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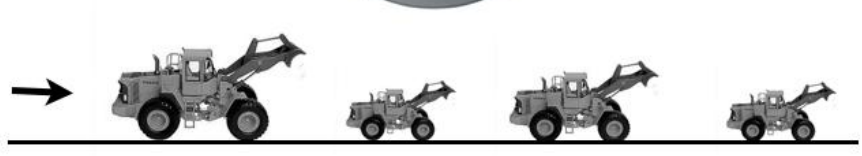

Mixed-model assembly line at Volvo Construction Equipment

Requirements for mixed-model assembly line at Volvo Construction Equipment and a case study at the Arvika plant

Master of Science Thesis in Production Engineering

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Abstract
Traditional mass production was based on dedicated assembly lines where only one or few products were assembled in large quantities and thereby achieved a high productivity by the principles of economies of scale. In today’s marketplace where customers demand high product variety and short lead times, mass customization has been recognized as the new paradigm for manufacturing. Mixed-model assembly lines are considered to be an enabler for mass customization and are therefore today replacing many of the traditional mass production assembly lines in industrial environments. No general framework covering all important areas of mixed-model assembly has been found in literature. Consequently this Master´s Thesis could be seen as a framework filling that gap.

Volvo Construction Equipment (VCE) in Arvika is, to be able to improve in a number of areas, planning to integrate their two assembly lines into one mixed-model assembly line.

This Master´s Thesis presents a model that identifies the prerequisites for mixed-model assembly lines, maps the problems and identifies the challenges most important. Methods and solutions to handle the challenges are presented in more detail. General advantages and disadvantages with mixed-model lines and serial flows are identified and presented. The model is valid for VCE operations in Sweden and production systems with similar products. This thesis also presents which of the challenges in the general model that has to be fulfilled in the context of VCE in Arvika. The appropriate methods and solutions needed to be able to solve the potential problems in the Arvika case are identified and analysed. One challenge is analysed more in detail.

The problem that causes the largest challenges was found to be the difference in assembly time between different models. The literature poses that the largest difference in assembly time can be about 30 per cent but it has been seen from the empirical findings that a difference of 50 per cent can be handled.

Two of the advantages Volvo Construction Equipment hope to gain when implementing a mixed-model assembly line is the possibility to get shorter learning times and less need of floor space. However, the conclusions from this Master’s Thesis did not confirm those statements.

A noteworthy conclusion is that a mixed-model assembly line would require a higher dependability than several dedicated lines. This is due to that the assembly system becomes more sensitive to disturbances when having only one flow.

It is recommended that standardised work is fully implemented and in place before a transition to mixed-model line. A pick-to-light system in combination with barcodes and scanners is recommended for VCE in Arvika for them to solve their problems with picking errors, which was the challenge that was analysed more in detail.

The model presented in this thesis is considered to be comprehensive but each part of the model is not fully explored. When implementing mixed-model assembly lines, each part of the model could be more thoroughly analysed based on the specific company’s current prerequisites and context.

Keywords: Assembly System, Assembly Line, Mixed-Model Assembly Lines, Mixed-Product Assembly Line, Time losses in assembly system, Methods to handle time losses, Product Variety.

Acknowledgments

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Gothenburg, June 2011

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1 Introduction

This chapter gives the reader a background to Volvo Construction Equipment. It also explains the background and purpose of this Master´s Thesis and why the subject is important. The research questions and the limitations, which define the frame of the project, are also described.

1.1 Volvo Construction Equipment

Volvo Construction Equipment (VCE) was started in 1832 in Eskilstuna, which makes it the oldest industrial company in the world still active in construction machinery. VCE has grown and developed throughout the years through a number of mergers and acquisitions. The company manufactures construction machines such as articulated haulers, excavators, and wheel loaders. (Corporate brochures & presentations, 2011)

VCE is manufacturing construction machines and components in four plants in Sweden. The plants are located in Arvika, Braås, Eskilstuna and Hallsberg.

Volvo's main factory for all production of wheel loaders is located in Arvika, were the first wheel loader was produced in 1966. In addition to Arvika, wheel loaders are built in Asheville in North America and in Pederneiras, Brazil. The final assembly of wheel loaders in Arvika is performed at three assembly flows. (Corporate brochures & presentations, 2011)

VCE is part of Volvo Group which has approximately 100,000 employees, production in 25 countries and operates on more than 185 markets. VCE has approximately 15,000 employees worldwide of which 1100 works in Arvika. (Corporate brochures & presentations, 2011)

VCE has a market share of seven per cent of the construction equipment industry market worldwide. Wheel loaders are the second largest business area after excavators within VCE, representing 24 per cent of VCE's total sales. (Corporate brochures & presentations, 2011)

1.2 Background and motivation for thesis

The wheel loaders are assembled in three assembly flows at VCE in Arvika. At the first assembly line, wheel loaders of model L60 up to L120 are assembled and at the second assembly line, wheel loaders of model L150 up to L250 are assembled. The largest model, L350, is not assembled at any of the assembly lines but at a separate workshop.

VCE in Arvika is, to be able to increase their resource utilization and to meet customers increasing demand of flexibility, planning to integrate their two assembly lines into one mixed model assembly line. On a mixed model assembly line, different models are assembled at the same line.

The main benefits that VCE hope to gain with the transition to a mixed-model assembly line are the following:

- Reduced surface need
- Reduced investments
- Increased volume flexibility
- Increased variant flexibility
- Possibility of shorter learning times
- Shorter lead times
- More consistent quality

Traditional mass production was based on dedicated assembly lines where only one or few products were assembled in large quantities and thereby achieved a high productivity by the principles of economies of scale. In today’s marketplace where customers demand high product variety and short lead times mass customization has been recognized as the new paradigm for manufacturing. Mixed-model assembly lines are considered to be an enabler for mass customization and are therefore today replacing many of the traditional mass production assembly lines in industrial environments. Although mixed model assembly is an enabler for high variety, such systems tend to get very complex as variety increase.(Zhu, Jack Hu, Koren, & Marin, 2008)

Mixed-models assembly line complexity as well as advantages and disadvantages are described in production related literature. See for example Becker & Scholl, 2006.

No general framework covering all areas of mixed-model assembly including prerequisites, problems and solutions has been found in literature. Consequently this Master´s Thesis could be seen as a framework filling that gap.

1.3 Purpose and research questions

The purpose of the first part of the Master´s Thesis is to; based on theoretical and empirical data, develop a model that identifies the prerequisites for mixed-model assembly lines, maps the problems with mixed-model assembly lines and identifies the most important challenges. Methods and solutions to handle the challenges should be presented in more detail. The model should be valid for VCE in Sweden and production systems with similar products.

The model should be able to be used to highlight what is demanded of a production system and products when implementing a mixed model assembly line. Several methods that could help a company to overcome the challenges presented in the model should be described in more detail.

The purpose of the second part of the Master´s Thesis is to come up with which of the challenges in the general model that have to be fulfilled in the context of VCE Arvika when implementing a mixed-model assembly line for the wheel loader models L60 up to L250. The appropriate methods and solutions needed to be able to solve the potential problems in the Arvika case will be identified and analysed. One challenge will be analysed more in detail.

A summary of the purpose of this thesis is presented below:

- Develop a model for a mixed-model assembly line that should be valid for VCE operations in Sweden and for similar products.
- Perform a case study at the VCE Arvika plant and apply the model.
- Develop, in more detail, methods and solutions for one challenge at VCE in Arvika.

Three research questions have been constructed. The aim of the research questions is that their answers should fulfil the purpose of the master´s thesis. The questions are presented below:

RQ1: Which problems and challenges have to be overcome when implementing a mixed-model assembly line in VCE operations in Sweden or in production systems with similar products?

RQ2: Which are the possible methods and solutions to be able handle the challenges?

RQ3: Which challenges will be most important in VCE Arvika and which methods and solutions should be used to overcome them?

1.4 Limitations

The intention of this master's thesis is not to give guidelines for product design to the product development department regarding for example number of common components between models that could help enable a transition to mixed-model assembly line. The intention is instead to focus on demands on the production system regarding for example operating system, material handling system and production planning and control.

Solutions related to the decisions regarding desired product structure that must be made to be able to use mixed-model assembly line systems are not questioned in this thesis. This involves strategic and tactical decisions regarding which models should be produced for different markets, which functions and options should be available on different markets etc. These problems are not treated in this master's thesis because they involve much wider factors like business strategy and marketing.

1.5 Report Outline

The outline of this Master´s Thesis and what is covered in each chapter is briefly described below.

1. **Introduction**
   This chapter introduces the reader to the scope of this Master´s Thesis as well as the importance of the subject. It also describes the company that initiated the thesis.
2. **Literature review**
   This chapter describes how the areas important for a mixed-model assembly line system are described in the literature.
3. **Volvo Production System**
   This chapter aims at ensuring that the view of the areas that are important in terms of mixed-model production is in line with Volvo production system's view of the same.
4. **Method**
   This chapter explains the research method used in this Master´s Thesis.
5. **Empirical Findings**
   This chapter summarizes the views of professionals within the field of production regarding mixed-model assembly lines.
6. **Analysis Part 1**
   In the first part of the analysis a general model with problems, requirements, methods and solutions related to a mixed-model assembly line is developed. Thereafter general advantages and disadvantages with mixed-model lines and serial flows are presented and finally the model is presented.
7. **Analysis Part 2**
   In this chapter the model is applied at the VCE plant in Arvika. The advantages and disadvantages that VCE in Arvika may experience after the transition to mixed-model assembly are then discussed. Finally, a station where assembly quality is low in Arvika is analysed.
8. **Conclusion and Discussion**
   This chapter summarizes the conclusions from this Master´s Thesis. The considerations made during this Master´s Thesis and a discussion about the outcome is also held.
9. **Recommendations**
   This chapter presents recommendations to VCE in Arvika regarding how they should continue their work towards a mixed-model line.

1.6 Terms and abbreviations

Terms and abbreviations	Description
Assembly	Assembly involves collecting and fitting together various parts in order to create a finished product. Parts may be divided into components and sub-assemblies and the unfinished units of a product are called work-pieces.
Assembly line	An assembly line is a manufacturing process in which parts are added to a product in a sequential manner along a serial flow line to create a finished product much faster than with conventional handcrafting-type methods.
Assembly sequence	The order in which the parts must be assembled. Can be described with a precedence graph (PERT diagram).
Balance loss	It is not possible to divide the assembly operations into sufficiently small pieces so they can be perfectly balanced out on each station on an assembly line causing balance losses.
Balancing	The work in distributing the operations to the different stations in an assembly line.
BOM	A Bill of Material (BOM) is a list of the product structure including raw materials, sub-assemblies, intermediate assemblies, sub-components, components, parts and the quantities of each needed to manufacture the end product.
Collective assembly	A assembly flow based on a parallel flow.
Cycle time	The cycle time is the sum of the operation times within each individual station.
DFA	Design for Assembly.
DFM	Design for Manufacturing
ERP system	Enterprise Resource Planning system.
FIFO	First In First Out
Five S (5S)	A methodology within standardised work to eliminate waste and improve the workplace. Stands for Sort, Straighten, Shine, Standardise and Sustain.
JIT	Just-In-Time.
MES	Manufacturing Execution System
Mixed-model assembly line	A serial flow assembly line where different models are assembled.
Models	There are today several different models of wheel loaders from L60 to L350.
MPS	Master Production Schedule
MRP system	Material Requirements Planning system.
Multi model assembly line	A assembly line where different products or models are assembled in batches.
Operation	The sum of all operations adds up to the total work content in an assembly process. The time it takes to perform an operation (task) is called operation time. An operation cannot be divided into smaller work elements without creating additional work.
Planned cycle time	The takt time is based on the demand but the time the assembly system is planned for is called planned cycle time and can be lower than the takt time to absorb time variations.
PLM	Product Lifecycle Management

Product and model generations	A number of updates to an existing product or model that are introduced at the same time and that may change the requirements of the production system.
Product family	The product family consists of all models of wheel loaders.
S&OP	Sales and Operations Plan
Sequencing	The work in deciding the sequence in which different products or models should be released to the same assembly line.
Single model assembly line	Assembly line where only one product or model is assembled.
Station	A station is a segment of a line where a number of operations are performed. The work at a station can be either manual or automated. The work performed at a station is called station load. Stations can be open and closed.
System loss	A result from that human worker operation times varies according to a time distribution causing losses in an serial flow assembly line.
Takt time	The takt time is the time that must pass between two succeeding unit completions in order to meet the demand, if the products are produced one unit at a time, at a constant rate during the net available work time.
Varian loss	A result from that different variants of a product (or different models) require different amount of work content causing balance losses.
Variants	Each model of wheel loader can be configured in many different ways, resulting in a large number of variants.
WIP	Work In Process
VPS	Volvo Production System.

2 Literature review

The purpose of this chapter is to describe areas that are important for mixed-model assembly lines. First an introduction to different assembly systems is given and especially the concept with assembly lines is elaborated. The rest of the chapter describes how standardised work, product design, planning and control, time losses, material handling and supply and finally assembly quality affects and influences a mixed-model assembly line. A gathered description about how mixed-model assembly should be handled, as the one developed in this Master´s Thesis, has not been found in literature. Consequently, the headlines in this chapter have been identified by the researches as the most important to cover all aspects of mixed-model assembly.

2.1 Assembly systems

2.1.1 Performance of assembly systems

One way to measure the performance of an assembly system is to use performance objectives described by Slack & Lewis (2008) and Slack, Chambers, & Johnston (2010), see Table 1. The performance objectives are Quality, Speed, Dependability, Flexibility and Cost and the purpose of the objectives is to articulate the market requirements in a way useful to operations. Within each performance objective a number of competitive factors are grouped together.

Table 1 Performance objectives and their measures according to Slack, Chambers, & Johnston (2010)

Performance objective	Example of performance measures
Quality	Number of defects per unit Level of customer complaints Scrap level Warranty claims Mean time between failures Customer satisfaction score
Speed	Customer query time Order lead time Frequency of delivery Actual versus theoretical throughput time Cycle time
Dependability	Percentage of orders delivered late Average lateness of orders Proportion of products in stock Mean deviation from promised arrival Schedule adherence
Flexibility	Time needed to develop new products/series Range of products/services Machine changeover time Average batch size Time to increase activity rate Average capacity/maximum capacity Time to change schedules
Cost	Minimum delivery time/average delivery time Variance against budget Utilization of resources Labour productivity Added value Efficiency Cost per operation hour

There are two important characteristics of operations performance. The first characteristic is that all measures of performance will not have the same importance for an individual operation. The second characteristic is that some aspects of performance will, to some extent, trade off against each other. An example from Slack & Lewis (2008) of the relative performance of several companies in the same industry in terms of their cost efficiency and their variety of products are showed in Figure 1. The ideal case would be that all operations offer a high variety of products and still have a very high level of cost efficiency but a high variety generally reduces an operations ability to operate efficiently. Figure 1 illustrates how different companies A, B, C, D has chosen a different balance between variety and cost efficiency. All of them are positioned differently on the "efficient frontier" and none could be said to dominate any other operation. However, company X has an inferior performance because company A has the same cost efficiency but a larger variety and company C a better cost efficiency with the same variety as X. Also, company B has the same ratio between variety and cost efficiency but is achieving them more effectively.(Slack & Lewis, 2008)

Figure 1 shows how company B has moved the efficiency frontier by improving both the variety and the cost efficiency. This improvement could be the result of for example implementing modular design resulting in better cost efficiency and potential for more variety.(Slack & Lewis, 2008)

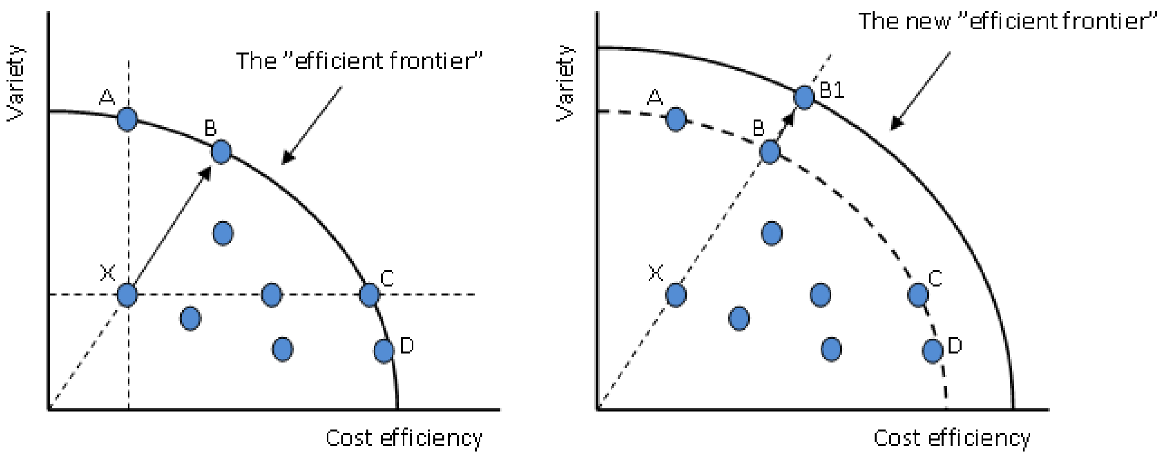


Figure 1 The efficient frontier after Slack & Lewis (2008)

One way for lean production systems to handle large variety in assembly production is to use mixed-model assembly lines. MacDuffie, Sethuraman, & Fisher (1996) tries in their paper to test if lean production plants are capable of handling higher levels of product variety with less adverse effect on manufacturing performance than traditional mass production plants. The study is based on International Motor Vehicle Program at MIT. Traditionally coping with product variety forces a manufacturing firm to face the trade-off with the increased revenue that can result from offering many models versus increased costs through the loss of scale of economies. The paper by MacDuffie et al. (1996) suggests that this trade-off point is shifted. Lean production plants are believed to have the capability to shift the trade-off point between costs and product varieties.

According to MacDuffie et al (1996) there are many ways in which variety may decrease productivity and quality in assembly plants. When both parts and options complexity increases labour productivity and quality may suffer because workers face a more complicated array of different parts to install and less predictable combination of the parts. Line balancing becomes more complicated with many models resulting in possible balance losses. Also indirect labour productivity may be affected because the tasks facing production support staff may be more complex, both within the assembly plant (scheduling machines, performing setups, parts inspection, rework etc) and also dealing with suppliers (expediting parts orders, parts delivery scheduling, coordinating negotiations and communications etc).

MacDuffie (1996) et al expects lean production organizations to be able to better handle the above-mentioned problems than traditional mass production plants. MacDuffie et al (1996) also accounts for that the product policies that Japanese auto manufacturers is using to cope or diminish product variability in their assembly plants is not so much reducing the number of platforms or options offered to the customers. It is more used to reduce the number of variations per platform and the number of parts complexity for each body style. This could be achieved by make more options standard from the beginning.

The conclusion in the paper by MacDuffie et al. (1996) confirms their hypothesis that lean plants can handle variety better. For fixed investment systems in making the plant leaner a plant has a greater potential to absorb product variety without facing the variable cost often associated with increased variability as described in Figure 1.

The term mixed-model assembly line is associated with lean production because it is used extensively by Toyota and other Japanese manufacturers.(Shtub & Dar-el, 1989) Lean production, and thereby mixed-model assembly lines, can thereby be said to be a mean for shifting the trade-off point between cost and variability.

2.1.2 Classification of assembly systems

An important characteristic of industrial manufacturing is the type of production used. On the one hand, there is the job shop production system and on the other hand there is the flow-line production system. In between these two there are a number of hybrid systems that contain properties of both. Job shop production is characterized by that machines that perform similar operations, as for example milling machines, are grouped together in workshops. In a flow-line production system the machines or stations are arranged according to the technological sequence of operations. (Scholl, 1999)

Table 2 Different assembly systems according to Wild (1975)

Assembly system	Characteristics
Mechanical line	Paced lines with fixed or removable items.
Non mechanical line	Without mechanical pacing and usually with buffer stocks between stations.
Individual assembly	Complete manufacturing by an operator in a no-flow basis.
Collective assembly	Operators work together on an item.

There are several production systems that can be suitable for assembly of products. Wild (1975) suggests the flow-line production system where there are two basic types, the mechanical and the non-mechanical line. Further he identifies two alternative systems; the individual assembly system and collective assembly system, see Table 2 for descriptions of the systems. A classification of the assembly systems presented by Wild (1975) is further developed by Shtub & Dar-el (1989). The first factor considered is division of labour, then the conveyance or material handlings system and last the type of operators used, see Figure 2.

