IDEF0, as mentioned above is the function modeling method [12].

The modeling method is structured by functions with arrows connected with the functions. The meaning of the arrows in an IDEF0 can be seen in Figure 2.2. The functions represent activities, actions, processes or operations. Arrows are then linked together with other functions to visualize the flow of information. The parameters control and input are required to get the output from a function. The functions can be further described on a lower level by creating functions inside a function and describe the activities on that level. However, the amount of functions on a level should never be less than three functions or more than six, except for the first level that has just one function [12].

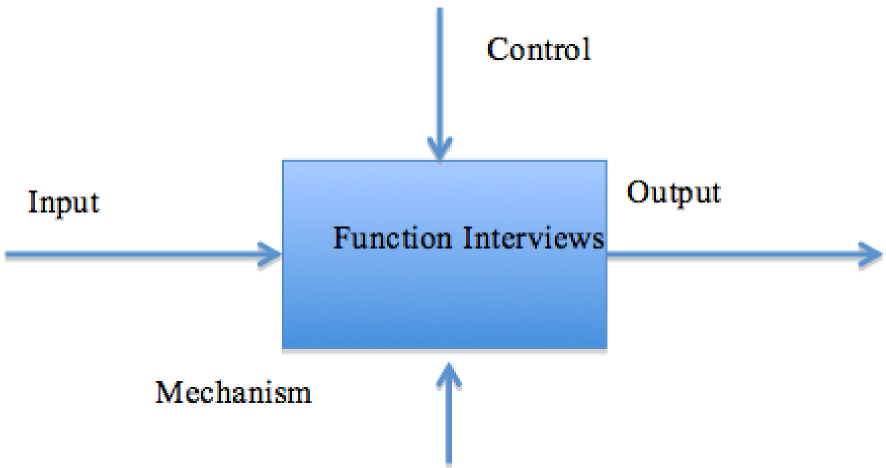

Figure 2.2: Description of the meaning for the different arrows that are connected to a function, as described by the ICAM project.

The drawback of using IDEF0 is that it is time consuming and that it only gives the resulting flow of activities and functions and does not show in which order the activities are performed [12, 13].

This method was chosen because it can be produced in a structured way, with the required information for the model and it visualizes the complexity within an organization, providing a clear overview.

2.3 Model development

In the beginning of the development, a specification for the simulation model was created, based on the demands and wishes on the result. The model was then developed by using an iterative process. The process started by implementing the department that was the most important on the priority list the pre-study resulted in. When this department was implemented the work continued with the next department on the list. This went on until all of the departments on the list were implemented to the model.

To implement a department, first a current state analysis was performed for the department. The current state gathered all the necessary information and data needed to perform the implementation. The information from the current state includes the activities that the department performs, when the activity is performed and what parameters that affects the time of the activity. With this information from the current state available, the work consisted of sorting out what parameters that are affecting the time of the activities the most. The sorting was made by studying the activity and investigate which part of it that is the most time-consuming and which parameter or parameters that control the activity. After this investigation, the other parameters were studied to see if any of those parameters were linked or if they only had a limited impact on the time. If this was the case, the parameters were grouped together or removed, with an added constant if this was possible. A function for the activity was then implemented in the model so that a time for the activity is received based on the given parameters.

The project then continued to the next department, starting with a current state and later the implementation. This work continued until the model included the most time-consuming activities performed in the assembly shop.

2.4 Validation

The final part of the project was to validate the output of the model to determine the accuracy of the model. The data that were extracted from the databases at VCT were validated by controlling that randomly picked events from the databases correspond to reality by sampling the event. If the data, after a few samples were heading towards an asymptotic value the data was considered validated and correct. This type of validation, used when validating events, is called "Event validity" by Sargent (2004). The drawback of using this validation method is that it can be time-consuming to get the model completely valid [14].

The results from the functional structures and the model were validated using "Face validity" and the previously mentioned "Event validity". Face validity is a method where the results are shown to an experienced employee within the subject at VCT. Event validity is comparing specific events in the model to the real life event [14]. How much the results could deviate depends on the impact the values have on the results and specification for the model.

2.4.1 Time studies

Time studies are important to conduct in order for the company to get an understanding on how much that is possible to produce. There are several ways to estimate the time a task requires. If the task is similar to other tasks, historical data can be used. If such data is unavailable, an estimation can be made by observing an experienced worker perform the task in a standardized way. A stopwatch can then be used during the observation to get the required time to perform the task [15].

Another way is to use pre-determined time systems to synthetically assess the time. These systems rely on breaking down the work task into smaller subtasks, to a specific level depending on what system that is used. There are several different pre-determined time systems. For example, MTM and SAM, which are tools used to optimize the required time to perform a task. They calculate the required time by dividing the task into subtasks. These subtasks are then assessed a time from a table or by estimation. These times are then added up and the result will be the optimized time required to perform the task. When using MTM and SAM the time unit used is called TMU where one TMU equals 0,036 seconds. This unit is used to be able to get more accurate calculations without having to use decimals [15].

When performing a time study with a stopwatch it is important that the observer takes the performance level of the worker into consideration. The total time for the task should then be adjusted based on the performance level of the worker, so the estimated time is in a pace a normal person can work in a whole workday without getting injuries over time. Allowance is then added to the estimated time to compensate for fatigue and other events [15].

A problem with using time studies is that disturbances are not taken into consideration and therefore there is a need to adjust the observed time. The observant can miss certain aspects of the work due to the fact that the observation is only made under a certain period [15].

3

Theory

This part presents the theory used about complexity and how this complexity is created by the production system used at VCC. Additionally, theory about simulation is also presented.

3.1 Complexity in production

Complexity is commonly used to describe when something is hard to explain, analyze or solve. There are several definitions of complexity depending on the area, the definition of ”Complexity” in the dictionary is when things are joined together, building something complicated [16]. Complex systems exists in many areas and are getting more and more common, as more functions are integrated into products [17]. These complex systems are however, harder to handle and design. For example, in computer networks where complex networks lowers the transportation effeciency for data packets [18, 19]. With the globalization of business, demand for systems instead of products and need for efficiency, the complexity in the world is growing, specifically in the production area [20]. This results in more parts that need to be assembled, more variants and more logistic handling. This in turn brings more traffic in the factory and utilization of space problems.

While these factors are increasing the complexity in the production, a definition on what the complexity results in is not clear. An attempt to define the complexity in production was made by Fässberg et.al (2011) where they concluded that complexity depends on parameters such as the number of variants, material planning and the product. This conclusion was made based on interviews performed at VCC, Stoneridge Electronics and Electrolux [21].

There are different methods available on how to calculate complexity. One method is an entropy approach developed by Frizelle and Woodcock that calculates complexity by measuring information, choice and uncertainty [22]. There is also a tool developed by Mattsson et.al (2011) called CXI, which calculates a subjective complexity by asking the employees questions [23]. The answers from the questions are then inserted into a table where they are calculated in order to get a value about how complex the assembly station is. Another method used by Fässberg et.al (2012) is measuring choice complexity and comparing this with assembly errors. It shows that there is a possible connection between complexity, quality and cognitive automation. The study was done by using Level of Automation, which is a measurement tool, measuring how much physical and cognitive assistance that the assembly worker has at his disposal [24].

ElMaraghy states that complexity depends on two parameters, the number of variants produced and the needed effort. This is used in ElMaraghy's information diversity tool that calculates the ratio of diversity [25].

There are several different complex systems in a manufacturing plant, research shows that complexity has a negative impact on the productivity of the factory [3, 21, 24, 26, 27].

3.2 Production systems

There are several ways to manufacture a product. Depending on the demand and how diverse the produced products are, several manufacturing process can be used. When working with a high volume production of products with similar shape and function, an assembly line is often preferred. In the assembly line, the product travels a pre-defined route and the assembly workers are stationed in different stations, performing the same assembly on each product that travels by. The drawback with an assembly line is the lack of flexibility, which is important in today's competitive market. A way to address this issue is to use mixed model production [28].

3.2.1 Mixed-model production

A tendency in automotive manufacturing is to assemble more products on the same assembly line, this method is called mixed-model production. As can be seen in Figure 3.1 where several different products travel on the same assembly line. This is done by having the assembly workers on the line performing different work task depending on what model that is currently at the assembly station [28].

Introducing mixed-model production affects the whole company and requires a new attitude when solving problems with the assembly. To solve these new problems, there are different methods available to smoothen out the problems.

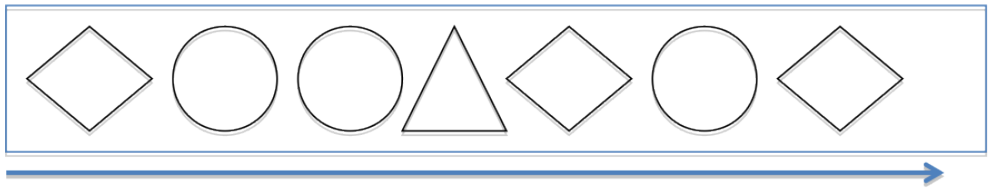

Figure 3.1: A visualization of mixed-model production, with different products on the same assembly line.

For example production leveling, which is a tool that aims to even out the uneven workloads as much as possible [29].

Mixed-model production is used to solve the problems that occur with the increasing variability, by being more flexible in the production. If demand on a certain product varies, the other products made in the same line can be used to balance the output of the line, by producing more or less of those products [26, 28].