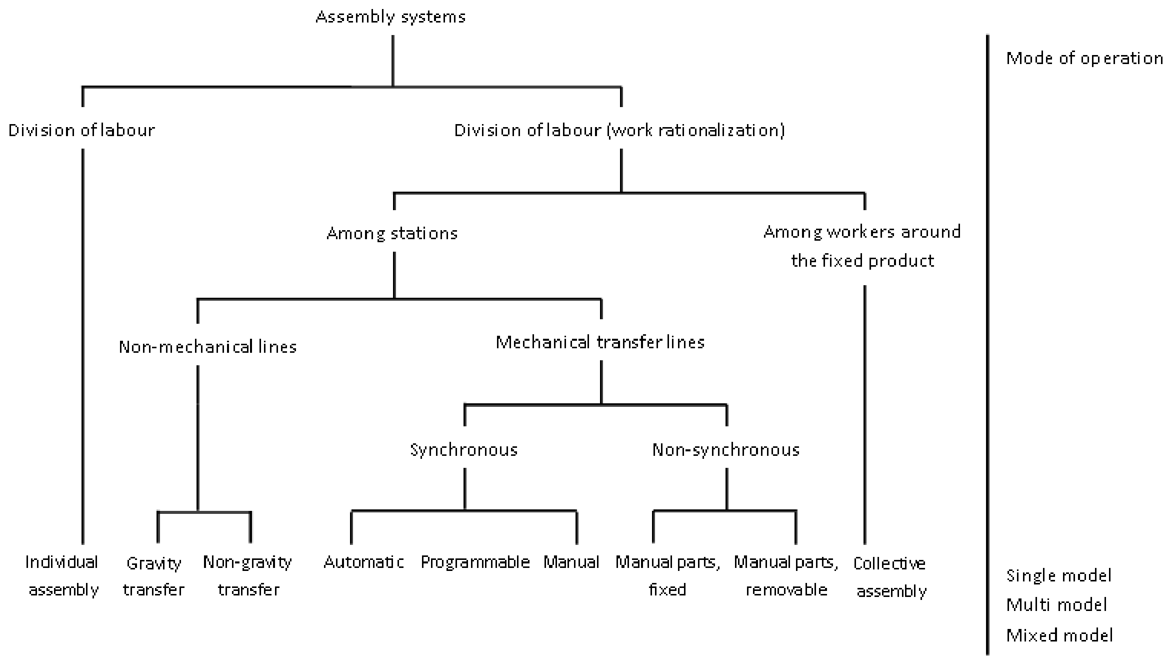


Figure 2 Map of different assembly systems after Shtub & Dar-el (1989)

According to Shtub & Dar-el (1989) there are four fundamental principles that are the basis for most assembly systems:

1. Division of labour
2. Workflow
3. Interchangeability of parts
4. Minimum distance moved

Division of labour is the oldest principle in use for many years in mass production systems. One advantage with division of labour is that untrained workers become very efficient performing the same limited task over and over.

The principle of workflow is carried out in its extreme in the process industry but is also carries out in some extent in “discrete product” manufacturing plants. In assembly plants the product moves down a predetermined route and operators (human or robots) perform the required operations on the product and as the product moves down the line it becomes more complete. The objective is often to smooth out the flow making it similar to that experienced in process industries. This objective is often stressed in modern production systems (JIT approach) inspired by Japanese auto manufacturers.

The principle of interchangeability of parts is crucial to the assembly of products with many parts. Interchangeability of parts enables assembly operations to be performed in exactly the same manner on every product assembled.

The last principle, minimum distance moved, is used by the facility planners and material handling system planners.

Derived from the four principles Shtun & Dar-el (1989) classifies assembly systems into two natural subsystems – the material handling subsystem and the operating subsystem. These two subsystems are coordinated by the manufacturing planning and control subsystem. The material handling subsystem is designed according to principles of work flow and minimum distance moved while the operating system is designed according to principles of division of labour and interchangeability of parts.

According to Shtub & Dar-el (1989) there are three main methods for assembly systems in the auto industry based on some mix of the four fundamental principles for assembly systems. The first method is *the collective assembly* used at for example Volvo in Uddevalla which is based on a parallel system layout. The next type is the *mixed model assembly lines* used by Toyota in Japan. The next type of system is the traditional *single model assembly line* dedicated for each model. According to Scholl (1999) there is also the *multi-model method* with setup between batches.

2.1.3 Assembly system concepts

The following basic concepts within assembly systems are important for the understanding of the following chapters in this thesis.

Operation

The sum of all operations in an assembly system adds up to the total work content in an assembly process. An operation is sometimes called a work task. The time it takes to perform an operation is called operation time. An operation cannot be divided into smaller work elements without creating additional work. Scholl (1999) divides operation times into three different categories; deterministic, stochastic, and dynamic. Most assembly line planning and control models are based on fixed deterministic operation times. Deterministic operation times are justified when the expected task time variability is sufficiently small. The deterministic operation times may be modified by adding a stochastic time component that takes the probability of machine breakdown and the duration of repair process into consideration. Systematic reductions of the operation time are possible due to learning effects or successive improvements of the production process. These dynamic operation times are common when a new assembly line system is installed. (Scholl, 1999)

Station

A station is a segment of an assembly system where a number of operations are performed. The work at a station can be either manual or automated. The work performed at a station is called station load. (Scholl, 1999)

Cycle time

The cycle time is the sum of the operation times within each individual station. (Scholl, 1999)

Takt time

The takt time is the net available production time divided by the demand and thus how long between successive products must be produced. An important note is that the takt time always is based on the demand.

According to Baudin (2002) all deviations from the takt time create waste. The time difference between the takt time and the cycle time is called idle time. The sum of idle times for all stations on an assembly line is called balance delay time or balance loss. (Baudin M. , 2002)The planned cycle time can be different from the takt time and is often smaller.

Modular assembly

Modular assembly means having suppliers put together major subsystems of the product and thereby cutting down the amount of work in final assembly of the plant. (Baudin, 2002) Modular assembly is not to be confused with subassembly that is performed in the plant.

Assembly sequence

The sequence in which parts can be assembled is based on the product architecture. Some parts must be assembled before others. A precedence graph is often used to show what tasks that have to be completed before a specific task can start. (Scholl, 1999)

2.1.4 Deciding the method for assembly

In order to explain the four methods for assembly systems that are presented in chapter 2.1.2 one must understand the concept of takt time and how to decide the minimum number of assemblers in the assembly system. When those two factors are decided the method for the assembly system can be evaluated.

The takt time is the time that must pass between two succeeding unit completions in order to meet the demand, if the products are produced one unit at a time, at a constant rate during the net available work time. The value of the takt time drives the key design choices for the assembly system. (Baudin, 2002) The takt time is defined in equation (1).

$$Takt\ time = \frac{Net\ available\ production\ time}{Demand} \tag{1}$$

When the takt time is known one could decide how many assemblers and stations that are needed.

It is quite hard to determine the number of assemblers needed in order to complete a product but here one basic method is presented. After the number of assemblers has been decided the number and layout of processes can be decided. The minimum number of assemblers can be calculated with equation 2 (Baudin, 2002).

$$Minimum\ number\ of\ assemblers = \frac{Total\ assembly\ time}{Takt\ time} \tag{2}$$

If for example a product takes 100 minutes to assemble and the takt time is 1 minute, the process needs 100 assembler minutes every minute, consequently 100 assemblers. The formula does not take into consideration other activities that the operators perform apart from assembling such as picking and handling. A production system is also dependant on support labour which will of course increase the number of assemblers needed. (Baudin M. , 2002)

When one has determined that the process is in need of 100 assemblers, the next step is to decide in which way the work should be allocated between the assemblers and thereby which method of assembly that should be used. On the one hand, one operator could work with one product from start to finish for 100 minutes. On the other hand, the total work content could be divided into 100 operations each taking 1 minute to perform. In between these two extremes any structure is possible of which one is exemplified in Figure 3. (Baudin M. , 2002)The structure that is chosen decides which method of assembly that is used. Collective assembly is used when working in parallel in Figure 3 and the assembly line methods are when working in serial in the figure. Still, 100 assemblers are needed.

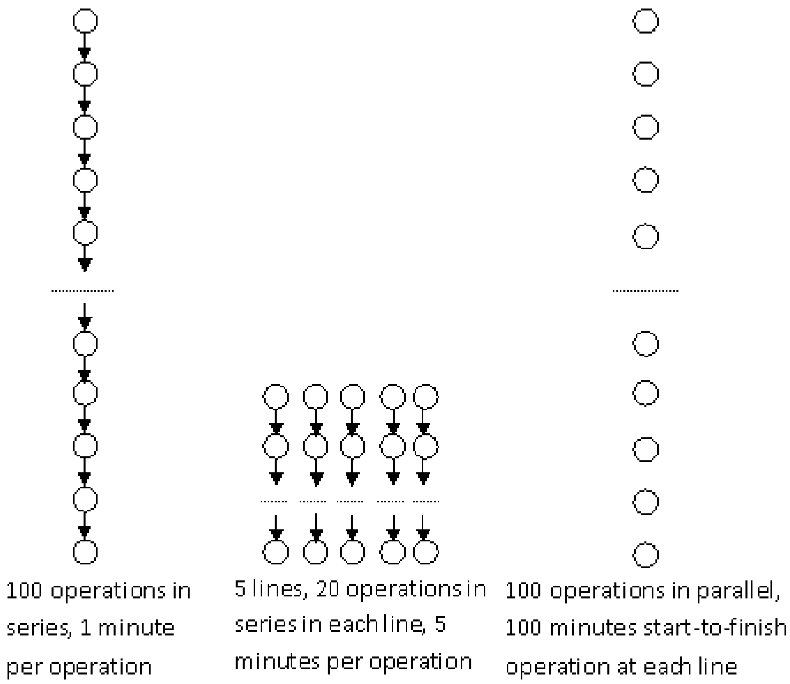


Figure 3 Possible breakdowns for a 100-minute assembly process after Baudin (2002)

2.1.5 Collective assembly

A collective assembly system is characterised by parallel stations with long cycle times, see Figure 4. In the most extreme case a model is assembled in only one station. In other cases the same team of assemblers assembles the product from start to finish on a number of stations. (Ellegård, Engström, Johansson, Nilsson, & Medbo, 1992)

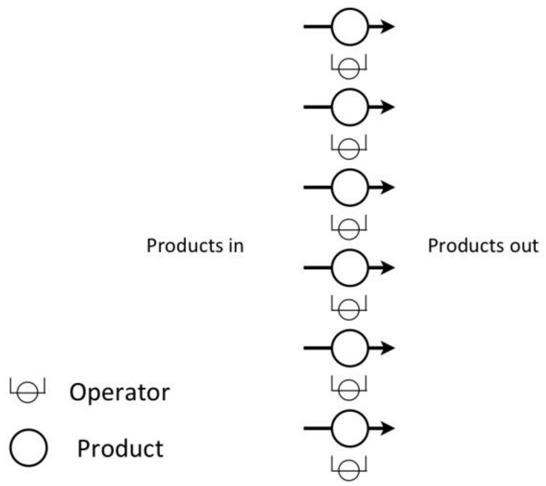


Figure 4 Parallel flow assembly

2.1.6 Assembly lines

Assembly lines include single-model assembly lines, mixed-model assembly lines and and multi model assembly lines. There are different layouts of the different assembly lines and different assembly lines may be operated differently.

Layout of assembly lines

The traditional layout of an assembly system is the serial line where stations are arranged in a straight line along a conveyor belt. Serial lines have disadvantages such as low flexibility, low-motivated operators, quality problems and large inventories. (Scholl, 1999) A serial flow assembly line is presented in Figure 5.

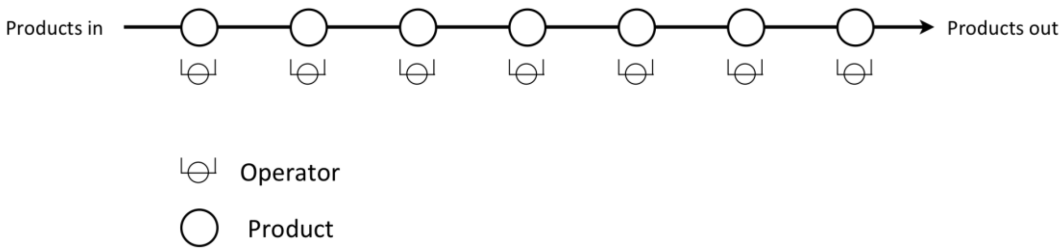


Figure 5 Serial flow assembly line

According to Becker & Scholl (2006) the disadvantages with straight serial lines may be overcome by a U-shaped assembly line. Both ends of the line are closely together forming a rather narrow "U". The stations can be arranged so that two work pieces can be handled at different positions during the same cycle. In Station 1 in Figure 6, the first tasks on one work piece and the last tasks on another work piece are performed. Stations 1 and 5 in Figure 6 are called crossover stations because they can handle the same work piece in two different cycles. U-shaped assembly lines have advantages such as job enrichment and enlargement strategies, and they might result in a better balance of station loads due to the larger number of task-station combinations.(Becker & Scholl, 2006) U-shaped lines also lead to higher quality and increased flexibility.(Scholl, 1999)

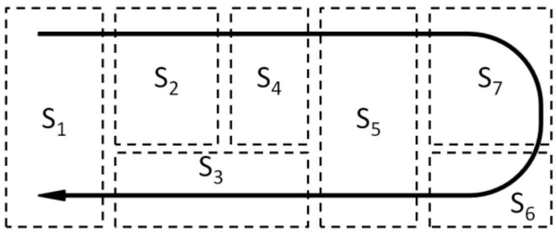


Figure 6 U-shaped assembly line after Becker & Scholl (2006)

Several parallel lines for manufacturing one or several products may lead to increased flexibility and decreased failure sensitivity of a system. Parallel lines give the management the chance to react to demand changes, due to that the number of lines can be changed, and the risk of machine breakdowns is lowered. Parallel lines also allow the enlargement of cycle times which has one advantage such as horizontal job enlargement. A strategic problem related to parallel lines is to decide how many lines to install because additional lines lead to increased capital investments. (Scholl, 1999)

If some operations have longer cycle times than the desired takt time, parallel stations can be introduced to lower the takt time of the system. The simplest form of paralleling is when a station is duplicated. Two stations provided with the same equipment perform the same tasks. Duplicated stations have a local cycle time of twice the regular cycle time and are fed with work pieces that they release alternately. An example of a line with parallel stations is shown in Figure 7. (Becker & Scholl, 2006)

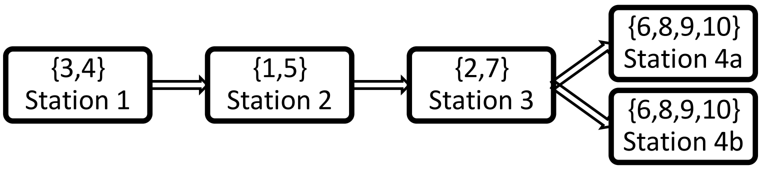


Figure 7 Parallel stations after Becker & Scholl (2006)

Different supplementary units and feeder lines are often used to produce sub-assemblies to the final assembly lines. The supplementary units may be organized as job shops, flexible manufacturing cells, or feeder lines. It is important to synchronize the different production processes when using supplementary units. (Scholl, 1999)

Single-model line

Assembly lines where only one type of product or model is manufactured are called single assembly lines. Single-model assembly lines are seen Figure 8. (Scholl, 1999)

Multi-model line

An assembly line where different products are manufactured in batches is called a multi-model line. Multi-model lines are often used when there are significant differences in the production process between the products. This leads to that rearrangement of the line equipment is required. Multi-model assembly lines are also visualized in Figure 8. (Becker & Scholl, 2006)

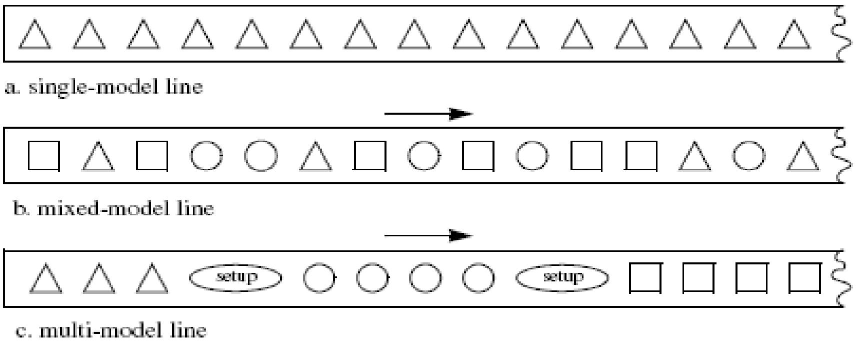


Figure 8 Assembly lines for single and multiple products after Becker & Scholl (2006)

Mixed-model line

Assembly lines where more than one product or model is manufactured are called mixed-model assembly lines, see Figure 9. The models at a mixed-model assembly line may differ from each other with respect to size, colour, used material or equipment such that their production requires different tasks, task times and/or precedence relations. In mixed-model assembly line, the setup time is zero between models, and successive units coming down the line can be for different products or models.(Baudin M. , 2004)

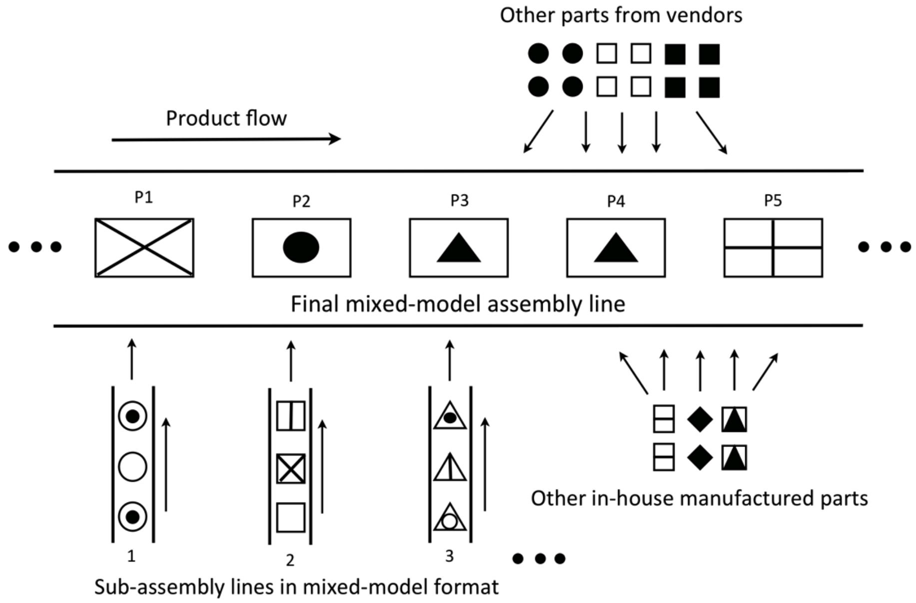


Figure 9 Schematic image of a mixed-model line after Aigobedo and Monden (1997)

Traditional mass production systems were based on assembly lines dedicated for one product or model that were produced in large quantities as seen in the single model case. These systems were based on high productivity through the principles of economics of scale and division of labour among the stations. (Zhu, Jack Hu, Koren, & Marin, 2008) A typical example of such a system is the original Ford Model T assembly system.

Zhu et al. (2008) mention that in today's marketplace the customers demand high product variety and short lead times. Mass customization has today been recognized as a new paradigm for manufacturing for individualized products at mass production cost. As a result of this paradigm shift assembly systems must be designed to be responsive to customer needs while at the same time accomplish mass production quality and productivity. (Zhu et al., 2008)

According to MacDuffie, Sethuraman, & Fisher (1996) companies can no longer follow the principles created by Henry Ford to capture market share and high profits by producing large volumes of standardised products. In today's marketplace customers needs and wants changes rapidly. Companies that understand these new circumstances and respond to them quickly, with appropriate products, can gain a significant competitive advantage.(MacDuffie, Sethuraman, & Fisher, 1996)

The use of mixed-model assembly lines to handle increased product variety has according to Zhu et al. (2008) increased. Today various industries are using mixed-model assembly lines and the variety of products assembled in these lines has increased. Often the assembly lines are exposed to an enormous number of build combinations and this leads to difficulties in the design and operation of the assembly systems. As an example in the automotive industry BMW claims, "That every vehicle that rolls of the belt is unique and the number of possible automobile variations in the BMW 7 Series alone could reach 10^{17}". (Zhu et al., 2008)

Mixed-model assembly has, according to Rekiek, Pierre, & Alain (2000), become important because of diversity. Other goals such as low costs, high productivity and standardization are in contradiction with diversity and therefore the success of a company depends on its ability to deal with complex products and process designs. The use of methods such as design for manufacturing and design for assembly have resulted in significant improvements such as; product simplification, improved quality, reduced time to market, and lower assembly and manufacturing costs.

Mixed-model lines have, as mentioned before, gained wide acceptance in Just-In-Time (JIT) systems as well as in conventional systems.(Aigbedo & Monden, 1997) The mixed-model assembly lines are used in industries to keep several models in production rather than to produce batches of models and keep in inventory.(Thomopolous, 1967)

According to Johansson (1989) the occurrence of variants in a mixed-model assembly line causes a number of problems. According to Johansson (1989) these problems can be derived from two main effects. The fist is the time expanding effect of variants. Different models require different assembly times. The second effect is the increased number of components required to be able to assemble all products on the same line, which causes problems both in the assembly area and in the materials handling function.

Paced- and un-paced assembly lines

In paced lines mechanical material handling equipment, for example conveyor belts, links the stations in an inflexible manner. The work pieces are either moved from station to station by the conveyor belt at constant speed, or moved irregularly after being processed. The stations have in both cases the same amount of time to perform the assigned tasks on the work pieces. (Scholl, 1999)

Un-paced lines have buffers that hold work pieces between stations. Blockage occurs when a subsequent buffer is full on the line and the work piece from the preceding station cannot enter the buffer. The station is then idle until the subsequent buffer is empty. Starvation is another inefficiency that occurs when the input buffer of a station is empty after terminating the current job. The reason for starvation may be lower production rate or breakdown of the preceding station. Small buffers make the system vulnerable to breakdowns whilst large buffers decouple the stations almost completely. Dimensioning the buffers is important because of the trade-off between down-time costs and inventory related costs. The station times in a mixed-model assembly line often vary with the models. Consequently, a mixed-model assembly line is most often un-paced even in the case of a steadily moving conveyor belt. If the station lengths are larger than the length of the work piece the conveyor belt itself serves as a buffer. A work piece may leave a buffer in another order it entered the buffer, hence buffers allow re-sequencing of work pieces. This may be an effective way to reduce sequence dependant inefficiencies in a mixed-model environment. A buffer also allows on-line repair of defect parts without stopping the line. (Scholl, 1999)

Launching discipline for assembly lines

The efficiency of a assembly line system is influenced by the intervals at which work pieces are launched down the line. Scholl (1999) describes two main launching strategies: fixed rate launching and variable rate launching.

- *Fixed rate launching* - When using fixed rate launching, consecutive units are started down the line in regular intervals. The interval is equal to the cycle time in paced systems. The distances between the consecutive work pieces are the same along the line. (Scholl, 1999)
- *Variable rate launching* - In variable rate launching, the next unit is launched after the first station has finished work on the current one. Variable rate launching is more flexible than fixed rate launching and the strategy avoids starving of the first station. The distances between consecutive work pieces are different along the line. Stocking may occur in consecutive stations if work pieces with low workloads follow a heavy workload work piece in the first station. Consequently, if the workload of the work piece in the first station is heavy it may lead to idle times in later stations. The launching intervals should be based on bottleneck stations to make sure that they are utilized as much as possible because they are most critical with respect to unused capacity. (Scholl, 1999)

Open and closed stations

In closed stations at assembly lines the operators cannot cross the station boundaries. Closed stations are a necessity if the proceeding station is for example a paint shop or a heating chamber. The openness of an open station is often restricted by the range of the power tools and the material handling system. Operators are often not allowed to cross station boundaries and work simultaneously on a work piece even if the station is open. (Scholl, 1999)

2.1.7 Advantages and disadvantages of serial assembly lines

One-piece flow assembly systems are the closest approximation of takt-driven production. According to Baudin (2002) the closer a production can come to a takt-driven production the more will the cost, delivery and quality performance objectives improve. According to Baudin (2002) this is the common basis to lean assembly concepts. (Baudin, 2002)

Table 3 and Table 4 list advantages and disadvantages with serial assembly lines and in some cases compared to collective assembly. A schematic representation of serial flow assembly line is previously presented in Figure 5 and parallel flow collective assembly in Figure 4.

Advantages with serial flow assembly lines

Table 3 Advantages with serial flow assembly lines

Advantage	Description
Easy to follow takt time	It is possible to ensure that finished product units come out exactly according to takt time. (Baudin, 2002)
Assembly skills and division of labour	Each operator only needs to learn the work content of the cycle time or his station. Only less skilled operators that can be trained more quickly are needed. In collective assembly workers need to learn the complete assembly from start to finish resulting in learning problems.(Baudin, 2002) (Scholl, 1999)
Few resources needed	In an assembly line each station only needs tools and fixtures needed for the cycle time at that station. In collective assembly each station needs all tools and fixtures. (Baudin, 2002)
Setups are permanent	Each station is permanently setup in an assembly line. Collective assembly often requires multiple setups. (Baudin, 2002)
Simple logistics	In an assembly line each component only needs to be delivered to one place. In a parallel flow each component must be delivered to all stations. (Baudin, 2002)
Quality	In an assembly line operator's only need to perform tasks at their stations making it easier to guarantee consistency in quality. In collective assembly a greater number of operators need to perform the same tasks. (Baudin, 2002)
Low inventories	In process inventories are kept very low. (Scholl, 1999)
Control	The flow of material is regular and can easily be controlled. (Scholl, 1999)
Little manual material handling	Only little manual material handling is needed, because work pieces are transferred by mechanical handling equipment like conveyor belts. (Scholl, 1999)
Floor space	The requirement of total floor space is small, because less space is needed for storage and material movement. (Scholl, 1999)

Disadvantages with serial flow assembly lines

Table 4 Disadvantages with serial flow assembly lines

Disadvantage	Description
Poor job satisfaction	In collective assembly the operators feel accomplishment from assembling a complete product from scratch compared to alienation and boredom at the assembly line work with short cycle times and monotonous job content. Longer cycle times results in a greater job enlargement. (Baudin, 2002) (Engström, Jonsson, & Medbo, 2005)
Time losses	Serial flow assembly lines suffer from an inability to absorb time losses. Time losses are system losses, difference in assembly times between models called variant losses, balance losses and handling time losses. According to Engström et al. (2005) parallel systems are capable of handle these variations. A conclusion that can be drawn from this is that the capacity utilization is lower in serial flow assembly lines.
Floor space	Regarding need for floor space a disadvantage with serial flow lines is that they require more than parallel systems. (Engström et al. 2005) This is in contrast to Scholl (1999) who mentions less floor space as an advantage with assembly lines.
Low flexibility	Serial flow lines have a low flexibility with regard to production volume, product mix, product changes and introduction of new products. (Engström et al., 2005) Low flexibility is a result from the high specialization of assembly lines. (Scholl, 1999)
High capital requirements	The installation of assembly lines causes high capital requirements. (Scholl, 1999)
Maintenance and repairs	Maintenance and repairs are critical issues due to that machine breakdown may stop the complete system. (Scholl, 1999)

2.1.8 Issues with long and short cycle times

According to Baudin (2002) the value of the takt time drives key design choices for the assembly system. Typical takt times by industry are presented in Table 5. According to lean production literature producing to takt time at each station is the ideal and therefore drives the design choice for the system. (Baudin, 2002)

As a note, it is often the case that the cycle time at each station in an assembly line is different from the actual takt time. The assembly system can for example be designed with two parallel assembly lines resulting in twice the cycle time at each station compared to the takt time. Another way to increase the cycle time is to increase the takt time by increasing the net available production time. The opposite can be used to reduce the takt and cycle time. Different authors mention different incentives for having either long or short cycle times.

Table 5 Typical takt times for different industries. After Baudin (2002)

Takt time	Industry
0,02 seconds	Cigarettes
≈ 1 second	Detergents
≈ 5 seconds	Printer cartridges
10 to 30 seconds	Automobile parts
1 to 5 minutes	Cars
5 to 10 minutes	Large motorcycles
1 day	High volume narrowbody airliner
1 week	Large ships

According to Jürgens (1997) the length of the individual cycle time at each station is one of the major planning parameters and factors affecting the quality of work on the assembly line. With longer cycle times, and therefore longer work tasks, the number of operations increases and also the variety of job content increases. This leads to job enlargement, which has been a necessary prerequisite for job enrichment according to literature regarding quality of work and humanization. (Jürgens, 1997)

At assembly lines with long takt times the jobs are often called long cycle jobs. According to Baudin (2002) takt times of ten minutes or more challenges the operators and causes problems and Duggan (2002) discusses a takt time of 5 min or more as challenging. When performing a long sequence of tasks, assemblers run the risk of forgetting where they are and accidently skipping steps. Consistency and cycle time is therefore more difficult to assure with long cycle jobs than with short cycle jobs. (Baudin, 2002) (Duggan, 2002) According to Duggan (2002) standard work becomes critical to handle the increased variability if takt time exceeds 5 min.

According to Baudin (2002) it is impossible to design manual assembly jobs that take less than one second to complete. Systems producing at this takt are often fully automatic. According to Baudin (2002) manual assembly lines running at a takt time of 30 seconds or more can retain permanent employees, meaning that the employee turnover is acceptable. There are factories with manual assembly lines running at a takt time of 10-15 seconds but this high pace stretches the limit of human endurance. Repetitive stress injuries are often common at this lines but a takt of 10 to 15 seconds pace is still not high enough for automation to be an obvious solution. (Baudin, 2002)

According to Jürgens (1997) today's development towards short cycle times can be seen as a part of the adaption to the lean production trend. With the introduction of JIT concepts as well as total quality principles, short cycle times is excepted to help better monitor quality problems from upstream deliveries and suppliers. Long cycle jobs is seen as to provide the opportunity for the individual to solve problems and correct faulty parts instead of the stricter time of short work cycles that would reveal such problems and force management to correct the root problems. Job enrichment in such a system is questioned but is believed to be fulfilled if other compensatory mechanism exists that don't involve enlargement of the cycle time. Such mechanism could be involvement in problem solving and off-line responsibilities. (Jürgens, 1997)

2.2 Standardised work

Almost all employees regardless of industry or job position believe that every work task is unique and that they have their own best way of performing it. People often are of the opinion that standards will set them back. In the manufacturing industry there have historically been a resistance against standards due to tradition of managers monitoring operators and performing time studies to be able to squeeze out every extra bit of productivity of the operators. This created a situation where the operators deliberately worked slower to avoid inhuman standards. This situation has throughout the years been a major source of conflict between management and workers. (Liker, 2004)

Standardised work is often described as connected to or the foundation for continuous improvements or "kaizen". (Liker & Meier, 2006) (Martin & Bell, 2011) But in the context of mixed model assembly using standardised work is important to be able to cope with the variations in assembly time between different operators (Duggan, 2002). Standardised work helps stabilize the process in order to be able to in small steps improve without the risks associated with large and complex changes (Martin & Bell, 2011).

Standardised work is described by Duggan (2002) as:

"any operator following a prescribed method, with a proper workstation and proper tools, should be able to perform the amount of work required in the same amount of time, with perfect quality, without risk to health or safety."

There are some prerequisites for standardised work. (Liker & Meier, 2006) and (Martin & Bell, 2011) states that:

1. The work has to be repeatable.
2. Line equipment, tools and workplace must be reliable.
3. Quality issues must be minimal.

Furthermore (Martin & Bell, 2011) also adds

4. It must be a work that a human can perform safely and ergonomically with desired quality and within available time.

If prerequisites are fulfilled the next step is to discuss the required components for standardised work as described by (Martin & Bell, 2011):

1. Cycle (takt) time.
2. Work sequence.
3. Standard inventory or in-process stock.

Standardizing work with the consideration of the above mentioned components is a challenge in most manufacturing companies. Duggan (2002) states that "If each operator can follow the same method, the time to perform the work will become more consistent." In a mixed model environment with long takt times Duggan (2002) mentions that it is difficult to create standardised work but it has to be done to combat variability. The person writing a standard that other people are supposed to understand and work after must be convinced of its importance according to Liker (2004). Liker (2004) goes on saying that standards should be written by the people performing the work to avoid a situation where the managers do the thinking and the workers are supposed to blindly execute them. The worker should be seen as the most valuable resource instead of a pair of hands taking orders.

Standardised work should not be forced on the workforce but instead it should be the basis for empowering workers and innovation in the work place.

Working with 5S, to achieve an optimal work environment, is often seen as prerequisite to be able to develop good standards at a workplace. (Liker, 2004)

2.3 Product design

2.3.1 Product architecture

Ulrich & Eppinger (2004) defines the physical elements of a product as the parts, components, and subassemblies that perform the product's functions. The physical elements can be grouped into physical building blocks. The architecture of a product describes what functions the different building blocks have and how they interact. (Ulrich & Eppinger, 2004)

Ulrich & Eppinger (2004) describes modular architecture where physical elements with different functions are allocated to separate building blocks. The architecture is strictly modular when a building block consists of only one or a few functional elements and when their interactions are well-defined. This approach allows design changes to one building block without the need to change another one for the product to work properly. This also means that they can be designed quite independently from each other. (Ulrich & Eppinger, 2004)

Ulrich & Eppinger (2004) describes integral architecture as when a functional element is divided and implemented in more than one building block, and when a single block contains more than one functional element. The interactions between blocks in an integral architecture are therefore more complex. Consequently, a design change to one component in the product can lead to extensive redesign of the entire product. (Ulrich & Eppinger, 2004) This is also mentioned by Blackenfelt (2001) in terms of that the complexity could be reduced with an increased level of modularity.

Ulrich & Eppinger (2004) mentions that products are seldom strictly modular or integral, a product can instead consist of more or less modularity.

The decision about the level of modularity to impose on the architecture influences several important issues of an enterprise, such as: product change, product variety, component standardization, product performance, manufacturability, and product development management. (Blackenfelt, 2001; Ulrich & Eppinger, 2004)

Product architecture is important when it comes to the range of product models that a company can produce. A modular approach allows the company to produce more models because the products can be changed without adding too much complexity to the manufacturing system. (Ulrich & Eppinger, 2004)

However, Blackenfelt (2001) and Johansson (1989) mentions that companies tend to increase the variety of components to an unnecessary level when they introduce new models. Blackenfelt (2001) states that this could be due that the cost of adding more components to the production is not emphasized enough in the design phase. Johansson (1989) states that minimizing the number of components is one of the most important factors for the assembly times when designing manual assembly.

Blackenfelt (2001) and Sivard (2001) mentions that there is a big challenge for companies to offer a big variety of models without adding to much extra parts. One approach when designing products is to vary parts between products where the customer experience the difference, and to try to keep the remaining parts common within the product family. (Blackenfelt, 2001; Sivard, 2001) Baudin (2002) describes that companies seldom use software that can search for existing parts closest to their requirements and reuse them when designing new products. That is according to Baudin (2002) one reason why it is hard to achieve a high level of common parts between products.

According to Rekiek, Pierre, & Alain (2000) and Duggan (2002), for a mixed-model assembly line to be possible, the variants produced on the line must have some similarity. It is difficult for the workstations to cope with the differences if the models are significantly different. Baudin (2002) mentions that to compare the products´ similarity in complexity and parts analytical tools can be applied to the products' bills of materials. Duggan (2002) states that, as a guideline, if products are to be produced on the same line the difference in total work content between products should not be more than 30 per cent.

The complexity of deciding a common assembly sequence increases when several products or models are to be produced on the same line. Swaminathan and Nitsch (2007) argues that the design cost may increase when one are trying to achieve a common assembly sequence because some components may need to be redesigned. However, Swaminathan and Nitsch (2007) and Johansson (1989) mentions that investments at the design stage could lead to savings at the manufacturing stage.

Using standard components or modules in several models can lead to benefits in economics of scale because the company can produce larger volumes of the components or modules, or they can buy larger volumes externally.(Ulrich & Eppinger, 2004) Sivard (2001) mentions cost benefits related to mass production of standard components or modules, and that the diversity of products in this case is achieved by varying the standard components or modules.

According to Johansson (1989) there are some research regarding the connection between product structure and production costs. The research in this field is characterized by a mathematical approach with the focus on storage costs and not so much on how the product structure affects the ease of assembly. The focus could be to deal with commonality between components used in different product lines and the degree of standardization of parts.

Systems for evaluating ease of assembly of a product like design for assembly (DFA) methods often focus on the characteristics of single components. It does not focus as much on the relations between different components on the product structure, consequently the total variety in the assembly systems. (Johansson, 1989)

2.3.2 Product-quantity analysis tool

Product-quantity (P-Q) analysis is a tool used to group products in volume categories to serve as a basis for laying out the production floor. In mixed flow assembly the analysis extends into the bills of materials to classify parts and components by the consumption volume and product commonality. (Baudin M. , 2002)

Concept description

The P-Q analysis breaks down the product mix in three categories. Typically it can be found that a few products are high volume, so called "A" products, and account for more than 70 per cent of total volume. Each one of these deserves a dedicated line. The "B" products often account for 25 per cent of total volume and do not by themselves deserve dedicated lines but can be grouped together into product families that deserve dedicated lines. The majority of the items are "C" products and can made on request using generic resources, they typically account for 5 per cent of the volume. (Baudin M. , 2002)

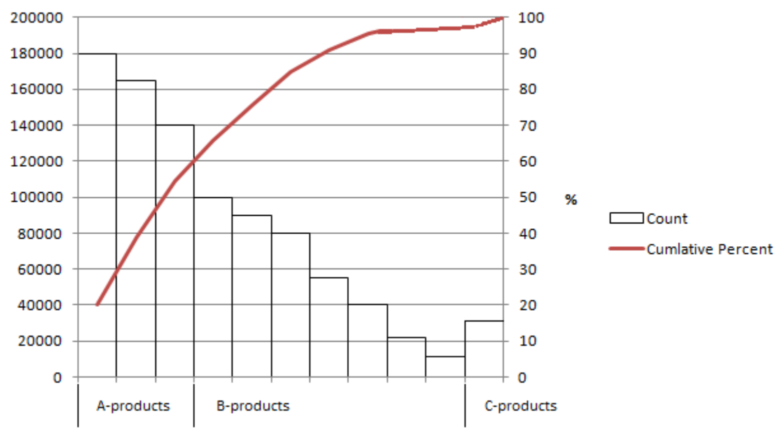


Figure 10 Example of P-Q Analysis Pareto diagram after Baudin (2002)

A Pareto diagram of volume by product is used to yield an ABC categorization of products, see Figure 10. It is often based on three to six months´ worth of data from the company´s computer system. Often multiple charts are drawn categorizing products in terms of sales or units assembled instead of volume and this may result in different categorizations.(Baudin M. , 2002)

Bill of material analysis for mixed model lines

The analysis necessary for a mixed-flow involves aggregating data about several products using the Bill of material database in the ERP system. The information in the bill of materials for different products in a mixed-flow line can be used to, for example, identify large differences in parts between different products or to quantify part commonality among products.(Baudin M. , 2002)

The results of the analysis often performed with tools such as Access and Excel is tables showing items counts by category or part counts by product for a product family. Matrixes can then be created to generate daily consumptions for all parts and number of items common to pairs of products as well as commonality ratios for a family of products. (Baudin M. , 2002)

2.4 Planning and control

2.4.1 Manufacturing planning and control

Important parts of the manufacturing planning and control system are the Master Production Schedule (MPS) and the Material Requirements Planning (MRP). The master production schedule (MPS) is the disaggregated version of the sales and operations plan (S&OP) at product family level. That is, it states which end items or product options manufacturing will build in the future. The sales and operations plan in turn balances the sales/marketing plans with available production resources. (Vollmann, William, Whybark, & Jacobs, 2005)

The MPS must be disaggregated into detailed material planning. Firms often produce a wide variety of products with many parts per product. For those firms, detailed material planning can involve calculating requirements for thousands of parts and components, using a formal logic called material requirements planning (MRP). MRP determines (explodes) the period-by-period (time-phased) plans for all component parts and raw materials required to produce all the products in the MPS. Important information is obtained from the bill of materials (BOMs) of the products as input to the MRP logic. The material plan can thereafter be utilized in the detailed capacity planning systems to compute labour or machine cell capacity required to manufacture all the component parts. The MRP information is also used for detailed scheduling of the shop floor as well as detailed information to suppliers. (Vollmann et al, 2005)

The manufacturing planning and control system is often part of a computer software system called enterprise resource planning (ERP) used as a business information integration system for the company. (Vollmann et al, 2005)

Planning and control of the production can be divided into short term, medium term and long term horizons: (Vollmann et al, 2005)

- *Long term* - The manufacturing planning and control system is responsible for providing information to make decisions on the appropriate amount of capacity (including equipment, buildings, suppliers, and so forth) to meet the market demand of the future. (Vollmann et al, 2005)
- *Medium term* - The most issues addressed by the planning system is matching supply and demand in terms of both volume and product mix. Although this is also true in the longer term, in the medium term, the focus is more on providing the exact material and production capacity needed to meet customer needs. Medium term planning involves planning level of number of employees, raw material inventor and work in process inventories, finished goods inventories and excepted delivery times. (Vollmann et al, 2005)
- *Short term* - Detailed scheduling of resources is required to meet production requirements. Details are decided for time, people, material, equipment, and facilities (Vollmann et al, 2005). This involves sequencing, machine loads, work schedules and order quantities.