The drawback of a mixed-model production is uneven time requirements for the products, which can make it harder to balance the production flow and increase the complexity for the assembly worker. A research performed by MacDuffie's et.al (1996) showed that increasing the complexity of a product has a negative impact on the performance of the workers. Additionally, MacDuffie (1996) states that when running mixed model production, this creates a larger need for balancing the assembly station and it creates more work for the support functions. This leads to that the need for unbalanced labor for the station increases [22].

3.3 Methods for complex production

In order to be able to deal with the complexity in the production, several methods and tools can be used, some are described below.

3.3.1 Modular assembly

To improve the flexibility and efficiency in an assembly situation with a large variety of products the method modular assembly can be used. Module assembly can be used when part of assembly operations is assembled before it comes to the assembly line. This breaks a complex assembly process into smaller, more manageable operations. The modular assembly can be performed internally in the company or be outsourced and be done externally. The drawback of using this method is that it requires more components and it can prevent innovation [30].

3.3.2 Lean production

Lean is a philosophy that originates from Toyota and their Toyota production system. It states that the overall goal for a production is to create value for the customer and that all other activities performed is considered as waste and should be minimized and bring order to a complex system [5, 8].

Overproduction, waiting, unnecessary transport or conveyance, over- or incorrect processing, excess inventory, unnecessary movement, defects and unused creativity are the wastes that occur in the production according to the Lean philosophy. Overproduction is considered the most important waste to reduce since it leads to all the other wastes [5].

The lean philosophy uses a culture of standardized work and continuous improvements to reduce the wastes in the production. There are several tools and methods for reduction of the wastes such as 5S, which is a structural way of organizing a workplace and Just-in-time to reduce the excess inventory [5].

Several companies around the world have then implemented their own understanding of Lean [5]. VCC has implemented their understanding of Lean, called Volvo Cars Manufacturing System [31].

Standardized work

According to the Lean theory is it important to standardize the work, as it is considered necessary to be able to continuously improve the work. If the work is not standardized, all the changes made cannot be compared to a previous state and thus it is not known if the new way is better. Having a standard will make the workers work in the same way, making output predictable and quality more consistent [5, 32].

Quality assurance tools

To reduce the risk of quality errors on products, several tools can be used to assist the assembly worker to achieve a better quality output. There are tools that assist the assembly worker to pick the correct parts for the corresponding assembly and systems that controls that the parts of the assembly has been correctly executed. These are in the lean philosophy called ”Poka yoke”. Poka yoke is error proofing in Japanese and it has shown that this helps to reduce the risk of quality errors [5].

Some of the more common tools used by in assembly operations are described below and can vary from company to company.

Scanning

When the worker picks a part in a scanning system, the worker scans the part with a scanner. A system then controls if part is correct for the current assembly. The system gives feedback to the worker if it was the wrong part by emitting a sound, if the correct part was selected there will not be a sound and the worker can continue.

Pick by light

Pick by light is a method to aid the worker to pick the correct part for the current assembly. This is done by visually show the worker where the container with the correct part is located. At VCT, a green lamp is lit above the current correct container. To verify that the correct part has been picked the worker has to confirm the selection by tapping the lit lamp or similar.

Pick by light is used when there is a risk for the assembly worker to pick the wrong part, which occurs when the parts have similar design and size.

Pick by voice

Pick by voice is a system that tells the worker in a headset what part to pick next, the worker then walks to the pallet or box and picks the part. When this is done, the worker has to say a confirmation code that is located by the pallet or box that contained the part. If the wrong confirmation code is given, the worker is notified and can correct the mistake. These confirmation codes are changed regularly to avoid the worker from memorizing the codes.

A majority of the stations that replenish the sequencing racks at VCT uses the pick by voice method.

Smart tools

In order to relieve the assembly worker when performing actions that are critical for the product, tools can be designed to reduce the risks for errors, for example the operation on selecting the correct torque and control that the fastening is correctly executed. Critical fastening operation in the assembly can be fastened using torque-controlled fasteners. This device automatically loads the correct torque program depending on the product currently at the station.

The fastening operations for the current assembly are displayed on a monitor at the station and as they are successfully completed the operation changes colour on the monitor and emit a sound.

3.3.3 Push and pull ordering system

The ordering of material can be done using different methods. The incoming material from the suppliers can be moved directly to the assembly line or be further processed internally by the logistic department. The material can be bought as raw, such as steel, or as in finished or semi-finished products. It is important to have a good material planning to keep an efficient amount of inventory to reduce the tied capital while still be able to always have material available when a work task requires it [4].

There are several methods used for deciding when an order of new material should be placed. All these methods are however based mainly on two principles, the push or pull principle. The difference between the push and pull principle is from where the order for new material originates. When utilizing a push principle, the order comes from the planning department, usually based on forecasts. When using the pull principle, the order starts with a customer order, the order then travels backwards in the system ordering the required material to be able to finish the customer order at the end. This normally means when using a pull principle, smaller order sizes are made compared to the push system. The drawback with using the pull principle, compared to a push, is the increased need for transportations because of the smaller amount of material in each order [4]. However, this results in that the work in progress material is reduced, which in turn results in less bound capital in the production. An explanation on the push and pull principal can be seen in Figure 3.2.

To increase the ordering size in a pull system, a re-order point system can be utilized. The re-order point can depend on parameters such as lead-time, demand and safety stock. The quantity of each order depends on the order-up-to level, deciding how much material that will be in stock at most [4].

A way of having a pull based inventory system is by using a two-bin system. Here the ordering of new material happens when the current bin of material at the assembly station is empty. Then a full bin replaces the empty bin and the empty bin is then brought to a replenishment area to be refilled and later sent back to the workstation [29].

3.3.4 Downsizing

For a pull based system to work it could be necessary to reduce the inventory at the assembly station [5]. A way of doing this is reducing the size of the package so that fewer parts are transported to the assembly station. This is done by calculating the required amount of parts for a certain time in a bill of material, which is a ordering of the material that can depend on parameters such as how frequently the part is needed and the size of the part [29].

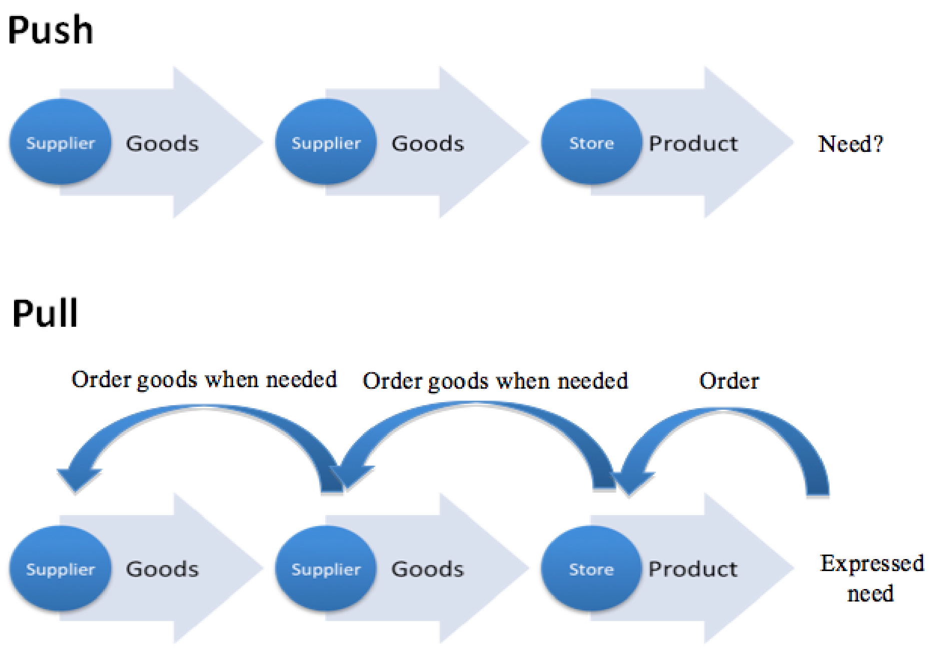

Figure 3.2: An illustration on the difference between the push and pull principle.

A drawback by using this method is that people are required to handle the part and it increases the cost per part. But the downsizing can improve the efficiency on the assembly.

3.3.5 Sequencing

Another method to deliver fewer parts to the assembly is to only deliver the parts that are required for a pre-determined period of time to the assembly. This done by in advance repackage the parts. An operator that has all variants available is picking the parts and placing them in the order they are needed by the assembly worker. The assembly worker will then only need to pick the next part in the container and the need for the worker to choose is eliminated. This will make the assembly workers job less complex and save space at the assembly line.

The drawback of this method is that it requires additional employees performing the time-consuming sequencing task. Even though the complexity is reduced for the assembly worker, the complexity is only moved one step away.

3.4 Simulation

Simulations are used to solve problems dynamic behavior in a complex situation [33]. To perform a simulation, a model is created with the desired parameters that then will interact with each other. Simulations can be used to observe how situation works and reacts in order to foresee the result and to save time and money. For example, several different layouts for a factory can be simulated and it is then possible to see which works the best [34].

A simulation model can be change- or event oriented. Change oriented models are built up by functions and how the functions depend on each other, this does however require a continuous calculation of the model state. An event based model is when model is build of events that occur in certain points in time, only discrete events will need to be calculated by the model thus making the simulation more effective [33]. Simulation of real life scenarios can often be described as events and how the events affect the system, thus enabling the use of the more effective discrete event oriented simulation [33].

Various tools can be used to create a Simulation model. One of the most commonly used tools when working with simulation models is by using spreadsheets since this is available on all types of operating systems [35]. However, there are powerful tools with built in functions and graphical representations. The disadvantage of using a spreadsheet is that it cannot handle stochastic variables as well as a simulation software. A simulation made in dedicated simulation software is more powerful and can simulate complex systems compared to a spreadsheet-based simulation. These advance simulations software does however require experience and is more time consuming to use compared to spreadsheet software. If the situation can be simulated by using spreadsheet software, it will be more time efficient.

The most time-consuming phase when creating a simulation model is the collection and reviewing of the data, which can take up to 31% of the time of building the model [36, 37]. The collected parameters are used to build a model that creates an output. The parameters that are used in a model can either be deterministic, meaning it does not change over time, or stochastic, meaning that it varies from time to time. Real life events are not predictable and change continuously, meaning that they are stochastic. However, the required data to achieve such environment is more complicated and requires more time to collect. A model created with stochastic parameters is often better since it better corresponds to reality [38].

4

Results

This chapter presents the results from this project.

4.1 Department priority list

As previously mentioned, the work started with a pre-study that resulted in a prioritized list on how important the different departments are to be accurately included in the model. The list was made by interviewing the head of each department, listing all the activities they perform and comparing factors like number employees in each department performing daily operations tasks, involvement in changes and time spent on administrative task.

The most important factor when prioritizing the departments was the number of employees performing daily operation work. The time spent on daily operations work was important to accurately implement because these tasks are performed several times each day and every inaccuracy in the times will be multiplied by the factor they are performed.

The second most important factor is the involvement in changes, as this factor decides how often they have to perform administrative work. If a department is involved in every change for example, the time they spent on these changes will be very important to accurately implement.

Lastly, the time spent on administrative tasks was considered to prioritize the departments. This factor is important to include because if a department rarely is involved in changes but when it is, the department has to spend much time to perform this, the contribution will be important for the accuracy of the time.

The work resulted in a prioritized list with the most time-consuming department at the top, as seen in Table 4.1. For the model to give an accurate estimation on the times for different scenarios, it is important that the most time-consuming activities are implemented correctly, as they affect the result the most.

Table 4.1: Department priority list, with the highest time-consumer as number one.

Department	Daily	Administrative
1. Logstics material supply	x	-
2. Logistics administration	-	x
3. Maintenance	x	-
4. Production engineering	-	x
5. FTEE	-	x
6. Production administration	-	x

As can be seen in Table 4.1, the logistic material supply was the department with the highest priority as they have the most employees doing unbalanced daily operations. The Production department has the most employees in the factory but they are mainly doing balanced work, which is not included in the model. The Logistic department had both the highest amount of time spent in daily operations and was involved in many of the changes that can occur in the factory when a new PII is introduced.

4.2 Current-states

This chapter presents the result from the current states of the analyzed departments. The analyses gave an understanding of the activities, why they are done and what parameters that affect the time required by the activities. This information was then used as an input for the model, together with data from various databases at the departments. The current states were performed according to the department priority list, which was presented in Table 4.1.

The current states also resulted in a map of the functional structure at VCT, describing how a change request that arrives to the factory is handled by the departments.

4.2.1 Logistic activities

The Logistic department is the second largest department in the final assembly shop, after production. They handle all the material supplies to the line and handles repackaging. The Logistic department also makes sure that the racks used for the assembly are made and develops new if required. The department works in close cooperation with the production, there is always a discussion if a product should be repacked, sequenced or be placed at the line. The decision is based on cost-estimations made by both production and logistics on how much it will cost to move a material handling from the line to the Logistic department. However, in some cases the material handling needs to be performed outside the assembly line because of limited space for pallets.

The activities performed by the Logistic department are described below in two parts, the material supply part, which performs the daily operations activities in the Logistic department and the administrative activities, preparing the changes for material supply.

Material supply operations

The parts used in the assembly are delivered mainly by lorries or by train. They are received by the Logistic department and handled depending on how they are packaged. The different types of packages are described below.

Pallets and combitainers

Pallets are delivered to the line when the parts are frequently used and if there is space at the assembly station. The parts are received as a batch of parts, where the number of parts in each batch depends on the parts size, how they can be packed and how fragile the parts are. This delivery method is cost effective, since it does not require any additional handling by the Logistic department. However, because of the limited space at the assembly lines in the factory, this solution is not always applicable.

The daily activities associated with the pallets are goods receiving, transporting to main storage, transporting to a marketplace area and replacing pallets at the assembly station.

When a pallet is received to the factory, it is received at a goods receiving area by lorries. The pallets are unloaded and placed on racks for pallets connected together as a train. Once the racks train is full the pallets are transported to a main storage area, where they are unloaded from the racks and placed in the main storage. When the pallet is needed by the production, the pallet is removed from the main storage and placed on a similar “rack train” for transport to a marketplace area, which is an area where the ”rack train” is placed. There are several marketplace areas for pallets, where stations close together share the same area. From the marketplace area, the pallets are unloaded and loaded to the assembly stations. The empty pallets are placed at the train for return handling.

The ordering system for the pallets is shown on a monitor in each MHV, informing the drivers when new pallets are ordered and where to get them. When a MHV driver handles a pallet, the driver uses a scanner to update the system that the pallet is being handled.

A combitainer is a special package used when the parts are too large to be efficiently placed in regular pallets. The activities however, are identical to the above described for pallets.

To summarize the pallets and combitainers daily operations, the factors that affect the time spent on these tasks are

- Quantity in each pallet or combitainer
- How often they need to be replaced at the assembly line

Boxes

When the size of a part is small and has a limited demand at the assembly stations, it is inconvenient to have a full pallet at the line. This would result in that the part will be at the line for a long time until it is required in the assembly and waste space. To reduce the space the parts use at the line, the parts are packaged into smaller boxes and are fed to the assembly when the re-order point is reached.

The boxes are either directly supplied by the supplier or repacked by the Logistic department, this operation is called downsizing. The downsizing activity is a task where boxes are internally filled with material that arrived in pallets or other packages. The material is usually pored into a box until it is full and the worker can continue to the next, making it time effective. However, in some cases the downsizing might take longer time, if the parts have to be packaged in a certain way in the box to be able to get the required amount in it.

The boxes are then stored in a marketplace and continuously fed to the assembly when needed, using a two-bin system. The assembly stations have shelves where the boxes are stored. There should be enough parts for two hours of production.

The replenishment of boxes at the assembly line is done by MHVs driving predetermined routes on a regular basis, replacing empty boxes with full ones. These MHVs have wagons behind where the boxes are stored.

Using boxes are costly since either there is additional workers performing downsizing or one has to handle the transportation of boxes from the supplier and sending empty boxes back to the supplier. Additionally, the downsizing requires an area for the operation and makes planning complicated for the logistic engineers and there is an increased risk to create defects since more people work with the part.

To summarize the boxes daily operations, the factors that affect the time spent on the tasks are

- Quantity in each box
- How often they need to be replaced at the assembly line

For the downsizing activity, these additional factors are important

- Quantity of parts in the receving package

Racks

The material can be delivered to the line in racks. Racks are containers built to hold an amount of a certain type of material depending on size and how frequently the material is required. In the racks, the parts are placed in the same order as the order the cars on the assembly line are queued. The benefits of using racks are that parts with high complexity that would normally take much space at the assembly station will only take up two pallet spots for the racks. Additionally, it is easier for the assembly worker to pick the correct parts for the assembly.

The racks can also be used for placing more then one part in the sequence, if the parts are being assembled at the same station, the assembly worker can then pick all the parts from one slot in the rack.

The sequencing in racks can either be done internally or externally depending on the available space at VCT and other cost factors. Internal sequencing is the preferred alternative of the two in most cases because of the controllability and flexibility.

The racks are transported between assembly line and the warehouse by MHVs that can be connected to the racks, which in turn can be connected to other racks, making it possible to drive multiple racks at the same time.

The time it takes to fill a rack depends on the complexity of the current part, because this affects the walking distance of the operator doing the sequencing and the size of the rack. Other factors that affect the time is if the operator has to perform assembly on the parts or if the parts are wrapped in packaging, which makes it time consuming to open.

All the sequencing operations are picked with a pick by voice system as an aid. If the parts are placed in the wrong sequence, there is a risk that the assembly worker will not notice this and assemble the part on the wrong product.

To summarize the racks daily operations, the factors that affect the time spent on the tasks are

- Quantity in each rack

- How often they need to be replaced at the assembly line

For the sequencing activity, these additional factors are important

- Quantity of parts in the receiving package
- Distance from the sequencing station to the assembly line
- Time it takes to sequence one part

Logistic administrative work

When changes are introduced to the factory that involves changes in the material supply operations, the logistic administration will handle these and make sure that they are successfully implemented in the factory. The tasks that need to be performed depend on what package the parts are contained in and what change that is implemented. The following section will describe the various tasks that need to be performed for the packages because of changes.

Pallets and combitainers administrative work

When pallets or combitainers are added the final assembly, each pallet needs to have a main storage area and an associated goods receiving area. The parameter that decides what area the pallet should be sent to is mainly what station the pallet or combitainer is going to, as the stations are linked to a main storage area. However, it is required to see if there is available space in the storage area and if there is not any room, the pallet or combitainer need to be sent to a storage area close by with free space. Additionally, there is a need to control if the ”racks train” can handle the additional pallets.