In a lean plant, the flow of orders needs to be combined with forecasts and filtered into a demand to support levelled sequencing and pull systems, which means that the aggregated production plans must also be levelled. Toyota generates a MPS that is subject to alterations based on dealer orders up to four days before roll-off from the assembly line. Levelled sequences for the assembly lines are calculated two days later. (Baudin, 2004)

2.4.2 Levelled and smoothed production plan

Liker (2004) describes that Toyota categorize different kinds of waste under three headlines, the three M's. The first and most common one is muda which means non-value-added. Muda includes all wasteful activities that, for example, lengthens lead times, causes extra movements and causes extra inventories. The second M is muri which means overburdening people or equipment. If machines or people work beyond natural limits it will cause breakdowns and quality issues. The third M is mura which means unevenness. (Liker, 2004)

An uneven production means that machines and personnel in periods have too much to do and in other periods have too little to do. A company with an uneven production need to have the personnel, equipment and material for the highest level of production available even if the average need is much lower. (Liker, 2004)

Liker (2004) argues that a company that tries to work after a strict build-to-order model will have a hard time to become lean. They will instead end up with piles of inventory, hidden problems, and quality issues. (Liker, 2004)

Heijunka means levelling out the production by both volume and product mix and it is one of Toyota's lean principles. Many companies try to eliminate muda to become a lean company. Liker (2004) argues that this approach is a mistake because muda works as a system together with the other two M's. Liker (2004, p. 115) states that: "Achieving heijunka is fundamental to eliminating mura, which is fundamental to eliminating muri and muda".

Liker (2004) mentions that Toyota in the beginning tried to produce cars in a true one-piece flow based on the sequence of actual customer demand. However they realized that it created an uneven production. They instead looked at the actual customer demand for a longer time period and determined a pattern based on volume and mix. They then produced after the levelled schedule every day. (Liker, 2004) Ohno (1978) mentions that Toyota developed Heijunka to be able to establish a production flow and to be able to maintain a constant supply of raw materials from suppliers.

One argument against levelled production is that a company cannot achieve economies of scale if there are long setup times between models on a line. One approach to this could be to produce products in batches. Toyota has, however, created methods that dramatically reduce setup times. (Liker, 2004)

Huttmeir, de Treville, van Ackere, Monnier & Prenninger (2009) mention that it becomes harder to achieve heijunka as product variety increases. They also mention that some companies may have problems maintaining heijunka because of variation in demand. They go on describing examples of where heijunka only was suitable in environments with a relative stable and predictable demand.

Even though levelled production is useful in any production environment it is especially an effective tool for industries with low-mix/low-volume production systems, according to Koide & Iwata (2007).

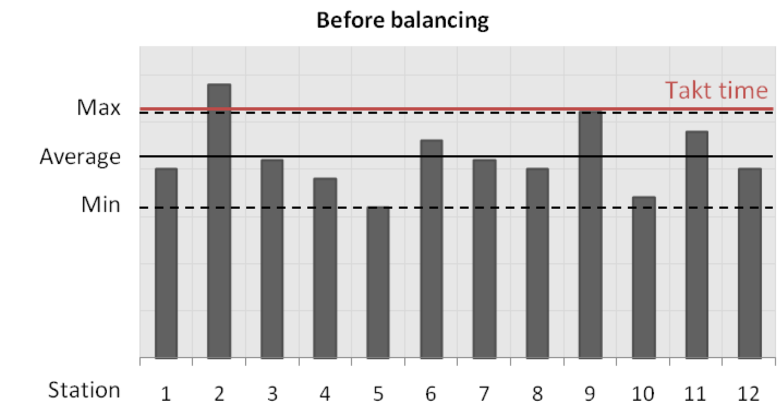
One of the most important incentives with a levelled schedule is, according to Liker (2004), to smoothen demand on upstream processes and the plant's suppliers. This will reduce the famous bullwhip effect backward through the supply chain.

Baudin (2004) describes, in contrast to Liker (2004), levelling also with respect to the different planning horizons and level of detailed information. Baudin (2004) describes sales and operations planning (S&OP) that results in aggregate plans at the product family level. In the more detailed master production schedule (MPS), the demand is levelled into a mix of products that should be produced each day; the MPS can be changed up to four days before production start. The levelled sequences, where the exact sequence of products that is to be produced per shift or day is determined, are calculated two days later.

Levelling of production is a term used in a wide time horizon to eliminate the three M's. In order to realise levelled production one must consider the sequencing of models to the assembly line as well as levelled production in the wider time horizon. The aggregated production plan must also be levelled in order for the sequence of models to the line to be levelled. Sequencing of models to the line is further discussed in chapter 2.4.5.

2.4.3 Mixed-model assembly line balancing

The main objective when it comes to the balancing of an assembly line is, according to Scholl (1999) and Rekiek, Pierre, & Alain (2000), the distribution of tasks among the workstations to equalize the workload along the line. Scholl (1999), Duggan (2002) and Baudin (2002) mean that it is more complex to balance a mixed-model line than a single-model line due to the difference in work content between models. The distributions of work tasks between different models are shown in the single-model case in Figure 11 and in the mixed-model case in Figure 12.



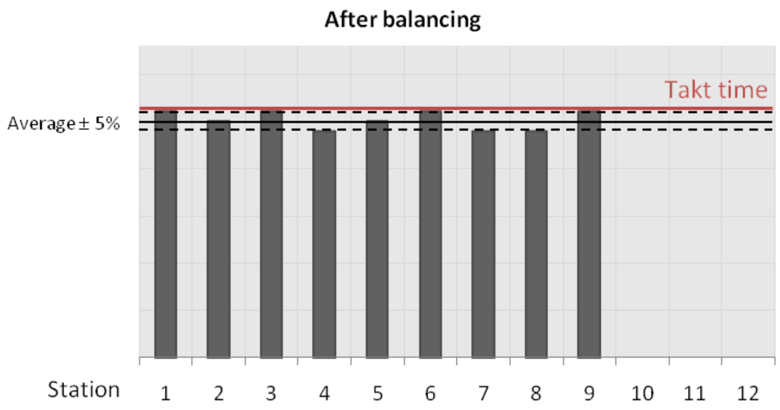


Figure 11 Line balancing for the single-model case after Baudin (2002)

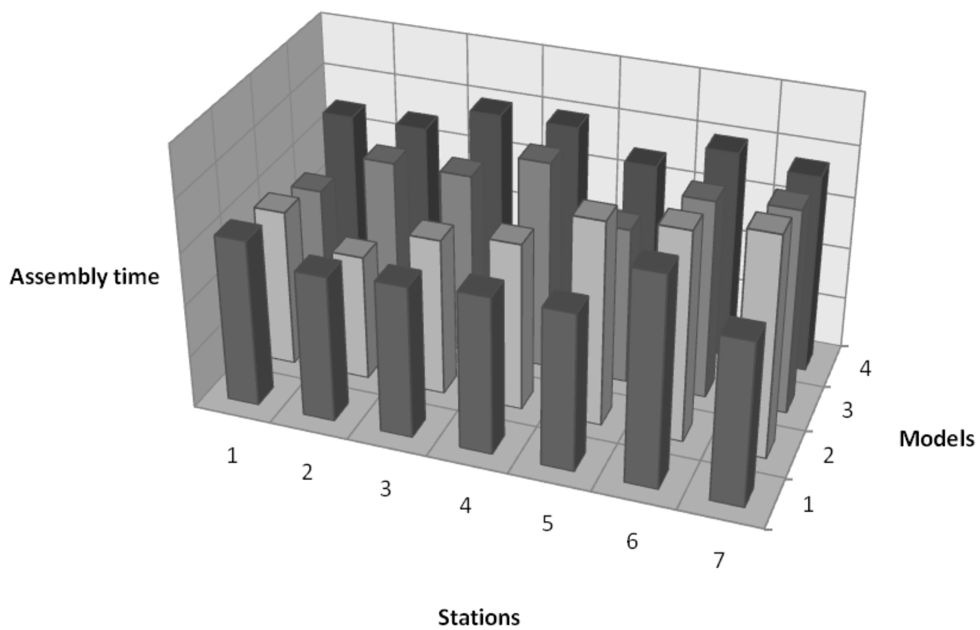


Figure 12 Line balancing in the mixed-model case after Bukchin (1998)

According to Bukchin (1998) problems in balancing the line in the mixed-model case includes what he calls station variability and model variability. The problem is that the assembly time can vary for a model at different stations as well as it can vary between models at the same station as shown in Figure 12. (Bukchin, 1998)

The input of most algorithms for assembly line balancing (single- and mixed-models) is the precedence constraints of each model, tasks durations and desired cycle time or number of stations (Bukchin, 1998). The precedence constrains can be summarized in a precedence graph (PERT chart) which shows what operations that have to be completed before a specific operation can start. (Becker & Scholl, 2006)

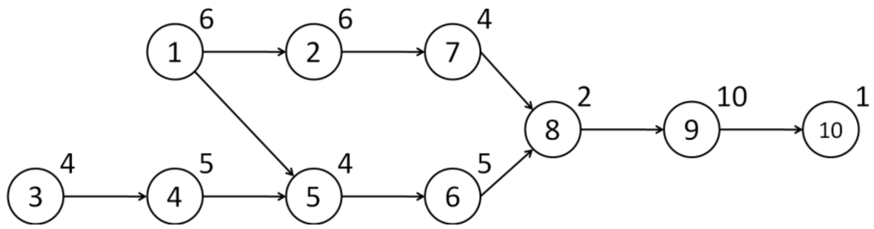


Figure 13 Precedence graph after Becker & Scholl (2006)

Figure 13 is an example of a precedence graph for one model. The numbers within the circles represents the name of the tasks and the numbers next to the circles represent the task times. The arcs show the precedence constrains.

In the mixed-model case the precedence relations between elemental work tasks may differ between models (Scholl, 1999). If different models have different precedence relations it may result in that duplication of stations may be necessary. The above mentioned challenge together with an inefficient line balance will, according to Rekiek, Pierre, & Alain (2000), lead to the need of an elongation of the line. One could also think that the duplication of stations would lead to that parts has to be delivered to multiple places resulting in a longer material façade and increased risk of picking errors as well as increased logistic costs.

Tasks which are common for several models have to be assigned to the same stations to be able to make use of learning effects, to be able to have a continuous flow of materials, and to avoid installing equipment several times. (Scholl, 1999)

The takt time in mixed-model environments correspond, according to Scholl (1999) and Rekiek, Pierre, & Alain (2000), to the average production rate and it is not treated as an upper bound on the cycle time. Duggan (2002) argues that one should balance the line slightly faster than the takt time to be able to compensate for operator fatigue and variations in work content between products. However, obvious wastes should not be taken into consideration. Duggan (2002) goes on saying that a good target to balance after is 92 to 95 per cent of the takt time and he calls this the planned cycle time.

Heike, Ramulu, Sorenson, Shanahan, & Moinzadeh (2001) mention that in the ideal case, a line should be able to be reconfigured so that any product within a family, could be assembled in any order, and only minimal effort should be required to redesign and rebalance the line. This is unfortunately not possible in most environments according to Heike et al. (2001). According to Baudin (2002), depending on the size and complexity of a line, it may be balanced or re-balanced in a few minutes by direct observation, or it may be a project involving a team of engineers for several months just to do the required analysis.

Scholl (1999) and Rekiek, Pierre, & Alain (2000) describe that the variations in the station times between models may be rather large on a mixed-model line and it is therefore the main objective to overcome those variations when balancing a line. Duggan (2002) mentions that bottlenecks can be created by operations that some products may exceed the takt time. Idle time on the other hand occurs, according to Scholl (1999), when a station has completed its work on a unit and has to wait for the next unit arriving at the station, or if they have to wait for the succeeding station to finish their tasks to be able to hand on the unit. Scholl (1999) mentions that the variations in station times which to some extent can be influenced by line balancing can be operation-dependant, model-dependant, or assignment-dependant. Different time losses in assembly lines are further discussed in chapter 2.5.1.

Chakravarty & Shtub (1985) argues that the objective of the mixed model line balancing procedures has in most literature been to minimize the total idle time at the stations. According to Bukchin (1998) the most common objective in line balancing is maximum throughput, minimum cycle time, minimum number of stations, minimum idle time, minimum flow time and minimum line length.

According to Johansson (1989) there are several methods and algorithms for solving the line balancing problem e.g. heuristic approaches, linear programming, dynamic programming, integer programming and network models.

One of the most prominent computer algorithms is the COMSOAL (Computer Method for Sequencing Operations for Assembly Lines) method. It is used in many of the computer software for line balancing that exists. (Sly, 2011)

Examples commercial software solutions are ProBalance from ProPlanner™ (Pro Balance, 2011) and Avix® Balance from Avix® (Avix Balance: Avix, 2006) as well as solutions from major PLM system providers such as Siemens, PTC and Dassault Systèmes. Input to the software products is operation times, precedence constraints and desired cycle time or number of stations.

2.4.4 The connection between mixed-model balancing and sequencing

In the ideal mixed-model environment, the total assembly times of various models are identical, and the total assembly time of each model is equally divided among stations (perfectly balanced), the sequence in which the models are released to the line has no importance for work overload or starvation at any station. In this case the sequence has no effect on the performance of the system. (Bukchin, 1998) The ideal solution is not possible to achieve in most cases and the sequence in which the models are released to the line becomes important.

The issues regarding mixed-model line balancing and mixed-model sequencing are, according to Scholl (1999), strongly related even though they arise in different planning horizons. The result from the line balancing is used as input data to the sequencing. The quality of the sequencing decisions directly depends on the quality of the work load balancing. The importance of the sequencing problem is minor when the line is almost perfectly balanced with respect to stations and models. However, it is almost impossible to find acceptable sequences when the balancing solution leaves considerable imbalances. The quality of the line balancing is though depending on the expected model mix and the sequences which may occur when operating the line. This kind of information is usually not available when the line is about to be balanced. The line balancing and the sequencing have to be solved separately due to their different planning horizons. Though, one should try to have the short-term problems in mind when balancing decisions are made. Scholl (1999) presents a method for this called the hierarchical planning approach described below. (Scholl, 1999)

The hierarchical production planning is a methodology that integrates balancing and sequencing decisions with respect to their different planning horizons and their interdependencies. The methodology decomposes a complex production planning problem into a hierarchy of sub-problems which are less complex to solve. The problems at high levels are based on aggregated input data and include long-term or medium-term decisions. The lower levels have to take detailed short-term decisions based on constrains or parameters which are imposed by the higher levels. The hierarchical decomposition makes it possible to postpone detailed decisions until more accurate data are available. (Scholl, 1999)

As mentioned before, long-term balancing decisions and short-term sequencing decisions show strong interdependencies. They are opposite ends of the planning hierarchy in terms of planning horizon and the certainty of data available. The balancing level and the sequencing level can be divided into three and two sublevels respectively. The resultant five-level hierarchy is illustrated in Figure 14. Scholl (1999) goes further on and explains the different levels with respect to the type of input data available, the planning horizons considered, and the decision problems to be solved. (Scholl, 1999)

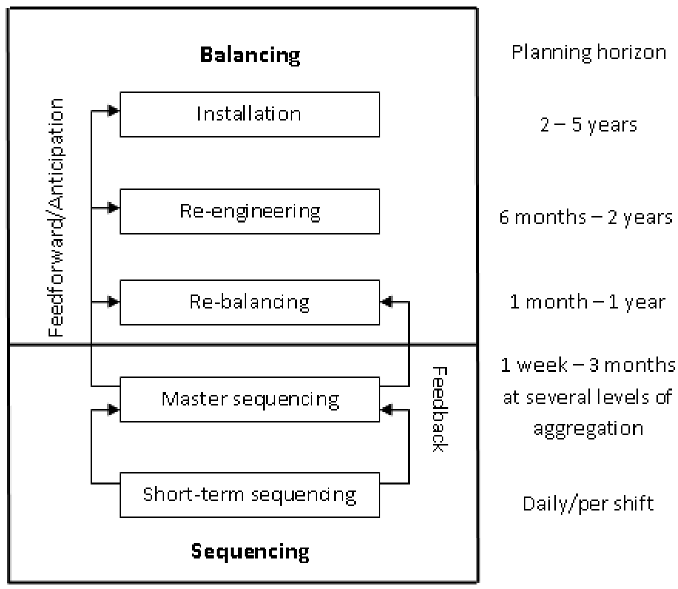


Figure 14 Planning Hierarchy of line balancing and sequencing after Scholl (1999)

The planning hierarchy above mainly concentrates on balancing and sequencing aspects. Consequently, it considers only a part of the decisions required for installing and operating a mixed-model assembly line. Monden (2008) describes that the procedure of designing a mixed-model assembly line involves the following steps:

1. Calculation of takt time.
2. Computation of minimum number of processes.
3. Preparation of diagram of precedence relationships among elemental jobs.
4. Line balancing.
5. Determination of the sequence schedule for introducing various models to the line.
6. Determination of the length of the operations range of each process.

2.4.5 Sequencing of models to mixed-model assembly lines

According to Johansson (1989) the sequence in which the models are fed to the assembly line will affect the efficiency of the line. The sequence of introducing models to the mixed-model assembly line is different due to that there may be different goals or purposes of controlling the line (Monden, 2008).

According to Baudin (2004) sequencing is used in mixed-model assembly lines mainly to smooth the incoming flow of materials and thereby contain or eliminate the bullwhip effect upstream in the supply chain. According to Baudin (2004) it has no direct effect to the customers but an indirect effect of creating more efficient assembly line and logistics system. This is the main focus for the sequencing in the context of lean manufacturing. (Baudin M. , 2004) This objective of sequencing is also discussed as an objective of a levelled production plan discussed in the preceding chapter.

According to Aigbedo & Monden (1997) a lot more has been documented on conventional sequence scheduling, such as sequencing for job shops, than on mixed-model assembly line sequencing. The main difference between conventional sequencing and JIT sequencing for mixed-model assembly lines lies in the nature of the sequence criteria or objective with the sequencing. Maximum tardiness, number of tardy jobs, and flow time has been the main objectives for job shops. The objective of minimizing flow time in a job shop is inappropriate for assembly lines because of the constant production rate of the line (Scholl, 1999).

In the pioneering work on mixed-model assembly line balancing and sequencing by Thomopolous (1967) the main criteria was the combined aim of balancing and sequencing mixed-models under the objective of maximizing operator utilization. According to Thomopolous (1967) the problems of achieving an efficient mixed-model assembly line includes the solution to two separate and related problems: the line balancing problem and the sequencing problem previously discussed. Because of the complexity of these problems there has traditionally been a tendency to have an oversupply of operators to meet the uneven flow of work of different models that have different assembly times. The objectives of maximizing operator utilization were thus considered most important by Thomopolous.

Scholl (1999), Xiaobo & Zhou (1999), Aigbedo & Monden (1997) and Baudin (2004) accounts for a number of objectives which should help find efficient sequences. Usually, time related goals are used, while only a few references in the literature presents cost oriented goals (Scholl, 1999). Also, many objectives are used to obtain an even consumption of materials in order to facilitate the realization of a JIT system. This is also discussed as the most important sequencing goal in Lean manufacturing as earlier mentioned above by Baudin (2002).