If a pallet or combitainer is changed on the assembly station, the Logistic department needs to see if the container needs to change storage area or otherwise edit any routing. After this is done, the systems need to be updated and the assembly workers informed.

When a pallet or combitainer is removed from the factory, the part needs to be removed from all systems. Additionally, the containers in the storage area needs to be removed.

Boxes administrative work

Administrative work for the boxes area is needed when a part or product is added as either to be supplied from the supplier in a box or downsized internally. The needed activities are allocating a space in the warehouse for the new part, place the new part in a transportation flow and allocate a space in the shelf at the line.

When placing the box at the line, the administrative worker will need to weigh the box in order to control where the boxes are allowed to be placed. The rules are that a box that weights more then seven kilograms is restricted to only be placed in the lower part of the shelf, in order to relive the MHV driver from heavy lifts. Additionally, the boxes are only allowed to weigh a maximum of 15 kilograms because of ergonomic rules at VCT.

If a product already is delivered in a box but due to space limits or similar issues, is required to be downsized. Then all the boxes of the product stored at the marketplace need to be removed, both in the computer systems and physically. The boxes are then transported to the downsizing area and placed in new smaller boxes. The activities that follow are the same as adding a new product to the downsizing.

When a part or product that are packaged in a box or downsized is removed, all the material that is currently stored in the whole warehouse needs to be removed. The part or product is then removed from the system.

Racks administrative work

When a part or product is added that will either arrive to the factory in racks or be sequenced internally, certain operations needs to be performed. If the products arrive in racks, the work consists of balancing MHV drivers for both the goods receiving and replenishment and return of the racks. However, if the parts are to be sequenced internally additional work is required. First, a space needs to be allocated where the sequencing operation can be performed and a control if there are any free racks that can be used for the parts. Then the systems needs to be updated, labeling for the new parts and prepare the pick by voice system to handle the new parts. The new sequencing operation needs to be measured and balanced to the sequencing workers along with balancing the MHV drivers.

If internally sequenced parts receive a change, the administrative tasks include updating the pick by voice system, labeling and update databases.

If parts delivered to the line in internally sequenced racks are removed, the tasks include removing the material at the sequencing station, remove the material from the systems and rebalance the MHV drivers. If the racks were externally sequenced the task is only to rebalance the MHV drivers at the goods receiving area.

4.2.2 Maintenance activities

The Maintenance department at VCT is responsible for the preventive maintenance and repairs of all tools, lifting aids, motors in the factory. As the report does not include time spent on repairs, only the preventive maintenance activity was considered.

The preventive maintenance is planned maintenance on equipment performed in order to reduce the risk of it failing in a critical moment. The preventive maintenance follows a schedule and the time between each activity depends on how important the tool is and how frequently it breaks down. For precision critical tools like torque-controlled fasteners, the Maintenance department is responsible to calibrate these on a regular basis.

4.2.3 Production engineering activities

The Production engineering department is the technical support for the production. The department works with improving the production to reduce problems with quality and rebalance the lines to make sure that the production is running smoothly. If there are problems with quality, the production engineer can order quality assurance tools or request changes to the part that are causing the problems. Additionally, they handle changes that arrive from the Manufacturing engineering department, which is the department that works with production development.

If the department thinks that investments in new tools are needed for the production, they work with collecting the data to get the investment approved. In order to get approved a TSU needs to be written, which explains the benefits of the investment and the projected cost. The projected cost for the equipment is mainly gathered by the FTEE department. This is then sent to the Finance department for approval.

Changes to the products arrives to the department as a changed or new PII, which is a instruction made by the Manufacturing engineering department that describes what tasks and in what order a assembly is needs to be performed, with information about equipment and what parts that are included in the assembly. Every assembly operation in the factory has a PII with the required information on how this assembly should be performed. When a new assembly operation is created or a change is introduced, the operations need to be balanced to the assembly stations. When the department receives a change, the main work of balancing is made together with the Production department and when larger changes are performed the IT department is also involved. The Production engineering department are mainly making sure that the equipment can handle the change and that the tools are being reprogrammed. They also make sure that the work is made according to the union agreements.

A change can vary from a changed article number to an introduction of a new assembly, with a difference in time that is required to complete and implement the change. The department will require additional time if the change affects pick by light stations, which has to be reprogrammed by the department and IT.

4.2.4 Facility, tooling & equipment engineering activities

The FTEE department handles all the tools and equipment introductions and changes to the factory. When there is a need for a new equipment or change on existing equipment, the department receives these orders as an EC, which is the ordering system for tools and equipment. Their main tasks consist of handling costs, writing specifications and handle the contact with subcontractor that will perform the physical work. Additionally, they are responsible for educating the Maintenance department with the required information about the new equipment.

4.2.5 Production administration activities

The Production department mainly consists of the assembly workers that do the balanced work in the factory. Additionally, this department includes team leaders, production supervisors and superintendents that perform unbalanced work. Their main tasks are to make sure that the daily operations are working as intended, that the line is correctly staffed, ensure that the workers are properly educated, handle sickness and handle changes in their area of the factory.

4.3 Functional structure

From the information gathered from the interviews, four different types of events that a PII can create were described in functional structures. These events are: a changed article number, introduction of a part, a new part is introduced that requires quality assistance and the removal of a part.

The four different scenarios were described using the IDEF0 method, which shows the required activities for each of the situations at VCT. The structures can be seen in Appendix B. All the presented functional structures have the same basic overview at the top level, describing the incoming PII to VCT. This is presented in Figure 4.1.

The "Volvo" function was then broken down into smaller parts, examining the involved department at VCT. The following section will explain the case of a PII being issued with introduction of a new part and a new quality assurance tool. This was chosen because it is one of the most complex changes and yet a common change in the factory.

The PII is first received to the Production department and Logistics department, which discuss delivery to the line and where to place the part. The Production department prepares and sends an EC for the required tools and machines to the FTEE department. Additionally, the Production department has to get the money for the new tools. In order to get this, they have to write a TSU and the investment needs to be approved by the Finance department.

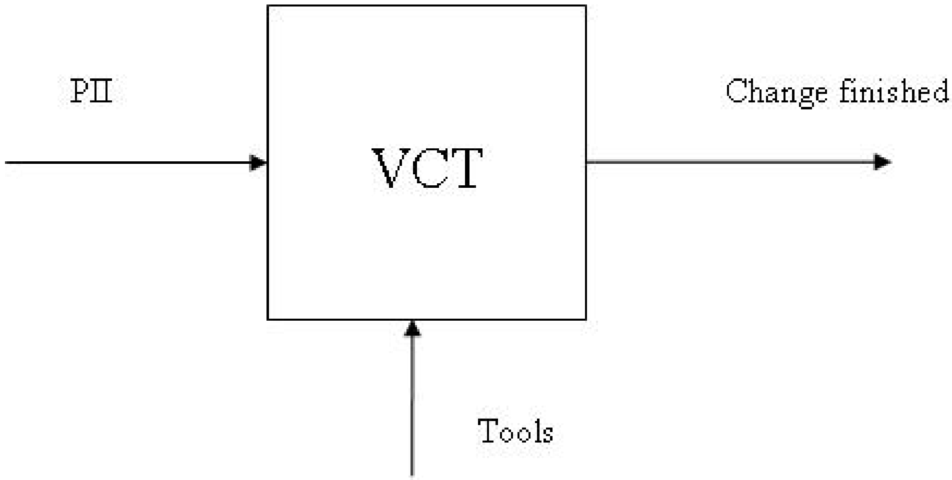

Figure 4.1: First level of the IDEF0 when a PII arrives at VCT

When the TSU is accepted, the FTEE department will prepare and place an order on the new equipment and oversee the installation of the equipment. Additionally, the FTEE department educate the Maintenance department on the new equipment. When this is done, the FTEE department will hand over the installed equipment to the Maintenance department, which will maintain the equipment during its operation.

The resulting broken down structure can be seen in Figure 4.2.

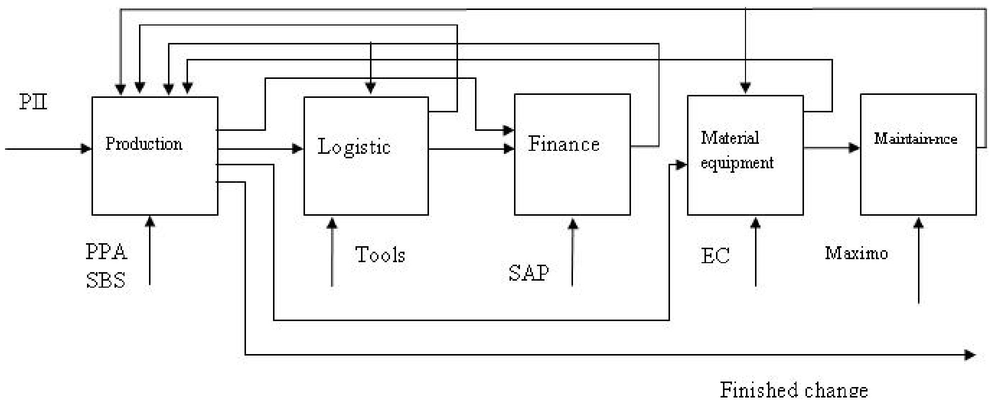

Figure 4.2: Overview of all the departments that are affected when a PII occurs

The functional structure has been broken down further, examining the "Production" and "Logistics" departments, as seen in Figure 4.3 and 4.4.