The most important sequencing objectives considered in the literature today are discussed in more detail below.

Sequencing objectives

Xiaobo & Zhou (1999) present four main sequencing objectives for mixed-model assembly lines. The following four objectives or criteria's has been identified:

1. Level the workload (total cycle time) at each workstation on the assembly line, so as to maximise the operators' efficiency or minimise the risk of stopping the conveyor/passing on unfinished products.
2. Keep the constant usage rate of every part used in the assembly line, so as to minimise the variation in production quantities and the work-in-process inventories in preceding processes.
3. Keep the constant feeding rate of every model fed into the assembly line, so as to minimise the variation in the delivery of products to markets.
4. Minimise the total line stoppage time emerged from the Jidoka concept in Toyota Production System, so as to assure the quality of products and maximise the output of the assembly line.

In addition Aigbedo & Monden (1997) recognises a fifth objective:

1. Smoothing of workload in the sub-assembly lines.

Objective One – Level the workload on each station
The first objective is also common in conventional assembly systems and derives from the fact that the varieties of products have different work contents. Products of relative high work content following consecutively leads to work overloading of the workstations, which might result in line stoppage or unfinished products. On the other hand a sequence of low work content products following consecutively may result in low utilization of the workforce and idle times. There must be a balance between the two extremes. (Aigbedo & Monden, 1997) Scholl (1999) presents total work overload as one objective and total idle time as another objective.

- *Minimise Total Work Overload* - A possible objective may be to minimize the total amount of work overload. A similar objective is to minimize times in which extra operators have to be employed in the planning period to compensate when work overload occurs at a station. (Scholl, 1999)
- *Minimise Total Idle Time* - Partly, idle times can be influenced by the model sequence. The lengths of the stations and the differences in cycle times between models can affect the idle times. Idle time represent unused capacities of the line and is often called balance losses. A possible objective is to minimize the sum of idle times. In a paced line idle times occur when an operator returns to the border of his station before a new unit arrives. Total idle time of an assembly line may contain unavoidable idle time depending on the unequal division of labour between the stations. This is then a problem dependent by the balancing of the line and not the sequencing of models to the line. (Scholl, 1999)

In the case when the balance dependent idle times are eliminated the two objectives in minimizing total work overload and idle times are identical. Since the balancing-dependent idle time is unavoidable and not dependent of the sequence the objective of minimizing the sequence-dependent idle time is equivalent to the objective in minimizing total work overload. Hence, it is not necessary to consider the two objectives at the same time. (Scholl, 1999) This discussion can be considered to be the same as the discussion about model variability and station variability in chapter 2.4.3.

Some references in the literature describe a number of similar objectives to minimise total idle time and minimise total work overload. One is to minimize the sum of total excess time and total idle time in a problem with open stations. This station type allows the operator to complete the product in an overlap area used in common with the subsequent station. The excess time is defined as the time interval during which the overlap area is needed. (Scholl, 1999)

Objective Two – Even parts consumption
The second objective ensures that the rate of withdrawal of each part type utilized by the final assembly line is as uniform as possible, thus eliminating the need to maintain large inventories of parts on the line. (Aigbedo & Monden, 1997) (Scholl, 1999) Material stocks are always expensive and in a mixed-model assembly line this becomes a critical issue because of the large number of different parts that has to be stored for many different models. According to Scholl (1999) in order to reduce the inventory levels of all parts as much as possible a just-in-time (JIT) system should be implemented when using a mixed-model assembly line. That is, the parts should not be provided before they are required, and the output should be matched with the demand. The application of a just-in-time concept is only possible if the usage rate of all parts is levelled (Scholl, 1999).

The use of pull concept in a JIT system is one primary characteristic that differentiate the JIT system from the conventional manufacturing. Subsequent processes within the manufacturing system exert a pull on the preceding process for their parts requirements. The JIT manufacturing concept generally creates system flexibility and reduces the amount of centralized production control and its attendance cost. But mixed-model assembly lines are used in both conventional and JIT production systems. (Aigbedo & Monden, 1997)

- *Similar Part Requirements* - In the case where the models have similar product structures, that is the models require almost the same number of parts and the same mix of parts, it is sufficient to only consider the final products. A constant part usage is almost obtained by levelling the rate of production for each model. The sequencing in this case must also be used to match the cumulative production volumes of each model and the rate of demand for each model. (Scholl, 1999)
- *Different Parts Requirements* - In production system different processes manufacture parts (components and sub-assemblies) which are demanded from the next process. In this case the final product is assembled on a mixed-model assembly line. In a JIT concept the preceding processes manufacture parts such as they are completed when the next process needs them. A sequencing objective may then be to consider the usage rates of parts at all levels because different models have different part requirements. (Scholl, 1999)

Traditionally in JIT systems the second objective has been the most important as also mentioned above by Baudin (2004). The need to make deliveries of parts several times in a day highlights the importance of this objective in a JIT system. (Aigbedo & Monden, 1997)

According to Scholl (1999) an exclusive use of the part requirements objectives for levelling the part usage rates when sequencing a mixed-model assembly line may lead to considerable operational imbalances to the system. Scholl (1999) stresses that it makes sense to also consider the objective of levelling the workload on each station.

Objective Three – Minimise variation of products to market

The main implication of the third objective is that it makes the models uniformly available from a market demand perspective and this is one possible mean of achieving this objective. In JIT systems this is also considered in a wider time horizon outside the sequencing scheduling framework. Production smoothing is then considered in the total production quantity in a wider time horizon. (Aigbedo & Monden, 1997)

Objective Four – Minimise total conveyor stoppage time

The fourth objective is to minimise the total conveyor stoppage time emerged from the autonomation concept in Toyota production system, so as to assure the quality of products and maximise the output of the assembly line. (Xiaobo & Zhou, 1999)

An objective concerns the minimization of the maximal distance any operator drifts to the end of the station. This objective is similar to levelling the workload on each station. (Scholl, 1999)

This objective has according to Scholl (1999) a drawback that neither extra workers nor later repair is used for compensating work overload (instead of stopping the line). (Scholl, 1999)

Objective Five – Level the workload in sub-assemblies

The fifth goal may be important if the work content in the sub-assembly lines vary between different models used at the main assembly line. (Aigbedo & Monden, 1997)

Other sequencing objectives
The five objectives above are all time related or material supply related. Time related objectives are according to Scholl (1999) sometimes not best to focus on. They may give identical attention to different types of inefficiencies. For example work overload at a bottleneck station is more critical than on other stations. Cost oriented objectives may therefore be more suitable. (Scholl, 1999)

- *Total Labour Cost* - A possible objective may be to minimize the sum of labour costs both for regular workers and utility workers (the use of utility workers or extra personnel is further explained in chapter 2.5.2). If the wages are equal for all stations and models, the objective of minimizing the total labour cost is equal to minimize the total work overload and idle time. (Scholl, 1999)
- *Total Operating Cost* - For example minimize the sum of labour costs, set-up costs, and in-process inventory costs. (Scholl, 1999)

Sequencing methods
Toyota is sequencing their final assembly of cars, by shift, using sequencing algorithms that smooth the flows of incoming items and therefore mainly considering the second objective as earlier discussed. The simplest approach for Toyota is to spread the shift quantity for each product over the length of the shift and drop these patterns onto a common timeline. This method only smoothes the flow if the models have similar parts requirements. Models assembled in a mixed-model assembly line often have a different degree of common parts. (Baudin M. , 2004)

Toyota has also developed a more advanced algorithm for sequencing models on the mixed-model assembly line manly considering the second objective and common parts between models. This method is called the Goal Chasing Method I as described by Monden (2008). A simplified version also used is the Goal Chasing Method II. In the Kanban JIT system used at Toyota, preceding processes supplying the various parts or materials to the line are given great attention. In this "pull" type of system the variation in production quantities or conveyance times at proceeding processes must be minimized. Also a goal is that the work-in process inventory is to be minimized. To be able to do so, the consumption speed for each part in the mixed-model assembly line must be kept as constant as possible. The sequencing methods used by Toyota are designed to meet this objective and smooth the production. (Monden, 2008)

The Goal Chasing Method mentioned above has been developed further and has evolved to a new version that has a function to include additional multiple goals. Monden (2008) calls this new version developed at Toyota The Goal-Coordinating Method. When the sequence of models has been decided by The Goal Chasing Method additional controls are added to solve the problem of smoothing the assembly workload (objective one) because this cannot be solved only using The Goal Chasing Method, which mainly focuses on keeping a constant speed of parts consumption (objective two). There is with The Goal Chasing Method a conflict between the part smoothing goal and the line-balancing goal with even workload among the stations. The Goal-Coordinating method may be used to solve this conflict. (Monden, 2008)

According to Baudin (2004) Toyota's methods of levelled sequencing is described in the lean manufacturing literature but is not widely practiced outside Toyota and a few other car companies. The objective with a levelled sequence for smoothing the part usage upstream the supply chain is often not a priority for assembly managers. They fail to see the value because it does not focus their area of responsibility. Levelled sequencing is not discussed in the logistics literature where the bullwhip effect is described but Toyota has shown that it is an effective tool of fighting it.

According to production management literature there are a number of similar algorithms and methods developed that complements and evolves methods developed by Toyota also taking into consideration the other sequencing objectives mentioned in the previous chapter. See for example Scholl (1999).

2.5 Time losses

2.5.1 Types of time losses in assembly lines

One way to evaluate the efficiency of a production system is to calculate the resource consumption in the form of amount of working time required. The difference in the amount of working time that is actually needed and the minimum amount of value adding working time to complete a product a is called time losses. Time losses can be divided in balance losses, variant losses, system losses, handling losses and learning losses. (Engström et al., 2005)

Balance losses

The sum of idle times at stations is often referred to as balance delay time or balance loss. The balance loss is a result of the line not being perfectly balanced and is often unavoidable. (Baudin, 2002) (Engström et al., 2005) (Ellegård, Engström, Johansson, Nilsson, & Medbo, 1992) (Wild, 1995)

The balance loss is caused by impossibility to divide the product and assembly work in sufficiently small pieces required for the work to be evenly distributed among the stations (see Figure 15). In addition to this the product must, because of the product architecture, be assembled in a certain sequence. (Engström et al., 2005) Mathematical methods to minimize the balance loss is called line balancing and sequencing methods and is further developed in chapter 2.4.3 to 2.4.5.

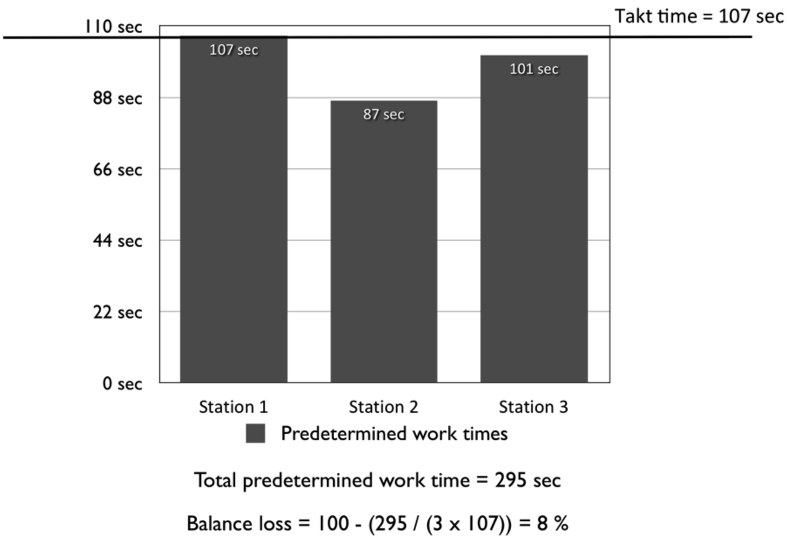


Figure 15 Balance time loss after Engström et al. (2005)

A factor affecting the size of the balance losses in a system is the takt time of the system and therefore the cycle time for each station. As seen in Figure 16 the balance losses increases as the takt time decreases because if using a shorter takt time it is harder to distribute the operations evenly among the operators and stations. (Engström et al., 2005) (Wild, 1975) A greater number of stations used at the assembly line are connected to shorter takt time, which also leads to greater balance losses. (Engström e al., 2005) Two curves are presented in Figure 16. This is a consequence of that products are different. Products with many small parts are easier to balance than products with few large parts. (Engström et al., 2005)

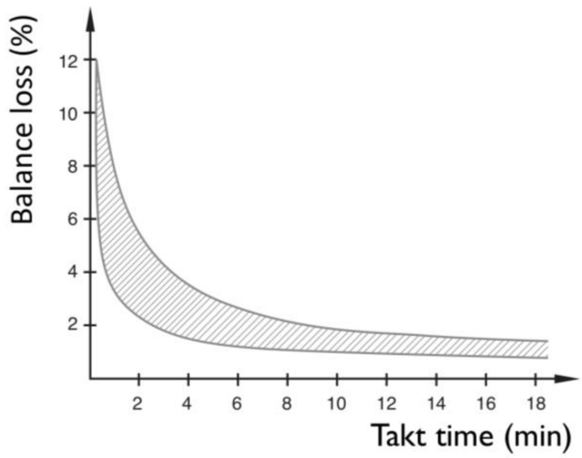


Figure 16 Balance loss as function of takt time after Wild (1975)

Variant losses

Different variants of products, for example different models, may cause difference in the amount of work content per variant and therefore differences in station loads. Variant losses can be seen as a part of the balance losses because they create idle times or work overload if the work is not evenly balanced among the variants and stations. (Engström et al., 2005) Variant losses may lead to high idle times if the cycle time is set after the highest work content variant in a paced flow. They may also create takt time violations (may cause line stoppage or unfinished product in a paced flow) if the work content of the variant at the station is higher than the takt time.

The reason for treating variant losses separated from balance losses is that even if the variation in assembly time between products variants were eliminated, the balance losses would still exist. The variant losses only increase and decreases with the number of variants but the balance losses are constant independent of the number of variants. (Engström et al., 2005)

System losses

Wild (1995) discusses what he calls system losses in assembly lines, which are dependent on human aspects in assembly flow lines with manual work. When designing assembly lines it is assumed that the work will be carried out according to the decided standard work method as well as that the time for the work is predetermined. The time in Figure 15 is based on predetermined time. Wild (1995) argues that even if the operator follows the decided work method there is still variations in time needed compared to the predetermined time. It has been shown that the time distribution of unpaced work follows the curve shown in Figure 17. This is the actual time used by workers to perform work or operations. In a paced assembly line where the worker only has the decided mean time to complete the task, on some occasions the worker may be unable to complete the task which may lead to incomplete product or line stop. On the remaining occasions the worker may have more time available than needed resulting in idle time. This is by Wild (1995) referred to as the system loss phenomenon.

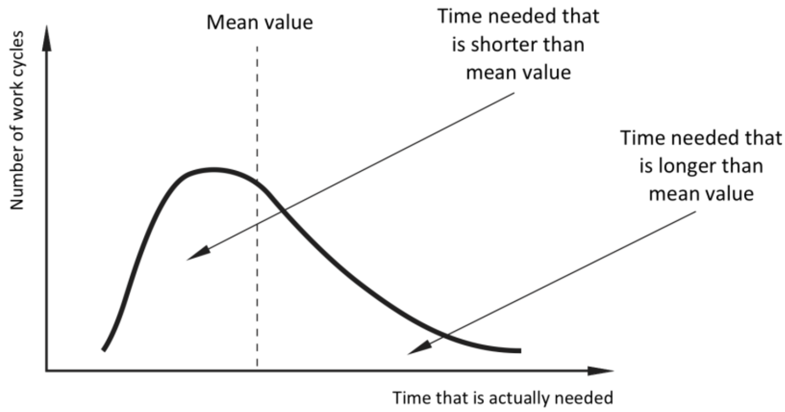


Figure 17 Unpaced work time distribution after Wild (1995)

Wild (1995) further argues that the system loss resulting from workers variable operation times are perhaps more important to consider than the balance loss resulting from an uneven balancing. Even if the system would contain no balance or variant losses there would still be system losses (Engström et al., 2005).

The system losses have a tendency to increase as the number of station increases in an assembly line (this is valid for unpaced assembly lines) (Wild, 1995). The system losses may be decreased if buffers are introduced to the line. See Figure 18. They may also be decreased if the cycle times are allowed to increase when the worker for example are allowed to work outside his station range at a paced line. (Wild, 1995) (Ellegård et al., 1992) Ways to decrease time losses is further discussed in chapter 2.5.2.

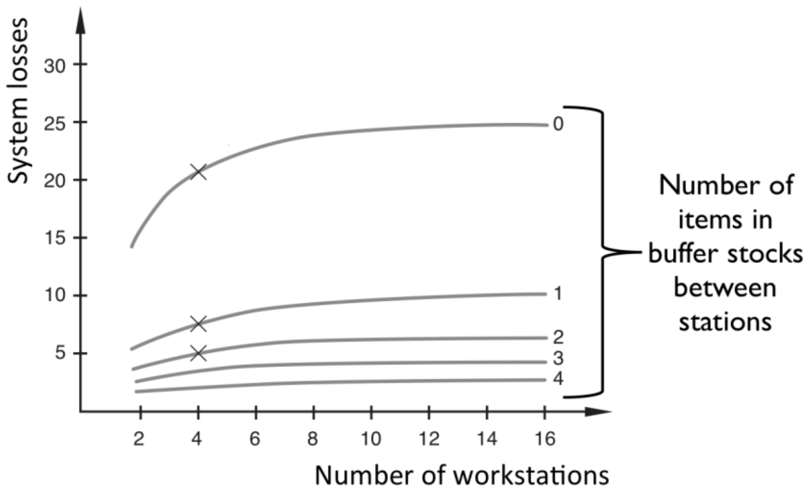


Figure 18 System losses depending on number of stations and number of buffer stocks after Engström et al., (2005) and Wild (1995)

Handling losses

Engström et al. (2005) and Ellegård et al. (1992) discuss that handling time losses could also, in addition to the above-mentioned losses, be of importance. Handling losses incorporates handling of tools and materials and movement in the workstation not adding any actual value to the product. The size of the handling losses is caused by the design of the material supply, material presentation and the workstation layout. The size of handling time loss may be increased if the cycle time is decreased. (Wild, 1975) (Engström et al., 2005) (Ellegård et al., 1992)

An effective way of minimizing the handling time losses is to use kitting, small material boxes and assembly friendly material façade. (Medbo, 2011)

Learning losses

Learning time losses refer to the time that is lost due to that operators need time to learn the work before being able to perform at full predetermined performance. (Wild, 1975) (Engström et al., 2005)

The learning time loss tends to increase when longer cycle times are used. (Engström et al.,2005). Short cycle times makes it possible to use less skilled workers that can be trained more quickly (Baudin, 2002).

The learning time losses are according Engström et al (2005) to a lesser extent affected by the cycle time and to a greater extent affected by employee turnover, how information is presented to the operator and how material supply and presentation is designed for the assembly work. Wild (1975) also suggests that the learning time is affected by the complexity of the tasks.

According to research on learning curves described by Johansson M. I. (1989) the assembly time per unit will decrease with an increased number of completed assemblies. As some operations in mixed-model assembly lines are unique to some models, the number of repetitions per time unit will decrease, causing an increased learning time. Thomopolous & Lehman (1969) studied the learning times connected to mixed-model assembly lines. The conclusion is that as some operations are unique to some models, the number of repetition per time unit will decrease causing an increased learning time compared to single model assembly lines. (Thomopoulos & Lehman, 1969)

Zhu, Jack Hu, Koren, & Marin (2008) mentions that quite often assembly processes are completed manually so variety will affect people performance because of the choice complexity at different stations. MacDuffie, Sethuraman, & Fisher (1996) also mention that there are many ways in which variety may decrease productivity and quality in assembly plants. When both parts and options complexity increases labour productivity and quality may suffer because workers face a more complicated array of different parts to install and less predictable combination of the parts.

2.5.2 Methods to handle balance, variant and system losses

Variant losses can be seen as included in the balance losses and increases as the work content for different models varies i.e. the assembly time varies between the models (see chapter 2.5.1 for a discussion on time losses). Significant idle times will occur if the line speed is adjusted to the most time-consuming highest labour content model (Fujimoto, Jürgens and Shimokawa, 1997). To be able to produce on a mixed-model assembly line it is important to consider methods used to absorb difference in man-hours between models to reduce the variant losses.

Methods used to absorb variant losses are also used to absorb the other type of time losses in the system, for example system losses. The difference in assembly time between different models in a mixed-model assembly line can be seen as the same type of disturbances as the normal occurring variability in operation times. (Medbo, 2011) (Johansson, 1989)

Several methods to handle the balance, variant and system losses have been identified in the literature. They are further explained below. Several of the methods that have been found are similar to each other and therefore they have been grouped under the same headline. Appropriate headlines have been chosen by the authors.

Offload work to sub-assembly lines

Baudin (2002) discusses the method of offloading assembly work from complex models to subassembly feeder lines so that the main line can handle any models without much adjustment. Fujimoto et al. (1997) presents methods in solving the problem with inter-model differences currently used in some of the latest assembly plants for cars in Japan. One method used is to offload work to sub assembly lines. Monden (2008) accounts for the method of models requiring exceptional operations are handled via a subassembly line, which configures the specialized parts and then attaches them to the model, while it is still on the regular assembly line to handle difference in man-hours between models, see Figure 19 and Figure 20. The method of offloading work to sub-assembly lines is according to Baudin (2002) the most effective approach to equalizing assembly times.

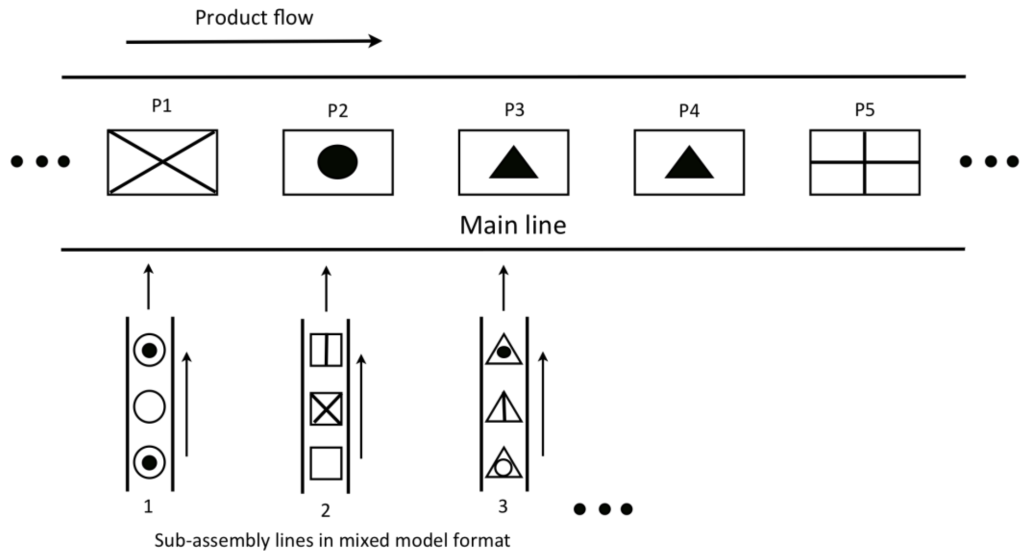


Figure 19 Sub-assembly lines in mixed model format after Aigobedo and Monden (1997)

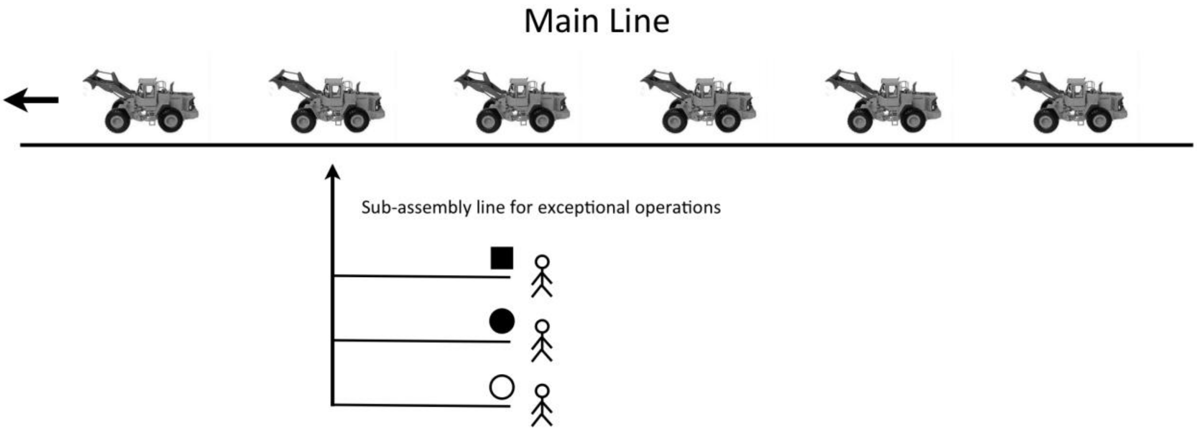


Figure 20 Exceptional operations sub assembly after Monden (2008)

Baudin (2002) also discusses if, on the other hand, there is a rich subassembly structure and many feeder lines then it is often possible to transfer the subassembly work to the main line .According to Baudin (2002) it is more likely to be able to equalize the work content of two products at a station by enriching the work content for the simpler variant than offloading some work content for the more complex variant. (Baudin, 2002)

Jürgens (1997) discusses the demand for longer work cycles and humanization of work in the 1970s and how the parallel system layouts with long cycle times are today replaced by serial assembly lines with short cycle times. According to Jürgens (1997) modular work was seen as both an answer to increasing model mix problems as well as the demand for longer work cycles in the conventional assembly lines in the 1970s. Special work areas were created for specific sub-systems, especially those where work content varied highly between different models. The reduced complexity of the operations on the remaining main assembly line helped to standardize those jobs to make the main line easier to balance and avoiding balance losses on it. (Jürgens, 1997)

By-pass line with different takt time

For models requiring long man-hours, a bypass line could be installed. Models are removed from the regular line to a bypass line that has a longer takt time. This system is used only for models of high labour content. See Figure 21 (Fujimoto et al., 1997) (Monden, 2008)

According to Fujimoto et al. (1997) this method is used in some of the latest Japanese car manufacturing plants.

A disadvantage could be that the method must also be dependent on the sequence in which models are released to the line to minimize disruptions on the main line when a model is taken off to the by-pass line.

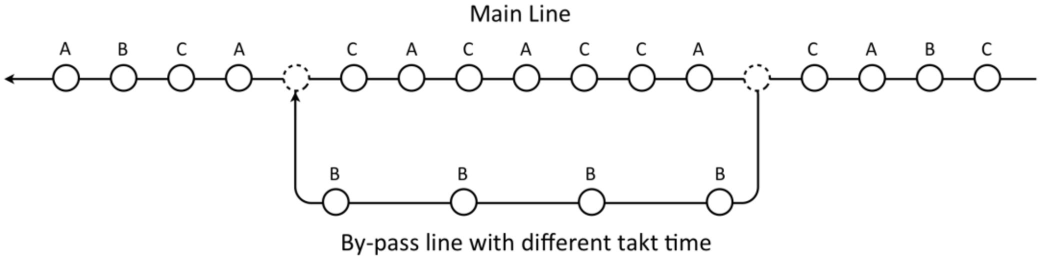


Figure 21 By-pass line with different takt time after Monden (2008)

Buffer stocks in serial flow lines

Buffer stocks in a serial flow line can be inserted between workstations, groups of stations or sections in the serial flow line. This enables equalization between the cycle times and decreases the different time losses. (Engström et al., 2005) (Medbo, 2011) (Johansson, 1989) (Wild, 1995)

The decoupling of the stations in an unpaced flow reduces the pacing between stations and therefore reduces the time losses. Temporary hold ups or delays at stations do not immediately result in idle time at subsequent station. (Wild, 1995) In a paced flow delays would result in line stoppage or unfinished products. (Ellegård et al., 1992) The effect on the time losses can be seen in Figure 22.

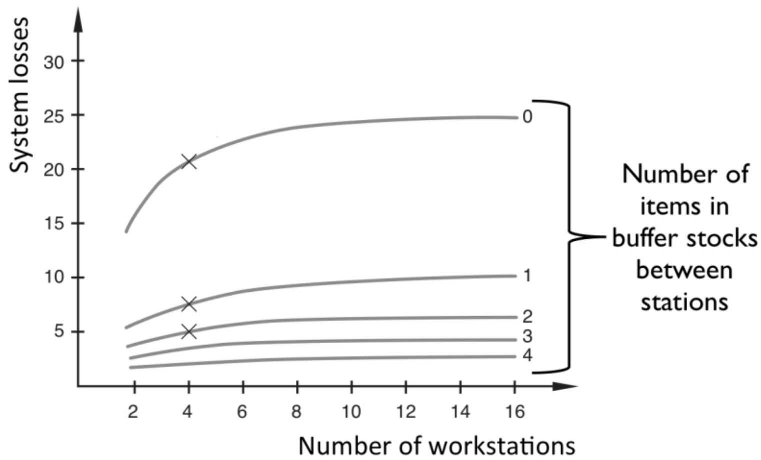


Figure 22 Effect of buffer stocks on time losses in an unpaced serial flow lines after Wild (1995)

Disadvantages with buffer stock are that tied-up capital as well as need for space increases. (Wild, 1995) According Wild (1995), because of the size of the product, in some cases it may be unrealistic to consider using buffer stocks.

Toyota has traditionally not used buffer stocks but instead long assembly flow lines without buffers. According to Baudin (2002) and Monden (2008), Toyota has in the 1990s come to rethink this approach and are now instead using line segments with buffer stocks of up to five units in between each segment. This enables a decoupling between the line segments to better handle disturbances. According to Baudin (2002) this actually decreases tied up capital and WIP because less adjustments and inspections are needed at the end of the line.

Alternative buffers

Engström et al. (2005) and Medbo (2011) discusses methods to increase the available work by including pre-work stations or/and increase the amount of products available for the operators to work at. In this way there are more work positions than there are operators increasing the flexibility in reducing the time losses. Engström et al (2005) refer to this as to increase the direct work. Medbo (2011) refer to this as alternative buffers when having a higher system capacity than operator positions or free working positions. Alternative buffers could be visible, invisible or floating (Medbo, 2011)

Monden (2008) discusses methods of using two ranges in a paced assembly line. This can be seen as increasing the amount of available products to work at mentioned by Medbo (16 mars 2011) and Engström et al. (2005). Monden (2008) discusses two ways of two range usage; inside bypass and exclusive use line.

Inside bypass is when for example the takt time is 10 min and three models with a cycle time of 11 min passes a station range in a row then the line may stop if next model have a cycle time of 10 min because the operator is 3 min behind and may not have time to finish inside his range. In such a case if there is no operator at the subsequent range the operator can manage by using two ranges called an inside bypass. But if the fourth model have a cycle time of 7 min the operator have time to finish inside his own range. In that case the sequencing method could be used to see to that the fourth model is a low work content model. (Monden, 2008) So the first method in such a case is using an alternative buffer called an inside bypass and the second method is using sequencing rules. See Figure 23 and the sequencing rules method explained further below.

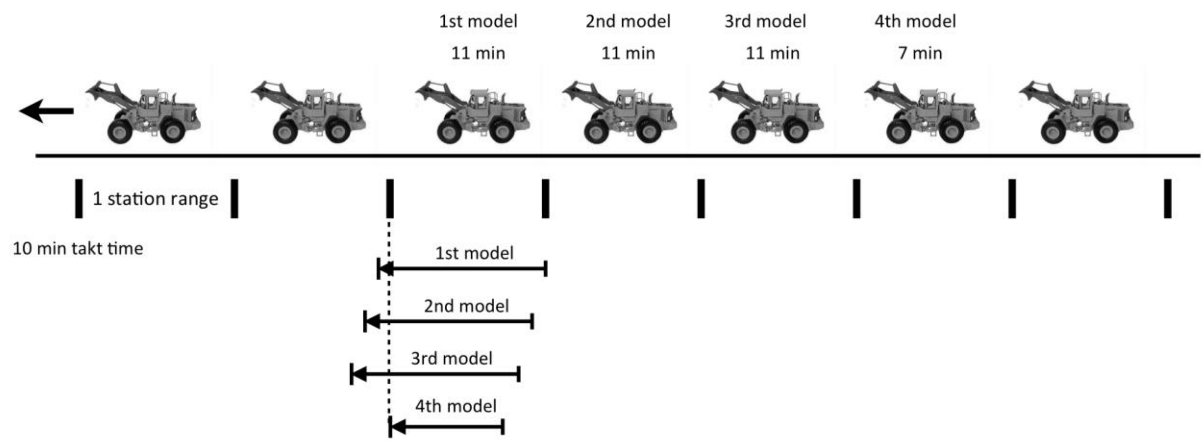


Figure 23 Inside bypass usage (two range usage) after Monden (2008)

When one model is to be equipped with optional equipment one station may be allocated just for that. All models without this equipment just pass the station. This is the other type of two-range usage discussed by Monden (2008) called exclusive use of line. See Figure 24. (Monden, 2008)

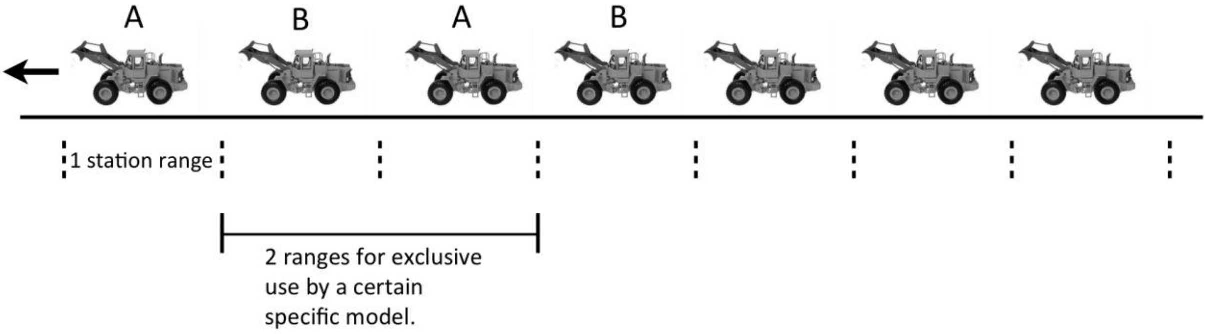


Figure 24 Exclusive use of work stations within a main line (two-range usage) after Monden (2008)

Monden (2008) also mentions the method of assembly lines having a certain number of positions for each product within the line. To absorb variances some positions within the line can remain empty.

Utility workers and flexible labour force

According to Scholl (1999) and Duggan (2002) one solution is to balance the line according to a weighted average based on the demand for the each model and then add labour when a heavy work content model exceeds the takt time. Utility workers (floaters) are used to accelerate the operations when work overload occurs at a station due to high work content models. The goal is to try to build products to the actual demand and absorb the differences in assembly time by adding labour. Flexibility in the labour force then also becomes important. (Duggan, 2002)

Enlargement of cycle time

This approach can, according to Wild (1995), Engström et al. (2005), Baudin (2002) and Duggan (2002), be used to reduce the time losses and keep the balance constant even if there is a difference in man-hours.

In a serial flow line that is paced this can be enabled if the operators are allowed to work outside their own workstation. Scholl (1999) refers to this as open stations. Open stations can solve short-term balancing issues because it is possible to depart from the station to finish work on units of labour intensive models.

A prerequisite is that tools and equipment needed is available outside the station range. A problem is that operators may be in each other's way if working at the same station resulting in handling time losses. (Engström et al., 2005)

Baudin (2002) refers to this method as slack time, or deliberate imbalances, giving the stations early in the flow more time than necessary to complete the work. Duggan (2002) argues that a planned cycle time that is less than takt time can help absorb variation in the mix.

In an unpaced line it can be realized if giving the operator a greater time available to work with the product. (Wild, 1995)

Medbo (2011) also accounts for the method of handling the time losses by designing the production system so that the takt time can be varied, by for example +/-25 per cent, depending of the work content of the current products.

Flexible division of work between operators
According to Engström et al. (2005) one method is to use self-controlling work teams where two or more operators work together. The operator may have flexible and overlapping knowledge of the work which enables them to help each other to reduce waiting times or high content station times. This diminishes different time losses.

Monden (2008) refers to this method in a paced line as the baton touch zone because the similarity to the zone used in relay races for handling over the baton. Broad spaces are prepared and intersected for respective preceding and subsequent processes. By using this method, line balance can be kept constant even if there is a difference in man-hours between models. In this zone the operators will help each other with high work content models. See Figure 25. (Monden, 2008)

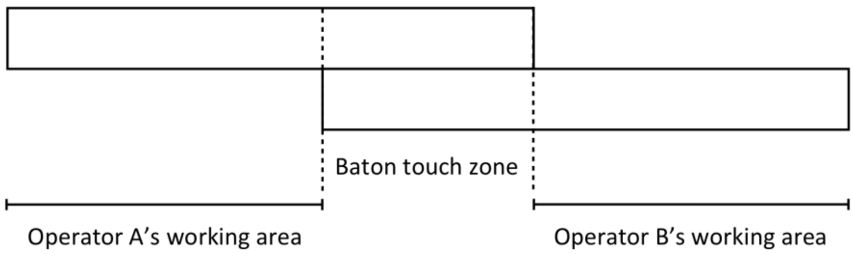


Figure 25 Baton touch zone method after Monden (2008)

A cross-trained workforce is, according to Heike et al. (2001), a prerequisite to be able to efficiently divide tasks among workers. A cost-benefit analysis of the employee cross-training process on an emergency vehicle manufacturer's mixed-model assembly line showed that the overtime costs saved exceeded the inherent costs of cross-training. The study also highlighted benefits with a cross-trained workforce not only related to time savings. They showed that the workforce got an improved understanding of the process and product, which in turn lead to process improvement, higher quality products, and smoother transitions as production changes occurred. (Heike et al., 2001)

Automation
According to Baudin (2002), a method to diminish difference in man-hours between models is to bring down the work content on the more complex models by applying automation to it. Baudin (2002) does not mention in what context the use of automation would be feasible or how the investment would be economically justified.

Increase the indirect work
Indirect work is related to including work tasks for the operators that is not directly connected to the product. This can be for example material handling, 5S-work or administrative work. In this way the operator's flexibility increases and in turn the time losses can be reduced. (Engström et al., 2005)

The method of using increased indirect work can be compared to the method of using increased direct work through pre-work stations or increased number of products that was mentioned under the headline alternative buffers. Both methods create the same type of operator flexibility but increasing the direct work also increases tied up capital.

Parallel flows
Replacing a serial flow line with many short parallel product flows will decrease the time losses because the interdependencies between the stations decrease and the cycle time increases. In the extreme case, every product flow only consists of one station and all time losses are completely removed by definition. (Engström et al., 2005; Ellegård et al., 2005)

Fujimoto et al. (1997) also mentions the Volvo Uddevalla assembly system earlier discussed as collective assembly systems. It is concluded that this system, by definition, is free from the line balancing problem as there is in principle only one station per line. This system is extremely capable of absorbing the difference in work content between products.

Standardised work

Engström et al., (2005) and Medbo (2011) mention standardised work methods as an effective way of reducing time losses. Standardised products and standardised work reduces the actual variety in assembly time. (Engström et al., 2005) Stable station times enables the line balancing to be better followed. See chapter 2.2 for further discussion about standardised work and how it is used to reduce variety. Standardised work is important if also using the method of a flexible division of work between the operators.

Sequencing of models

Medbo (2011) and Engström et al. (2005) mention a levelled production plan and in the short run a levelled sequence as a way to level the work load in the production and in this way handle time losses between models. This means sequencing the models so that less demanding models follow high work content models.

According to Fujimoto et al. (1997), conventional JIT factories have solved the problem of differences in assembly time between models by a combination of continuously paced conveyor lines, which can absorb variation of cycle time, and a levelled model mix.

Sequencing of models to the assembly line can be seen as interconnected with the line balancing problem and is further discussed in chapter 2.4.3. Levelling (Heijunka) is further discussed in chapter 2.4.2. Levelling the production plan can be seen in the long-term time horizon and sequencing the models to the line in the short run. Both sequencing and levelling is used in the same context.

Varying the takt time

Fujimoto et al. (1997) also presents new ways of solving the problem with inter-model differences that currently is used in some of the latest assembly plants for cars in Japan. The most sophisticated way is to use AGVs, which can automatically adjust pitches (i.e., intervals between models), according to the product content of each product.