The activities within the Production department start with the production technician. The technician is the person that handles the incoming PIIs from

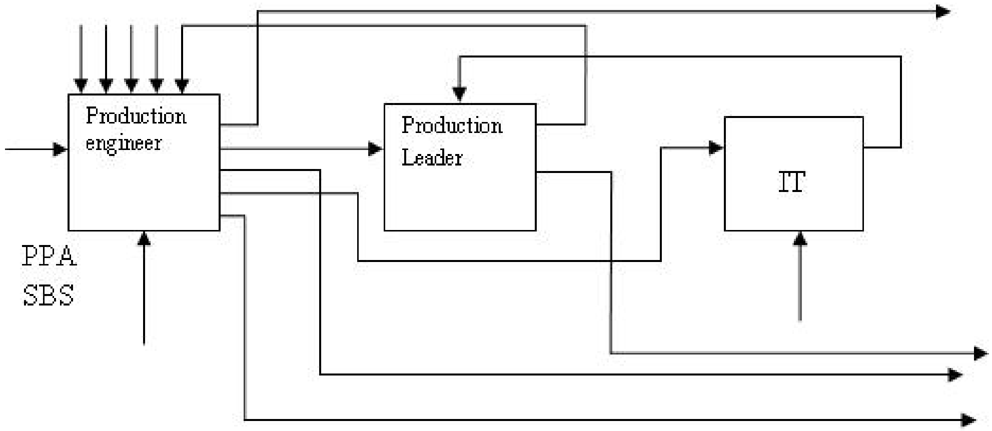

Figure 4.3: Overview of the production activities

the Manufacturing engineering department. After receiving the PII the technician discusses the change with the affected production leader about the balancing and where the part can be placed by the assembly station. There are also discussions about required quality assurance tools, if there is a risk for the assembly worker to mistake the new part with an older part or if there are other issues.

The production technician will take contact with a logistic technician when the quality assurance tool pick by light is required. They will then discuss the delivery from the storage to the line and where the different parts should be located in the pick by light shelves. The pick by light station will then require programming. This is done by the technician together with the IT department.

The activities within the Logistics department start with the Local logistic engineering manager, who inspects the incoming PIIs to the factory that affect logistic activities. The manager will then send the PIIs to the relevant logistic technician to prepare work before discussing with the Production department. Since there is limited space at the factory, certain compromises will have to be made with the changes. When introducing a new part that is internally handles, this will lead to rebalancing the repackaging workers and the MHV drivers. Additionally, the system needs to be updated and the stations need to be reprogrammed. An overview of the activities the Logistics department performs can be seen in Figure 4.4.

4.4 Model development

This part explains the development of the model and the result. The simulation model was created in Microsoft Excel, which is a spreadsheet-based software. The choice to use a spreadsheet based simulation model was taken because of the avail-

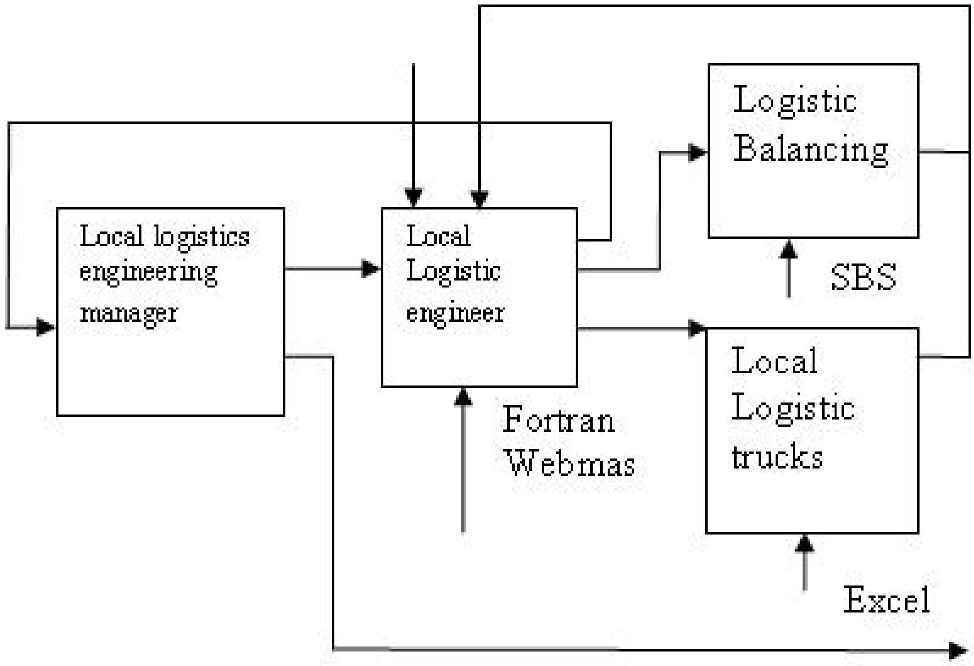

Figure 4.4: Overview of the logistic activities

ability of the software and that the software was known to the project members. In the model, the user can set a current state by setting different types of input parameters that describes the situation. The user can then investigate how different change scenarios, for example a changed number of variants, will impact the required unbalanced time of the various departments at VCT. The model gives an output of both the required time for daily support operations before and after the chosen scenario. Additionally, the model gives the distribution of balanced and unbalanced time for that product and gives an estimate on how much time the change will require to be implemented.

4.4.1 Model specification

The model was created using an iterative process to implement the unbalanced activities. This implementation followed the priority list that resulted from the pre-study.

A list of the demands and wishes for the model was made by interviewing employees with insight of the production at VCT. The people that mainly gave input in this area were the Production engineering manager, Local logistic engineering manager, the Project cost controller at the Strategic planning & control department and the plant man-hour control engineer at the Manufacturing engineering department. This list was made to ensure that the model at the end of the project has the desired properties.

The list of demands and wishes was compared with each other and given a +1 or -1 if it was more or less important than the compared part. This gave the following result.

Demands

1. The model shall visually show the result
2. The amount of parameters the user needs to add is limited to 15
3. Minimum amount of training
4. The model includes the major time contributors at VCT
5. The difference of the result is less then 50% of the real result

Wishes

6. The model will be updated automatically
7. The model includes all the departments at VCT
8. The difference of the result is less then 95% of the real result

Table 4.2: Pugh matrix to find the most important specifications for the model

a	1	2	3	4	5	6	7	8	Results
1	0	1	-1	-1	-1	1	1	1	1
2	-1	0	-1	-1	-1	1	1	1	-1
3	1	1	0	-1	-1	1	1	1	3
4	1	1	1	0	1	1	1	1	7
5	1	1	1	-1	0	1	1	1	5
6	-1	-1	-1	-1	-1	0	1	-1	-5
7	-1	-1	-1	-1	-1	-1	0	-1	-7
8	-1	-1	-1	-1	-1	1	1	0	-3

Table 4.2 shows that the most important attribute, according to the project group, was that the model includes the major time contributors at VCT. This was followed by the importance to get accurate results and that the model that is user-friendly.

4.4.2 Implementing the daily operations activities

The output from the current states as well as the information from the functional structure mapping was used to develop the model.

In the process of implementing the daily operations activities much effort were made to find the parameters that increases or decreases the duration of each activity. For example, driving sequence racks by MHVs, in this case the parameters that affect the time are, the distance from the sequence station to the assembly station, how many parts that are in each rack, what takt the assembly line has, the velocity of the MHVs, how the traffic currently is in the factory and the amount of product that require this part. This was done for the major time consuming activities for the departments on the priority list and resulted in a list of parameters linked to the various activities.

After this task, effort was put to reduce the required parameters for the model. This was done by combining similar parameters and removing parameters that had an insignificant impact on the time the activities will take. This was done in steps throughout the whole development. For example in the previously mentioned sequencing racks driver, the parameters of MHV velocity and the traffic could be combined with the distance parameter. Only working with the distance parameters was possible because the velocity of the MHVs is constant and limited to 10 km/h and the traffic situation only has a limited effect on the time.

Additionally, the required input parameters were redesigned to fit the information the operator has available. For example, instead of require the balanced time in minutes per hour that is spent doing the assembly, the model takes in the TMU for one assembly and internally recalculates the input for the calculations.

However, for certain cases additional parameters are required to accurately calculate the time. The cases are when having internal sequencing or internal downsizing. The time will vary with the number of parts that are inserted into a rack or box and therefore are these parameters required when this option is chosen. In the case of internal sequencing, the parameter of how long time the sequencing operation will take is also important to get, to get a good value from the model. The chosen path for implementation was to show only the required parameters depending on what choices that are currently picked and if one of the special cases is picked the user is presented with dialogs to complete the choice and the new parameters are shown in the model. If the case changes, the displayed parameters change to avoid confusing the user with input parameters that are not relevant for the current case. In the case of internal sequencing, the user is displayed with an input request for how many parts that will be sequenced in one rack along with a request to either input the time for the sequencing operation for the current case or to have the model to do an estimation based on some questions.

This estimation was created by investigating what parameters that affect the sequencing operation. It was identified that if the parts where heavily wrapping in plastic like electronics components or if the sequencing operation included assembly work had the biggest impact on the time. Additionally, the number of variants a product, the complexity, has an impact on the time, as many variants will result in a larger area where the parts are located and the worker will have to walk larger distances.

4.4.3 Implementing the administrative estimation simulation

The work continued with implementing the part that gives the administrative work estimation.

The implementation started with introducing functions that compare the parameters before and after the change to sort out what have changed. Then the time for the administrative work is calculated by adding the administrative time for each of the changed elements. The data for the administrative time for each changed element were collected during this phase and is based on interviews and estimations.

4.4.4 How to use the simulation model

An overview of the interface of the model can be seen in Figure 4.5. The user of the model starts by describing the current situation on the upper left area called Current properties, seen in Figure 4.6. Here the properties of the selected product are inserted, for example the package type it received in, how many tools it is required for the assembly of this product and so on. The parameters that can be edited in this area have a white background.

When these values have been entered, the resulting unbalanced time and distribution is shown in the results area in the upper left corner of the model.

The user can then implement changes to the product. The parameters from the current state can then be copied, by pressing the Copy properties button, to the area to the right of the Current properties area, called After the change. The After the change area with a highlighted copy-button can be seen in Figure 4.7. With the values copied, the user can then make changes to the parameters in the After the change area. Here the user describes how the situation of the product

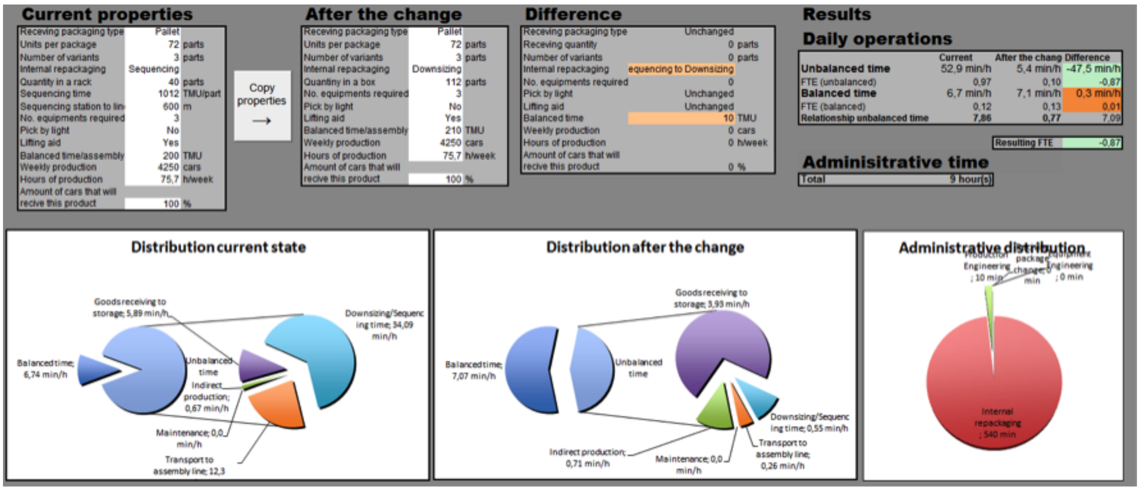

Figure 4.5: An overview of how the model looks like with parameters on the top and visualization of the distribution in the bottom

Current properties

Receving packaging type	Pallet	
Units per package	72	parts
Number of variants	3	parts
Internal repackaging	Sequencing	
Quantity in a rack	40	parts
Sequencing time	1012	TMU/part
Sequencing station to lin	600	m
No. equipments required	3	
Pick by light	No	
Lifting aid	Yes	
Balanced time/assembly	200	TMU
Weekly production	4250	cars
Hours of production	75,7	h/week
Amount of cars that will recive this product	100	%

Figure 4.6: Current properties area, where the user describes how the situation currently is

will look like after the changes have been made, for example if it is downsized instead of sequenced.

When these two areas are filled the model will first compare and display the difference between the two areas in the difference area, seen in Figure 4.8. Here the parameters that have been changed will change colour to orange to visualize that there is a difference.

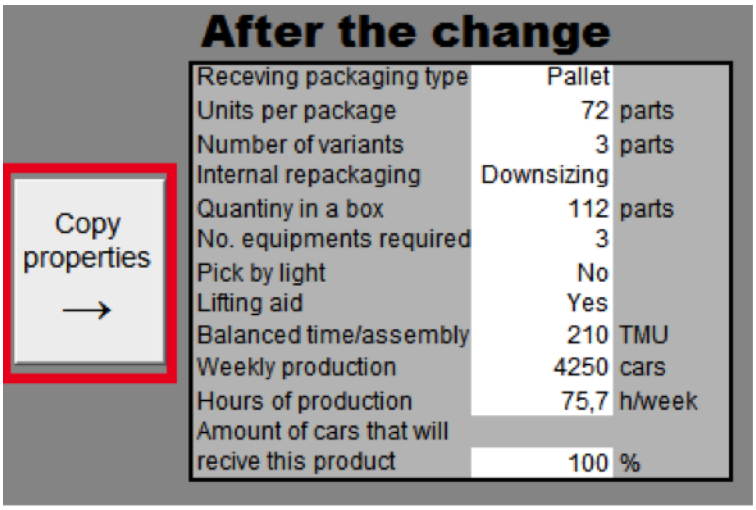

Figure 4.7: The Copy properties button highlighted in red and the After the change area in the model

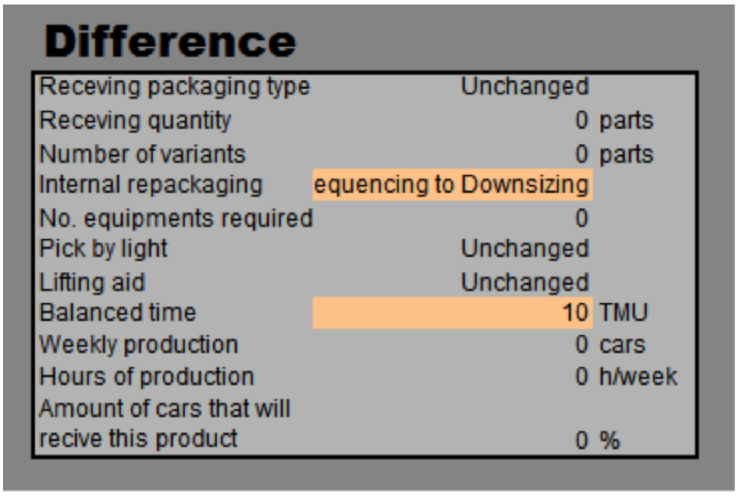

Figure 4.8: The difference area in the model that shows the difference done between Current properties and After the change

The last area called results displays the results in unbalanced minutes per hour both before the change and after, the results area can be seen in Figure 4.9. This area also displays the performed changes effect on the time for the daily operations. If the difference results in a positive change (reduced time required) the time will receive a green background and an orange background if the required time has increased. The required daily operations times are displayed both as in minutes per hour and in FTE, which tells how many workers that is required to handle this product. The "Resulting FTE" describes how the total amount of required workers, both balance and unbalance has changed because of the change on the product.

The Administrative time area gives an estimation on how much time that the change will take for administrative employees to prepare and introduce.

Results

Daily operations

	Current	After the chang	Difference
Unbalanced time	52,9 min/h	5,4 min/h	-47,5 min/h
FTE (unbalanced)	0,97	0,10	-0,87
Balanced time	6,7 min/h	7,1 min/h	0,3 min/h
FTE (balanced)	0,12	0,13	0,01
Relationship unbalanced time	**7,86**	**0,77**	7,09

Resulting FTE	-0,87

Administrative time

Total	9 hour(s)

Figure 4.9: The results area of the model with colours if the change has positiv or negativ effects.

The resulting distributions before and after the change are shown below the input areas, as pie charts, as can be seen in Figure 4.10. The first two charts from the left show the distribution between balanced and unbalanced time and show what activities the unbalanced time consist of for the current state and after the change. The third pie chart shows the distribution of time for the administrative tasks.

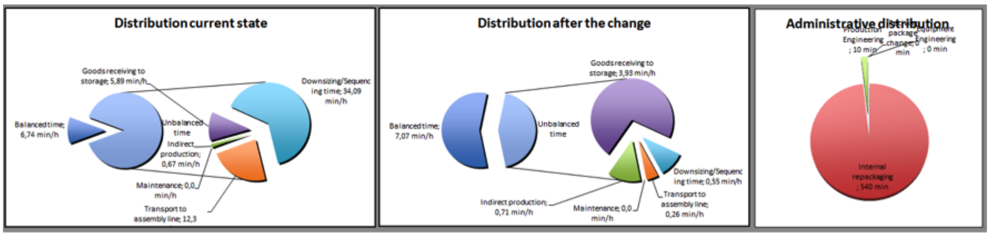

Figure 4.10: Pie charts, visualizes the distribution of time for the current state, after the change state and how the administrative distribution

4.5 Validation

The resulting daily operations times, administrative times and the functional structures were validated to ensure that the results were correct. The daily operations were validated by ”Event validation” while administrative work and the functional structures were validated with ”Face validation”.

The validation was iteratively performed during the project and was continously reviewed and corrected.

4.5.1 Validation of the daily work

The daily work was validated by choosing random event and see if the value that the model give is close to the measured time that was collected by examine the event with a clock.

Two different work tasks were validated in the daily operations work, the time to place parts in sequencing racks and the times to move parts by the MHV drivers. These were chosen since these times can vary the most in the different situations and they are the largest time-consumer.