In a paced line the same concept can be realised if the models is released to the line in a variable rate depending on the work content of each model. See the discussion on fixed or variable rate launching in chapter 2.1.

As a note one could also think that this could be accomplished if the assembly line is split up into line segments with buffers in between. The takt time on each line segment could be varied depending on the work content of the models currently present at the line segment.

2.6 Material handling and supply

One of the key decisions when designing an assembly line is the choice of how the materials feeding system should be designed. This decision affects all of the other activities performed as well as the performance of the assembly line.

There are many demands put on material handling systems used for material feeding in assembly systems. According to Johansson M. I. (1989) some of the demands comes from, or can be derived from:

1. The choice of the assembly system.
2. Production scheduling.
3. Characteristics of the materials handled.

The way parts are presented at the assembly line affects both quality and productivity. By presenting the parts too far away from the assembly station, or in the wrong direction, the handling time losses increases because walking and handling increases. Adding time on one assembly position increases the time losses in the entire system which was discussed earlier in this chapter. Quality is also affected by parts presentation. Making the parts easy to confuse will result in defective products. (Baudin, 2002)

Because of the fact that the assembler's time is extraordinary valuable, material handling and supply to the line must support the operators so that they are relieved of any work that is not direct assembly work. The material handling and supply must be designed so that walking and handling is reduced. (Baudin, 2002)

Another reason why material handling and supply is important is due to the diversity of variants in mixed-model assembly lines that results in that more part numbers are required at the line. This leads to difficulties in feeding materials in the traditional way, i.e that one unit load of each part number is placed at the assembly station. (Johansson M. I., 1989) The material façade gets to large if all parts are supplied in the traditional way. New methods of supplying parts to the line may be needed.

Johansson (1989) categorizes material supply systems with regard to the selection of part numbers exposed at the assembly station and the way in which these part numbers are sorted at the station.

In the first variable, supply systems can be divided into two types. First, systems where all part numbers are allowed according to product specification and work division at each station, and second, where a selection of part numbers are exposed at a time. In the second type only part numbers necessary for a fixed part of the production schedule are exposed. The second variable categorizes the material supply system into where components with the same part number are held together, or where parts intended for one assembly object are held together. (Johansson M. I., 1989)

This division results in three material supply systems:

1. Continuous supply.
2. Batch supply.
3. Kitting.

The three systems can exist simultaneously in one assembly supply system and for different kinds of parts. The categorization is shown in Figure 26.

	Selection of part numbers	All part numbers
Sorted by part number	BATCH	CONTINUOUS
Sorted by assembly object	KITTING	

Figure 26: Categorization of material supply systems (after Johansson, 1989).

Johansson & Johansson (2006) defines a fourth type of material supply system:

4) Sequential supply.

Continuous supply

Refers to the case where material is distributed to the assembly stations in units suitable for handling. All part numbers needed for production of all products is available at the assembly station at all time. Material is often placed at the assembly station in the supplier package or repacked if the quantity or package volume is too big. (Johansson M. I., 1989) Single part presentation is referred to by Baudin (2002) as when all parts are available but only one part is visible to the operator. The Japanese word for this is zentenatamadashi, which means single-piece presentation or literary "all items stick their heads out". This maximizes the number of different items presented at each station.

Refilling of parts at the assembly station is done in various ways for example with a two bin pull system, milk runs or pushing the material to the line with fork-lifts by line stocking.

According to Baudin (2002), different quantities of material delivered to the line may be used and the best method is to deliver matching quantities of material according to consumption rate during a certain time interval. Using forklifts to bring full, single-item pallets to the line causes unwanted peaks and valleys and an inefficient supply chain.

Batch supply

When using batch supply the material is supplied for a number of specific assembly objects. The batch of materials can be a batch of the necessary part numbers, or a batch of these part numbers in the requisite quantities. It differs from continuous supply in the sense that less part numbers are exposed at the assembly station and at different points in time. (Johansson M. I., 1989)

When the batch of assemblies is completed the batch of material may be returned to the storage or be used for the next batch of assembly objects. (Johansson M. I., 1989)

Kitting

Kitting means that the assembly stations are supplied with kits of components. One kit consists of a set of parts for one assembly object. Many kits for several assembly objects can be supplied at the same time but the parts for one object are held together. (Johansson M. I., 1989) According to Baudin (2002), the kits should be delivered to the line just before assembly so that the kits do not get obsolete. An example of kitting parts to a mixed-model assembly line is shown in Figure 27.

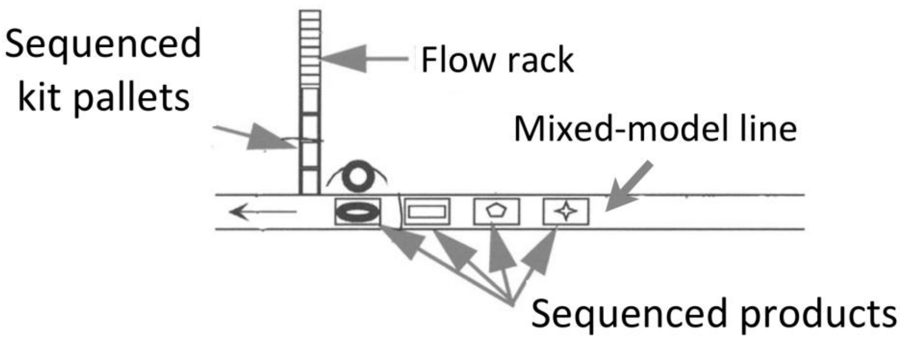


Figure 27 Kits delivered to a mixed model line after Baudin (2002)

According to the literature the main advantages with kitting are as follows:

- *Productivity* - Supplying kits of parts to the line reduces walking and handling at the assembly line. Picking operations when picking the kits are possible to design so that less picker time per part is needed compared to when the assemblers at the line pick the parts. Consequently, it increasing the productivity. (Baudin, 2002)
- *Assembly quality and learning* - According to Alper (2008), kitting can be used to control the pace of the assembly work and can be utilized as a work instruction ensuring assembly quality and reducing learning time. This would be especially important if cycle times are long to support the operators. It can also be used in this way to prevent the operators to work ahead if this is strived for.
- *Picking errors* - Baudin (2002) argues that the main advantage of supplying kits of parts or sequenced parts to the line is to prevent picking errors by the assemblers and thereby improve picking quality. The assemblers are less likely to confuse kits of parts for different products than individual parts.
- *Space requirement in the material façade* - Floor space requirements are less if using kits compared to line side stocking. (Bozer & McGinnis, 1992)

According to Baudin (2002), a reasonable strategy on a mixed-model line is continuous supply with single part presentation for common parts, and for as many product-specific parts as one can fit on the shelves, and kitting for remaining product-specific parts.

Sequential supply

Johansson & Johansson (2006) defines sequential supply as the supply method when part numbers needed for a specific number of assembly objects are displayed at the assembly stations sorted by object.

One advantage with sequential supply is the fact that, if the product is assembled on a serial line where only a few components are assembled at each station, kitting may require too much material handling to be economically justified. Kitting for this kind of assembly line would require a lot of extra material handling work to prepare kits for each station. (Johansson & Johansson, 2006) Another reason for using sequential supply instead of kitting is according to Baudin (2002) that the size of the parts may not lend itself to have in a kit. Sequencing of individual parts to the line may then instead be more feasible.

The work with sequencing the material can be located within or outside the assembly plant, which means that the materials feeding principle can differ between the assembly station and the supply chain. This is also true for the other materials feeding principles like batching or kitting. (Johansson & Johansson, 2006)

2.7 Assembly quality

2.7.1 Background

Several authors describe how product variety in assembly environment and especially mixed-model assembly lines are a source of different problems for the operators. The risk of picking the wrong part is often mentioned and, according to Baudin (2002), Bayers (1994) and Shimbun (1988), part confusion in assembly is the primary cause of defects in manufacturing today. This problem grows with increased use of mixed-model assembly lines. Other common problems related to model variety mentioned by both Cheldelin & Ishii (2004) and Zhu, Jack Hu, Koren, & Marin (2008) are that the operators must make correct choices among several alternatives. This includes for example choosing the correct tool, fixture and assembly procedure for the right variant. Swaminathan & Nitsch (2007) sees a problem in that the product variety requires the line operator to deviate from the standard operating sequence. They define it as the sequence of work elements for the base model at a given workstation and if the demand variety is handled at the level of the assembly line the operator also has to chose the correct component. The probability of choosing the wrong part increases with more variants.

Cheldelin and Ishii (2004) clarify and identify the most common human errors when putting products together in mixed-model environments as: omission, incorrect installation, installing the wrong part, and “other” incorrect operations. (Cheldelin & Ishii, 2004)

Shift changes and operator fatigue effect omission errors in all manufacturing environments. The omissions will increase in a non-linear fashion in mixed-model environments because of that the variety increases. The complexity of operations increases when they do not follow the same assembly routine all day, this will lead to that operators are more likely to omit a part or operation. (Cheldelin & Ishii, 2004) Incorrect installation can occur due to a number of reasons. Some examples are according to Cheldelin and Ishii (2004): Incomplete operations, usage of the wrong installation tools or fixtures, different installation requirements for each model, and varying assembly orders. Some examples of why the wrong part is used are: the operator selects the incorrect part from a bin of similar parts, the wrong part is presented to the operator during assembly, or the wrong part is manufactured and the problem is not caught. (Cheldelin & Ishii, 2004) There are several other problems related to mixed-model environments, some of them are related to production planning and material flow. It can for example be the case when an operator has to manually key in product codes and serial numbers which, if done incorrect, leads to wrongly presented process sequences and tracking issues. (Cheldelin & Ishii, 2004)

An approach in the literature for dealing solely with mixed-model assembly errors has not been found. Several of the techniques in the literature are applicable in many types of assembly systems. Cheldelin and Ishii (2004) argue that there are three techniques that show the most promise in reducing mixed-model errors. They are barcoding, kitting, and Active Part Tracking (ie- Magnetic ID, and Radio- Frequency Identification (RFID)). These are further explained in the following chapters.

2.7.2 Poka-Yoke

Different quality inspection approaches are described in the literature. Bayers (1994) and Shimbun (1988) describe judgement inspection as an approach to detect quality which means that companies search for defects and correct them after they have occurred. They also describe a second approach called informative inspection which means that when a specific quality issue reaches a certain level, information about it is sent back to the appropriate process so that action can be taken to reduce the defect rate.

There are two main problems with retrospective quality controls. First of all, the quality inspectors may not discover all the quality issues and some defect products will therefore reach the customers. The second problem is that the correction of defect products is expensive because it often requires that the product is repaired or reworked. (Bayers, 1994) Shimbun (1988) describes a third approach called source inspection which means that 100 per cent inspection is done at the source which leads to that mistakes can be corrected before it becomes a defect.

Poka-Yoke is a Japanese expression meaning mistake proofing. Poka-Yoke implies that defects should be eliminated during the process instead of afterwards. Bayers (1994) mentions that Poka-Yoke solutions can lead to that customer dissatisfaction and the high costs related to defects can be eliminated.

Shimbun (1988) describes that judgement inspection and informative inspection only can be used to control quality, but they cannot be used to eliminate the defects. Shimbun (1988) describes an approach called Zero Quality Control that leads to elimination of defects. Zero Quality Control is a combination of source inspection, Poka-Yoke and immediate action.

Bayers (1994) argues that Poke-Yoke devices should be developed in cooperation between operators and engineers. The operators are the people that perform the work every day which means that they have the greatest understanding of it. The engineers should coach the operators and encourage them to come up with new Poke-Yoke solutions instead of forcing new ideas on them. Shimbun (1988) mentions that design changes are a powerful Poka-Yoke tool. Baudin (2002) argues that a standardised product design, with as many common parts as possible and with constrains that makes it impossible to misplace a part, is the only way to make an assembly mistake impossible. This is unfortunately usually not possible; consequently, companies have to work with other methods such as for example part presentation. Shimbun (1988) goes on highlighting the importance of operator involvement when performing design changes such as refinement or redesign. This is important because the operators know the process and can therefore discover design changes that cause confusion without adding any extra value to the product.

The management's involvement in quality issues is important. The management must, according to Shimbun (1988), have a vision that creates a culture that supports the employees in their quality work. Bayers (1994) mentions that managers must improve processes to eliminate defects because everyone will eventually makes mistakes if there is any room for it. Time and effort have to be spent continuously to reduce defects in production (Shimbun, 1988).

2.7.3 Product design

Baudin (2002) discusses that the only way to make mistakes impossible is to design the products in a way that prevents mistakes. There are two methods to do this:

1. The first approach is to use common parts between models. Every time the same part is used on two models one opportunity to make a mistake is reduced.
2. The second approach is to design parts so that they are impossible to assemble on the wrong product.

Lean product development with more standardised interfaces, fewer parts and greater modularity results in that the product variety will have less impact on the assembly plant. (MacDuffie, Sethuraman, & Fisher, 1996) Zhu et al. (2008) also mentions product design strategies such as process commonality strategies and option bundling strategies.

Strategies involving the production process can be to delay the differentiation of the product downstream to minimize the risk. Another possible solution that could be used is to have parallel workstations at critical paths to reduce the number of choices at these stations if it is possible to wisely route similar variants to the same stations. However another problem arises because the assembly system is no longer serial. Balancing systems with parallel workstations is a demanding task. (Zhu, Jack Hu, Koren, & Marin, 2008)

Often the manufacturing department have little influence on how the product is designed, at least in the short term. If it is impossible to design out mistakes the people responsible for production must according to Cheldelin and Ishii (2004) either: identify where to install error proofing technology, identify approaches to simplify the assembly process, or inspect parts after assembly is complete. Some methods in these approaches will be further explained below.

2.7.4 Automatic identification

Radio Frequency ID (RFID)

Gaukler & Hausman (2008) describe a system used to improve picking quality in production called Radio Frequency ID (RFID). In a RFID system, tags, usually containing a computer chip holding information, are attached on parts, containers, components, or any kind of equipment. The tag sends information to a computer after being scanned with a stationary reader device when a unit is entering a station. The computer picks up the bill of material for the product that shows what components that are to be produced at the specific station. A reader could also be placed close to the bins where the components are stored; the reader only registers a component that is taken out of the bin, verifying that it is the correct one. When the unit exits the station the tags are scanned with another stationary device. The system verifies that all the right components have been assembled and it alerts if any disallowed parts have been assembled. (Gaukler & Hausman, 2008)

The difference between RFID and conventional bar coding is, according to Gaukler & Hausman (2008), that it does not require any operator interaction because the tags are scanned automatically. Budin (2002) argues that it is too time consuming letting operators scan components with a hand held device and that it is therefore more efficient to use readers that automatically scans components or units.

Gaukler & Hausman (2008) argue that RFID is a powerful tool when it comes to reduce defects caused by picking errors. It is useful in environments where several components that are different, but similar in appearance and interface, are presented to the operators. Gaukler & Hausman (2008) go on saying that RFID improves the quality of products and that it decreases the time spent on ensuring good quality compared to other solutions where the operators have to manually scan items. Cheldelin & Ishii (2004) mention that RFID is useful when it comes to achieve JIT deliveries to the line because it can alert when and in what order material should be delivered to the line. The most mentionable drawback with RFID is that it is not yet as mature compared to other technologies such as bar coding or pick-to-light (Gaukler & Hausman, 2008).

Bar coding

Baudin (2002) and Cheldelin & Ishii (2004) mention that a common approach to overcome picking errors in assembly or in warehouses is the use of bar codes. Bar codes are read with a hand held device connected to a computer. Bar codes are cheap but they can be inappropriate to use in manufacturing environments because of that dirt may lower the contrast on the label. Bar codes can be laser-engraved on metal parts but it is quite expensive. Laser-engraved bar codes, or 2-D barcodes, have much higher data density and therefore requires less space than conventional barcodes. They can also be used in manufacturing environments where conventional barcodes are inappropriate as mentioned above.

2.7.5 Kitting

The use of kitting eliminates the need for the operator to make critical decisions. Instead of choosing the right part from a bin with several parts, the operator gets the right parts needed in a kit. The kit should consist of the parts needed for an operation and it should be placed in a convenient location for the operator. A shadowbox is a variant of kit where a label with part name and number is placed next to the part. The kitting box could be shaped to fit the different parts. A kit together with shadowboxing helps the person filling the box and the operator performing the assembly. Another similar method used to avoid that the wrong parts are used is a visual part comparison board. An example is a bolt board with all the bolts used for assembling a specific product. The operator can compare a bolt he or she thinks is incorrect with the bolts on the board. (Cheldelin & Ishii, 2004) More advantages and information about kitting is presented in chapter 2.6.

2.7.6 Sequenced delivery

An approach is according to Fujimoto et al (1997) and Baudin (2002) the sequential delivery system, in which components are supplied to the assembly station in a sequence that exactly matches the sequence of body variations. This method is further described in chapter 2.6. There are an increased number of parts that are shipped in sequence by outside suppliers, or are sequenced inside the plant. In the automotive industry the number of parts that can be sequenced by outside suppliers is limited due to lead times. Often the sequence of models is decided as late as the first assembly station limiting the lead-time of the sequenced parts to a few hours.

2.7.7 Mistake-proofing line-side picking

Sequencing and kitting parts to the assembly line to prevent picking errors is the best way to go but may not always be possible. (Baudin, 2002) All parts may not lend themselves to be delivered in kits or in sequences to the line. Other methods like mistake proofing devices and automatic identification must then be used instead to assure that the line side picking quality is high even if the parts are supplied to the line in a traditional way. Simple mistake proofing devices can be for example a carrousel that rotates and only exposes the operator for the right part to pick for the specific model. An example of this is seen in Figure 28. (Baudin, 2002) There may be many types of variation of this theme based on mistake proofing the picking process.

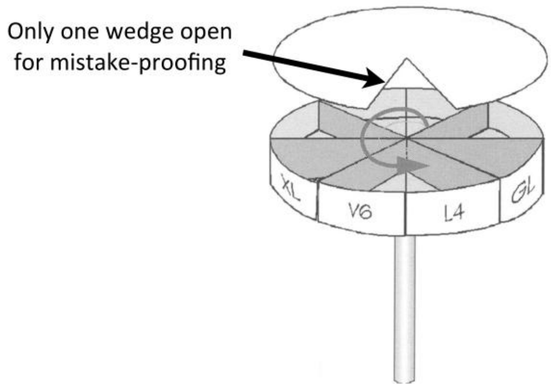


Figure 28 Example of mistake-proofing device for line side picking after Baudin(2002)

Naming items to avoid confusion may be an obvious and trivial approach but according to Baudin (2002) many companies use documents with confusing labels.

2.7.8 Pick-to-light and pick-to-voice

Pick-to-light is a visual aid system that can be used at the line to ensure that the operators are picking the right parts or components (Baudin, 2002; Gaukler & Hausman, 2008). However, the picking quality has to be ensured upstream in the supply chain if the overall quality of products is to be ensured. This is crucial in a situation where parts and components are presented to the operators in kits; consequently, pick-to-light can be used in the warehouse where kits are prepared. (Baudin M. , 2002)

A pick-to-light system can be combined with some kind of automatic identification system where a LED light next to a bin with the right component is lit when a unit passes a reader device. Baudin (2002) argues that a pick-to-light system increases productivity because operators do not have to search for the right item to pick from a list. He also means that it reduces the risk of picking errors. (Baudin M. , 2002) Gaukler & Hausman (2008) describe that there is no documentation of serial numbers of installed parts in a pick-to-light system. This could be seen as a drawback because of that traceability is important in some manufacturing environments.

Pick-to-voice technology is often used in the material handling area apart from the line to ensure that the correct parts are sent to the line. The picker gets instructions from a computer about what parts to pick through a headset. The picker reads a control digit through a microphone to confirm that the right part has been picked. (Rushton, Croucher, & Baker, 2006)

2.7.9 Pick quality from supplier to assembly line

The literature review in the previous chapters has been focused on picking quality regarding the operator at the line side. Of course, if the wrong parts are kitted or supplied from suppliers the operator will pick the wrong part anyway. Baudin (2002) mentions that one must also protect against mistakes made upstream in the supply chain. The methods mentioned above regarding picking quality must be used to prevent mistakes from the receiving dock to the assembly line as well as helping the suppliers use the methods so that right parts are delivered. As an example pick-to-light is often used in at the logistics function where operators pick kits for the assembly line as well as at the assembly line. (Baudin, 2002)

3 Volvo Production System

This chapter provides information on how Volvo Production System describes a production system. The information is based on Volvo Technology (VPS Academy, 2011) education material. The purpose of this chapter is to ensure that the view of the areas that are important in terms of mixed-model production that have emerged through the literature review and the interviews, is in line with Volvo production system's view of the same.