Validation of sequencing work

In the case of validate the sequencing work, the estimated time from the model was compared with the data from VCTs database. The value in the VCT database is considered true, since this value decides the manning requirement and is frequently controlled and adjusted. The results of the validation can be seen in Table 4.3.

Table 4.3: The time difference between the estimated time to sequence a part and the real value

Station	Estimated sequencing time [TMU]	Real sequencing time [TMU]	Difference
Pressure hose	871	651	33,79%
Airbag	816	1012	-19,37%
Luggage floor	663	557	19,03%
Speakers	639	595	7,39%
Air hose	680	500	36,00%
Belt	1148	1231	-6,74%
Tailgate handle	612	559	9,48%

This shows the model differ -19,37% to +36,00% depending on the scenario. However, the largest deviation was 196 TMU or 7 sec per pick. Because of the generalness of the model and the variation of this operation, this is considered to be accepted as a better estimation function will require much for information from the user. A variation that is less then 50% is accepted according to the specification of the model.

Validation of MHV transportation

The transportation times to move parts by MHVs were validated by clocking the time a MHV needs to travel from a sequencing station to the assembly station. The transports were randomly picked and clocked. The time was measured three times and the average was used as the value that was compared with the estimation from the model.

Table 4.4: The time difference between the estimated time for the MHV transports and the real value

Station	Estimated MHV time [Min]	Real MHV time [Min]	Difference
Plenum (1:42)	7,3	7,4	-1,35%
AC compressor (PP2)	5,8	5,3	9,43%
C-Panel (1:6)	7,5	8	-6,25%

As seen in Table 4.4 can the time vary between -6,25% and 9,43%. This is within the limitations that were made in the specification.

Validation of administrative work

The times on the tasks performed by a production engineer was validated by comparing the values given from several employees performing the same tasks. This showed that the time required performing the tasks was almost the same for them all, but the order the tasks were performed varied from engineer to engineer. A general way of the order the tasks are performed was made in the functional structure, which was agreed by the engineers as a way to perform the tasks.

Validation of functional structure

The overall functional structure was validated by face validation. It was shown to both the manager for the production engineers, who has an overview role over the production and the local logistics engineering manager, who has an overview role of the logistics. When discussing the structure with them, minor changes were made to correct the functional structures. The structures were then agreed to correspond to the reality for the various departments.

5

Discussion

The trend in the automotive industry to offer more customization while producing several car models on the same assembly line has led to a more complex environment in the companies, highly noticeable in the final assembly shop where all these variants is assembled. As the development of vehicles progresses, with more and more features and advanced safety function, the complexity in this area will probably increase even further.

In such an environment, the use of methods and tools to reduce the complexity for the assembly worker will increase in order to secure the efficiency of the worker and the quality of the work, methods such as the mixed-model production. Even though a mixed-model production helps to build several different cars on the assembly line, this causes problems for the assembly workers because of high amount of parts. This could be prevented if the company combined similar parts into one customizable part, using modular assembly. However, activities performed unbalanced around the assembly will continue to increase and to have a good understanding of this work will get increasingly important to stay competitive.

The work performed in this thesis consisted of identifying what unbalanced activities that are performed in the final assembly and why they are made. Then analyze how changes that are performed locally in the assembly shop are handled by the departments. In order to be able to analyze all the activities, the tasks were separated in two different categories, daily operations activities and administrative work.

This distinction was made because of the nature of these tasks. The daily operations work is activities performed continuously in the factory every day. This means that successfully lower this time will have a huge effect on the manpower requirement for the factory. The administrative work however, describes the tasks that are done one time for a specific change. This means that the resulting time will only be performed one time for the given change and this time can not be easily compared with the daily operations time.

The daily operation time in the model is presented as minutes per hour, or FTE, which is the working time of a full time employee. The administrative time is presented as the resulting hours to implement the change.

Data collection

A big part of this thesis was the collection of data about the activities. To accurately be able to simulate how much time that is required for different scenarios it is important to have good values. In the case of collecting data for the daily operations, much of the needed data could be extracted from various databases at VCC. The challenge in this case was to find a good value among many different. However, all values for the daily operations could not be found in any of the databases. In these cases, good values could either be calculated by combining existing data or measured in the factory.

In the collection of the times for the administrative tasks, these were gathered by having the employees performing them give estimates. This method has the drawback that it is hard for people to give estimates. The data would be more accurate if time-studies on the administrative tasks were performed. However, performing time-studies would be very time-consuming since the activities that needed to be measured were performed very seldom in some cases. Additionally, the amount of employees that needed to be monitored alone would make the task too comprehensive to be able to be performed in the given time-frame. In order to get good usable data, the activities would also be needed to be monitored several times to exclude randomness.

Functional structures

The functional structures presented in this thesis show the complexity in the organization at the final assembly shop alone. A lot of information is sent back and forth between the departments when changes are being handled. From this information, one can understand that many employees are required unbalanced for all the activities to be performed.

In the case of the validation of the structure, the chosen approach gave a good validation of how the process occurs at VCT for the various change scenarios.

The Model

The purpose of this project was to provide Volvo Cars with a deeper understanding on how the complexity at the final assembly affects the unbalanced time. In this case, the deeper understanding is provided as a simulation model that can give the user a distribution and a number on the balanced and unbalanced time for given scenarios.

The presented model could be useful for a number of departments at VCT. The model can be used in the production engineering department, when evaluating different options when implementing recent changes. There are also uses for the logistic department, when planning introduction of new variants.

Since the model is built as a spreadsheet could it could be easily accessed by a large part of the employees at VCT, since the software is available on every computer as standard. The model is designed for the users to have an easy access to the constants used in the model, to be able to make changes as the situation changes in the factory, or to export the model to other similar factories that have a different situation in some cases.

However, since the model is built to be broad and to include the most parts of the final assembly area at VCT, the results will only represent an average value for that kind of operation. This information can be used to get an understanding of the consequences of different changes rather then used to calculate the required manpower. However, the resulting times from the model on the daily operation is always better than the previous alternative, to have a factor on the balanced time.

Some conclusions can be drawn about complexity and the unbalanced time from the usage of the model.

The logistic department is the most unbalanced time consuming department at the final assembly, with the biggest part of the daily operations and usually included in the required administrative tasks.

The model shows that when introducing or make changes to a part that uses a quality assurance tool is very costly in administrative time. The introduction of a new tool is associated by a large number of activities that needs to be performed, for example programming. Additionally, much of these activities has to be re-done every time a change occurs that affect this tool, for example a changed variant count or similar. Then the tool requires re-programming for the new scenarios and management.

The model also shows that when increasing the amount of variants and complexity of a part the administrative work time increases while the daily operations time is largely unaffected. The daily operations activities are only affect by the increased walking time to pick the correct part when more variants need to be placed in the same area. This is only true if the internal handling operation remains unaffected by the changed variant count, which is the case if the part already is sequenced or downsized. However, if the part previously was delivered to the line in pallets and due to the new variant count is changed to internal sequencing, the daily operation time will be greatly increased.

Increasing the variant count and complexity of a part will lead to an increased amount of administrative work. At the very least, new variants or similar needs to be inserted in the systems, receive storage space and get handled initially. Additionally, if there is a shortage of space at the assembly line, the parts will require internal handling and sent to the line in smaller portions. Preparing internal handling stations will require much administrative work, as each variant needs to be handled in many systems.

When utilizing the model, it is important to understand that the model only gives a general representation about the unbalance work times in the final assembly factory. As the final assembly area at VCC is very large and do not look the same at all locations, the actual value can vary. However, as can be seen from the validation of the different parts of the model, it succeeds to give a good estimation on the reality.

The validations of the work were made by using face validity for the structure and even validity for the time results from the model. The validation proves that the model is within the limitations that were set for the model.

Another important part about the model is that it is only giving the time cost required of the different daily and administrative activities. This will result in that actions like outsourcing activities or replacing people with machines will give a positive result of the time cost in the model. However, if a total cost calculation were made, the actual cost can in fact increase. If the model was to take the total cost factor in consideration, it would be required to collect a lot of additional data. Data such as cost for installing new equipment, which highly depends on the surroundings, cost for reorganize employees within the company, etc. However, the time consumption is the largest part of the daily operations cost that can be changed.

Looking at additional usefulness of the model, it could result in that when optimizing the production and considering changes, the whole factory is considered. This could lead to that sub-optimisation is avoided, which could result in less monotone work for the workers. Having a better overview of the unbalanced activities in factory will also lead to better estimations and better decisions for new projects.

To extend the use of the model, additional functions could be added. For example methods that measure complexity in the production. The entropy approach could be implemented in the developed model. It could calculate a value for the complexity at a assembly station before and after a change. Then it would be interesting to see the connection between complexity and the amount of unbalanced work performed for a station. But since the model only examines one part at a time it will be difficult and time-consuming to implement this function. Additionally, the CXI method could be used as a complement to the model. The result from a CXI study could be used to identify upper limits for parameters such as variants since the model does not consider these constraints.

6

Conclusion

From the interviews conducted at VCT, it was observed that the main time-consuming activities were performed by the logistic department. The logistic department both had the major part of the daily operations as well as the administrative tasks. The most important factor in deciding the unbalanced time is if the parts are internally handled or not, as this requires much work. With increasing amount of variants, the work required to rebalance the workstations will increase. However, the time spent on the daily operations work is not affected by the variants to the same degree.

The functional structures presented in this report shows that many departments are affected when changes occur. It also shows that many different activities are required in order to perform changes in the factory. In the case of introducing a new tool for assuring the quality of the products, the required activities are very extensive. Every time a change in variants or articles occurs that affects the quality tools, many of the activities required when introducing the tool needs to be repeated. This makes the quality tools time-consuming for the administration, since article numbers are changed regularly. As can be seen in the functional structures, administrating change in the final assembly is a very complex situation requiring a lot of information and collaboration from the different departments. The functional structure in this report visualizes the complexity in a structured way, showing the required activities between the departments.

The simulation model that resulted from this project can calculate and visualize the distribution of time, based on given complexity parameters. It visualizes both the daily operations and the administrative work and can be used as an aid when planning changes at the final assembly.

7

Recommendations on future work

Here are some recommendations on future work:

- To make the model more extensive, the model could be extended to include the monetary cost for the listed activities
- The model should be adapted to specific departments and present input parameters that are relevant for them
- The use of Excel as the simulation tool, while it makes the model easily accessible within the VCC organization, has been limiting. A suggestion is to make a new model with a more advanced simulation tool

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A

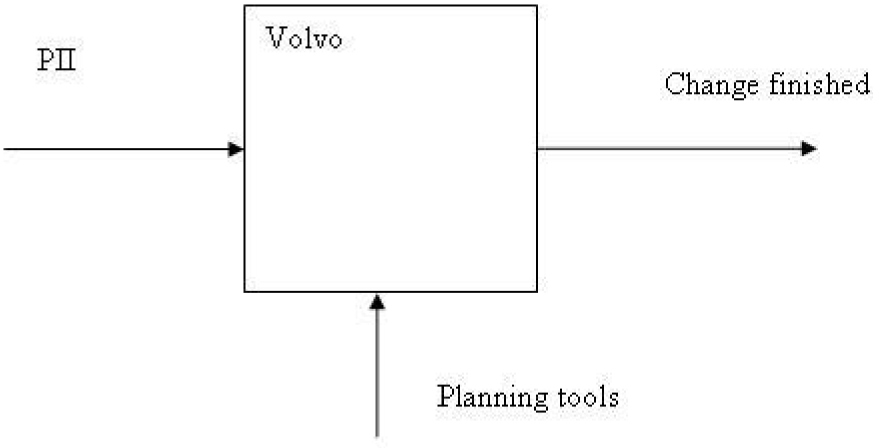
List of interviewes

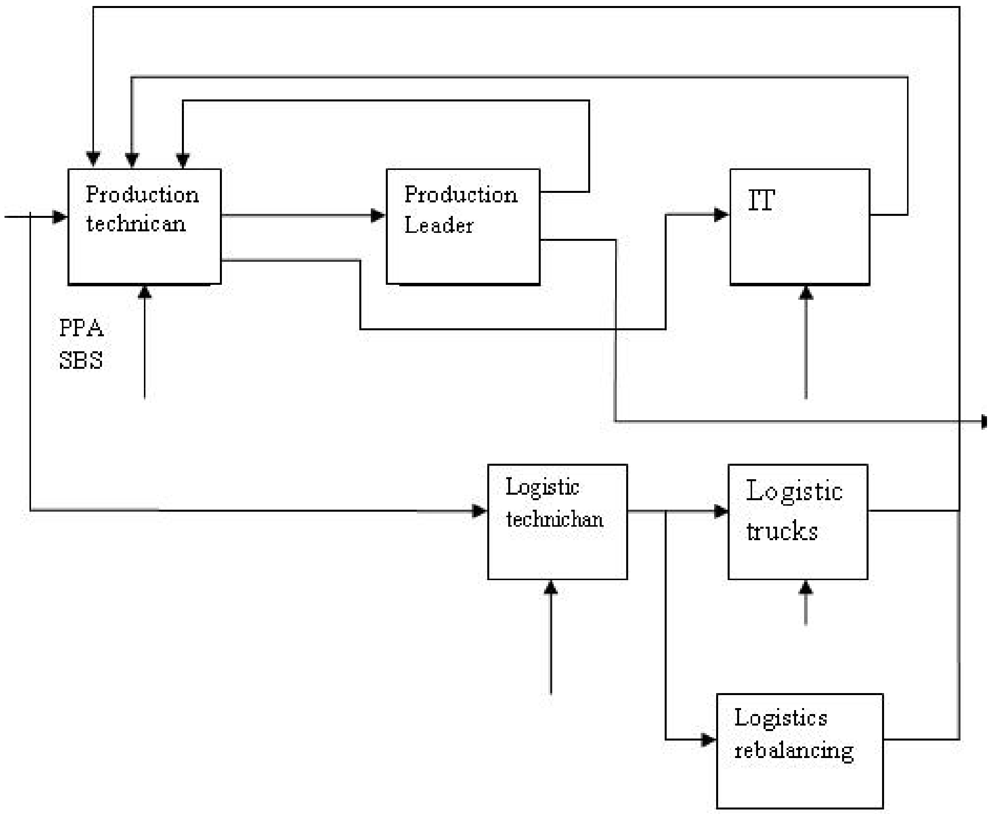
Name	Title	Department
Charlie Berner	Project cost controller	Strategic planning & control
Fredrik Asplund	Material handling engineer	Logistic engineering
Jerry Magnusson	Local logistic engineering manager	Logistic engineering
Jimmy Olsson	Manufacturing engineer	Production engineering
Jonas Brandt	Business Management System	Quality
Jose Samplin	Local logistic engineering manager	Logistic engineering
Lars Phanivong	Labour hour target setting	Strategic planning & control
Mats Nilsson	Manager	FTEE
Mattias Eliasson	Plant man-hour control	Manufacturing engineering
Mikael Johansson	Added value time spec.	Manufacturing engineering
Peter Hultman	Logistic engineer	Logistic engineer
Roinne Johansson	Logistic engineer	Logistic engineering
Sven Lundskog	Manager, Production engineering	Production engineering
Thomas Börjesson	Logistic engineer	Logistic engineering
Åsa Sundholm	Material handling engineer	Logistic engineering

B

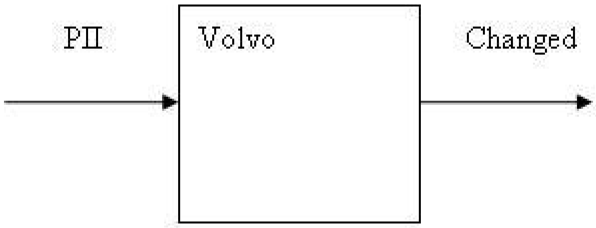
Functional structures

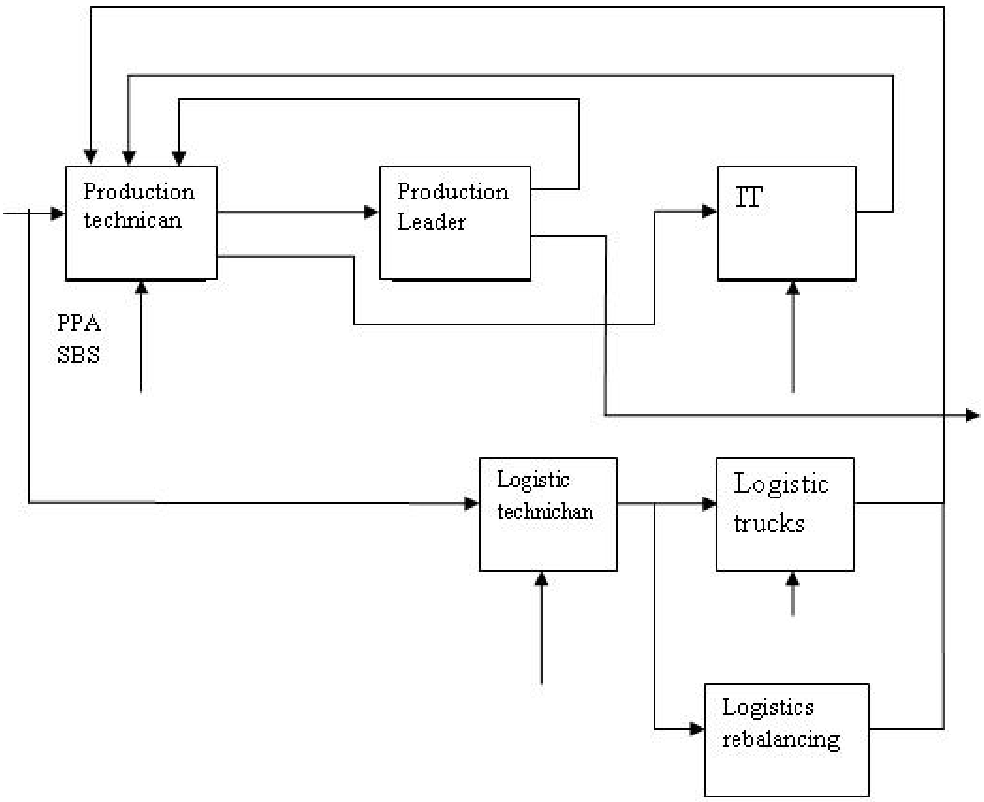
Scenario: Article name change




Production
technican
Production
Leader
IT
PPA
SBS
Logistic
technichan
Logistic
trucks
Logistics
rebalancing

Scenario: New article





Scenario: Removal of an article