3.1 Introduction to Volvo Production System

Volvo Production System (VPS) serves as the source of common principles and practices. The overall vision of VPS is:

"An organization where we continuously improve quality, delivery and productivity, in everything we do."

The Volvo Production System consists of three parts:

- *The model* - The Volvo Way is the foundation and together with the five main principles the focus on the customer is visualized, see Figure 29.
- *Implementation* - An implementation process is available to help guiding in how to implement VPS. Guidelines and suggested tools and methods are used to support the implementation in each phase of deployment.
- *Drivers* - KPIs are used to measure the effect of implementation and assessments, provide feedback on results achieved and show which and to what extent VPS tools and methods are used.

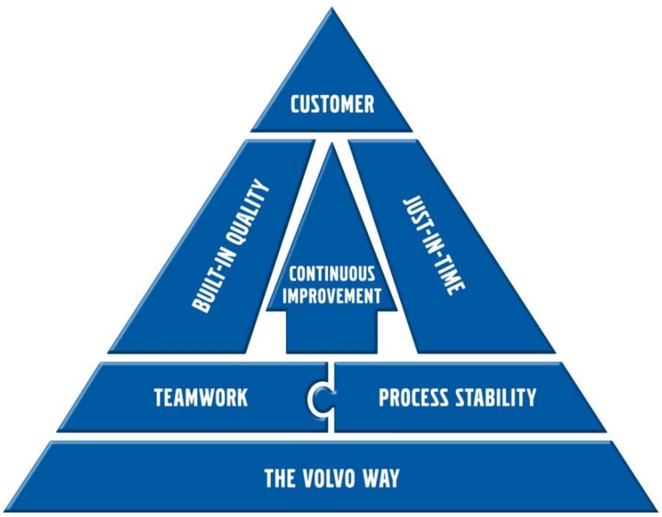


Figure 29 Volvo Production System model

Figure 29 shows the VPS model with the foundation; The Volvo Way, and the five main principles Teamwork, Process Stability, Built-in Quality, Just-in-Time and Continuous improvement. A short introduction to the principles follows below:

- *Teamwork* - An organization where all employees are involved in the improvement process. Everyone contributes to the achievement of goals and strategic objectives.
- *Process stability* - All kinds of waste and variability is reduced to create predictable and efficient processes.

- *Built-in Quality* - Detect and correct problems at the point of origin and do things right the first time.
- *Just-in-Time* - Produce what is needed, when it is needed, in the amount needed.
- *Continuous improvement* - Is the driving force behind the VPS efforts and is a long-term approach based on standardisation.

3.2 Assembly systems

3.2.1 Type of assembly systems

According to VPS Academy the production process should be structured according to the "fishbone factory" concept. Figure 30 illustrates a fishbone factory. The solid arrow represents a short main line and the dotted lines represent various sub flows. The products should be based on a base module. Deliveries through the sub flows should be in sequence and preferably in complete sub assemblies and standard interfaces/marriage.

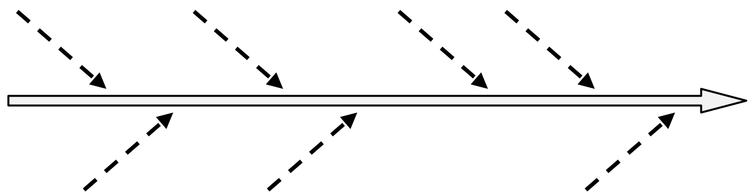


Figure 30 Fishbone factory

3.2.2 Takt driven production

Takt time is a part of the principle Just-in-time in VPS, see Figure 29. The takt is determined by the customer demand and it connects the customer demand rate with the flow of the production. Takt time is the maximum time allowed in order to meet customer demand and the cycle time is the time from the beginning to end of a process.

Takt time is important for determining several key operating decisions:

1. The number of people necessary.
2. The number of processes, machines and tools necessary.
3. Amount of work in progress required in the area/process.
4. The allocation of labour and machine combinations.

Using pure takt time is not always effective and therefore alternatives are presented by VPS Academy. Target cycle time is preferred if there are inefficiencies in the process or delivery constraints. Using weighted average cycle time is preferred if the work contents differ by typically more than ten per cent.

Target cycle time

Target cycle time or adjusted takt time is a function of the takt time. As a rule of thumb manpower issues results in an inefficiency factor between 90 per cent to 100 per cent and overall equipment effectiveness results in a factor from 80 per cent to 95 per cent. VPS Academy also suggests that historical data should be used to determine the best inefficiency factor.

$$\text{TCT} = \text{takt time} \times \text{Inefficiency factor} \tag{3}$$

Weighted average cycle time

If the work content on one line varies significantly and the production system is designed to takt, then the manpower requirements for each product will vary significantly. Then weighted average cycle time is suitable. Calculation of the weighted average cycle time is done with formulas 4 and 5.

$$WACT = \frac{\sum_{i=1}^{n} ACT_i \times D_i}{\sum_{i=1}^{n} D_i} \tag{4}$$

$$ACT_i = \frac{WC_i}{TM} \tag{5}$$

ACT_i = Average cycle time for product *i*
D_i = Demand of product *i*
WC = Work content of product *i*
TM = Total manning

3.2.3 Pull and continuous flow

In a pull production system a process step only continues when the next process order is received. The pull system has a positive impact on both delivery and productivity.

A pull system brings several benefits. It prevents overproduction, lack of parts and control inventory. It visualizes the production system and makes it easier to understand. It gives autonomy to the shop floor.

Before implementing a pull system a prerequisite are stabilized processes that are able to supply the next process with parts of good quality and at the rate required. Furthermore the flow should be one-piece-at-a-time and the takt should be the rate of customer demand, see Figure 31.

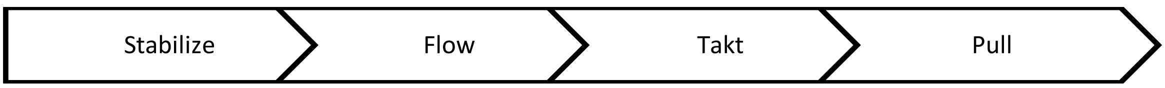


Figure 31 Implementation of pull system

Continuous flow

Continuous flow is obtained when removing the WIP between processes and producing one-piece-at-a-time, this reduces transportation, movement and space. The lead-time is reduced as a consequence of minimized in-process stock in the loop.

FIFO lane

A First in First out (FIFO) lane ensures that stored parts do not become old or that quality problems are built in to the inventory. The size of the FIFO lane depends on the variation in work contentment across variants in the preceding process. A FIFO lane requires a levelled production environment.

Supermarket

A supermarket is an in-process store that increases the flexibility in the production. The size of the supermarket depends on the reliability and changeover ability of the production process. The supermarket should hold at least one piece of every variant and be located and owned by the preceding process. The supermarket requires a levelled production environment.

Three types of pull systems

- Sequential pull systems are systems where upstream and downstream processes transform parts in the same order.
- Fill-up pull systems are characterised by a supermarket containing all variants after each process.
- Mixed pull systems function as fill-up or sequential pull for different variants.

3.2.4 Just-in Time

Just-in-Time is one of the five main principles in VPS, see Figure 29. VPS Academy defines Just-in Time as:

" Producing and conveying just what is needed, just when it is needed, in just the amount needed"

Just-in-Time is achieved by continually reducing the manufacturing lead time to achieve continuous one piece flow without any stagnation.

VPS Academy lists eight points to identify a Just-in time flow:

- Flows are dedicated to product/customer.
- Continuous one piece flows wherever possible.
- Balanced cycle times.
- Production adjusts without delay to the takt.
- Delivery time and precision meets the customer demand.
- Remaining stocks are either in visible FIFO lanes or in controlled supermarkets.
- All variances can be visually detected in real time.
- Bottlenecks are identified and running continuously, some machines stand still due to lack of demand or variability.

Figure 32 The Just-in-Time implementation process

The implementation of Just-in-Time is done in five steps, see Figure 32. The correct material has to be supplied to the station in the right time and be presented in a way that allows the operator to be efficient in picking. The flow in each production loop should be in one piece flow. The production should be at the same pace as the customer demand. A pull system should be utilized and finally the manpower should be flexible to be able to adjust to changes in demand.

3.3 Standardised work

Standardised work is included in principle Process stability in VPS, see Figure 29. Standardised work supports ergonomic and safety activities, quality issues, productivity and cost benefits. It should therefore be implemented in the beginning of a change process.

Standardised work forms a basis for continuous improvement (kaizen) as it makes it able to evaluate improvements if the work is standardised. Furthermore standardised work creates a smooth and efficient production flow and provides repeatable work.

VPS Academy describes the takt time, standard operating sequence and standard in-process stock as the basic components for standard operations.

- *Takt time* – Standard operations define and organize worker movements to meet takt time.
- *Standard operations sequence* - Defines the order of operator’s movement. Benefits include providing smooth operating sequence which reduces the waste of motion, ensures high quality, safety through repetitiveness, consistent steps and standard sequence used in training.
- *Standard in-process stock* - Is influenced by three factors, the direction of operator movement to material flow, manual vs. automatic operations and number of operator transitions. Standard in-process stock acts as a “lubricant” in the production line and is a prerequisite to maintain takt and one-piece flow.

Figure 33 Process to build standardised work sheets

Implementing and building standardised work sheets is done in three steps, see Figure 33. Measuring the work includes observing the current process to define the process and prepare applicable documentation. Defining the new process includes confirming the target takt time, eliminating unnecessary work steps and reallocate work element and preparing appropriate documentation. The third step is to plan, pilot and implement the new standard. It includes among others validating that the standard meets safety, quality and cost objectives and training affected employees. The end result is standardised work sheets.

To keep standardised work alive it must be shared and owned by every employee and be validated and proven as useful. Sufficient training is needed when implementing and changing the standard and it must be reviewed endlessly to reflect any change or build on improvements ideas.

3.4 Planning and control

3.4.1 Levelled production

Production levelling is a part of the principle Process stability in VPS, see Figure 29, and the key elements are production planning and schedule adherence. Smoothing out the volume and mix of items to minimize variations from day to day is a foundation for flow, takt and pull systems and it influences the need for flexible manpower. Production levelling is also necessary to avoid peaks in production of certain products that could create shortages of inventory.

The primary objective of levelled production is to promote flow and reduce waste and the secondary objective is to reduce lead times.

The first benefit with a levelled production according to VPS Academy is stability through reduced waste from operators and machines being starved or chocked for some time periods. Better visibility, introduced consistency and a sense of rhythm to the schedule also creates stability. The second benefit according to VPS Academy is the decreased inventory as a result of the levelled production. The demand can be met without large volumes of inventory and this result in reduced raw material and finished goods inventories. The third benefit is increased flexibility and response time to the customer. The production is closer to the real demand and changes in orders will not be catastrophic since production can be adjusted during the course of the day, week, or month.

Production levelling is divided into three levels:

- Capacity planning on a monthly basis
- Order levelling on a weekly/daily basis
- Production levelling and execution

Capacity planning

Capacity planning is based on forecast and the takt agreed upon with marketing, sales and manufacturing. Capacity is defined as the maximum amount of work that an organization is capable of completing in a given period of time. The capacity is calculated with the following formula:

$$(\text{Number of shift hours}) \times (\text{Theoretical cycle time}) \times \text{OEE} \tag{6}$$

Order levelling

The goal is to smooth out the customer demand. There are different ways to manage production resources to variable demand.

1. Match product capacity to “fixed” demand for a given period.
2. Level the demand to “fixed” capacity for a given period.
3. Use a combination of 1. and 2.

Production levelling and execution

Production levelling and execution is a method for smoothing the mix of products passing down the line in terms of frequency and variety. Production levelling is a prerequisite for Just-in-Time but it is not a perfect solution compared to if the products could be buildt in the sequence of orders received.

3.4.2 Balancing

Dividing the work load between the operators in order to be able to produce to takt is called line balancing. The output should be maximized. A prerequisite for balancing a line is that the takt time and time for each work element is known. Balancing is done by transferring work elements between stations or even to previous processes of the assembly line such as to the body shop or paint shop.

Operator balance charts

Dividing the work elements on the work stations can be done with the help of stack bar charts called operator balance charts or Yamazumi charts, see Figure 34. Because the stack bar chart graphically depict the work element times at each station in relation to the cycle time and takt time the chart can be used to reveal improvement opportunities. The chart can also be used when rebalancing the line.

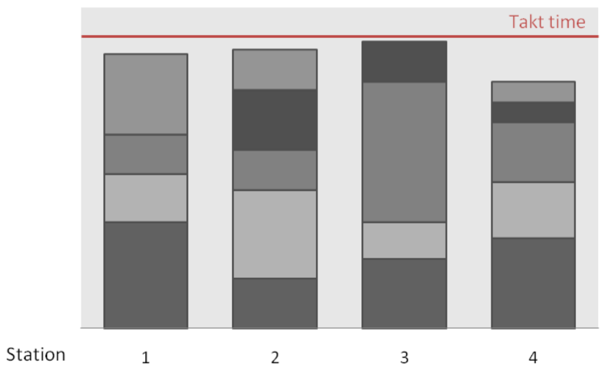


Figure 34 Operator balance chart

Steps to get a better line balance

VPS Academy gives seven hints that can help improve line balance.

1. Try to improve levelling conditions if a delay is caused by distorted levelling.
2. Focus on improving the model that has large work quantity.
3. Pay attention to the wasteful movement of fetching parts or tools.
4. Investigate whether any parts of lower quality have intermingled or not when the variation of the operation time appeared large.
5. Re-assign some work elements to the process having idle time.
6. Improve or re-design the jig or fixture if some part is difficult to be handled because of the car structure.
7. Try to examine the possibility whether an operation requiring two or three workers can be done only by one worker.

50 second rule

No repetitive manual operation should have a cycle time shorter than 50 seconds. The productivity is affected more if three seconds are lost on a 30 second cycle than a 60 second cycle. Stress injuries and fatigue increases when performing the same motion more often than 50 seconds. The quality increases as the worker feel more of an ownership and errors caused will affect her/him in the next task. The job satisfaction and morale increases when they feel they are building something when working in longer cycles than 50 seconds.

3.4.3 Sequencing

VPS Academy describes that in order to reduce unevenness and overburden a good sequence must be decided. Figure 35 illustrates that products with a high work content such as products A and C should be followed by products with smaller work content such as product C. It is then possible to have time to assemble A and C even though the assembly time is larger than the desired takt time.

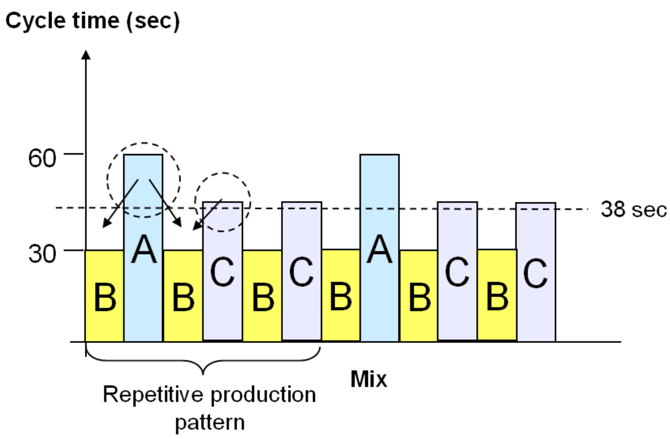


Figure 35 Sequencing

3.5 Time losses

3.5.1 Flexible manpower

Flexible manpower is a part of the principle Just-in-Time in VPS, see Figure 29. It is a way of increasing the flexibility to efficiently meet changes in customer demand.

VPS Academy describes four different options to apply Flexible manpower. Each option is triggered by a different level of variability.

Low variability - Option 1: Levelling
If there is variability due to small changes in demand and the variability are considered low, then it can be levelled out before the production starts without affecting the customer.

Medium variability - Option 2: Andon
When there are medium surges in the demand the use of an Andon Team Leaders or Andon support teams could be triggered.

Medium variability - Option 3: Overtime
If the demand variability surges continue then the next option would be to use overtime. This could be the case if for example the daily output cannot be achieved without extra operators or if there are known demand surges then planned overtime each day or on weekends could be used.

High variability - Option 4: Manpower allocation
High demand variability may require a full re-allocation of manpower. For example by adding or removing shifts, building additional lines or changing contracted hours. The manpower can also be moved between lines or be used in improvement projects. There is also a possibility to use temporary workers.

3.5.2 Bypass line
When products with different work content are to be handled on the same line it can be difficult to balance the line in a way that the work load on each station is as even as possible. For products with an extremely long assembly time a bypass line can be used.

3.6 Material handling and supply
VPS Academy presents a number of material supply tools to help facilitate stable flows of well presented material to the material façade. Material supply is a part of the principle Just-in-Time in VPS, see Figure 29.

Milk runs
Milk runs are routes that are used by replenishment trains or similar. The train travels a fixed route along the line and delivers components at the locations where replenishment of parts is necessary. The milk run process is initiated from the line where for example a physical kanban or scanning of an empty box is used to create a list of parts to be delivered on the next delivery. The train is loaded according to the list at a preparation area, for example supermarket or warehouse, and then drives to the first stop on the line. Empty boxes at the line are collected and returned to an empty treatment area.

Some advantages with milk runs are:

- Fixed optimal replenishment frequency.
- Several handling units of many different part numbers are replenished in the same loop.
- The delivery flow can be more easily managed and it is possible to even it out.
- Fixed route specially defined for each case, higher respect for security measures.
- Unique working routines optimised and set for all kind of parts.
- High replenishment frequency makes possible the use of smaller packing allowing the high diversity in the line and smaller working stations.
- Wide alleys allowing forklifts bends are no longer necessary. The space can be used for wider racks.
- Empty packing is collected by the same train at every stop.

Some disadvantages are:

- Line cover times must be analysed and adapted for all parts to be replenished by the train.
- Repacking may be needed as manually handling packing subject to weight constraints dictates requirements. It is also possible to include repacking in the train driver's workload.

2 bin system

A 2 bin system is a system of replenishment with two bins and where a new lot is called for as a previous lot is used up. The bins must contain enough parts to cover at least the maximum time for replenishment. The system is often combined with milk runs to reduce the stock in the material façade.

Sequencing

Delivery of components in sequence to match the production is called sequencing. Sequencing of components can be done at for example the point of consumption, in a warehouse or at the supplier.

VPS Academy lists some advantages with sequencing:

- Sequencing to the line side will possibly remove additional handling points.
- It will free up space in the warehouse and at handling points.

Some disadvantages are:

- Sequencing may require new containers to be able to deliver the material in sequence.
- The suppliers or earlier process steps must be able to handle sequence deliveries.

Kitting

The concept of only presenting the material required for the next product at the material façade is called Kitting. The material is presented on a tray or cart to be easy to handle for the operators. Reliable information of what is going to be produced is a prerequisite for using kitting as there must be enough time to pack and deliver the material kitted.

Some of the advantages with kitting are:

- Decreases the inventory on the assembly line.
- Decreases forklift movements inside the production area.
- Higher production flexibility.
- Eliminates time to find parts.
- Decreases operator movement.
- Alternative to smaller packages in serial flows.
- Complex products can be overviewed and understood.
- The material kit can be used as a work instruction.
- Optimizes the material presentation.
- Increased quality in production.

Disadvantages are:

- Requires special rack.
- Increased cost for material handling.
- Risk of kitting too much.

3.7 Assembly quality

The VPS principle Built-in Quality, see Figure 29, describes how to achieve good assembly quality and developing a quality culture. To achieve zero defects, systematic and pro-active work is needed in product design and process development. Built-in Quality means detecting and correcting problems at the point of origin and doing things right the first time.

To achieve a good Built-in Quality several steps must be taken. The product and process planning must ensure that new products and processes introduced to the production are designed with good quality. There must be a Quality assurance that continuously reduce the cost of quality and defects and ensures that only products of a good quality reach the customer. Finally tools and methods must be used to achieve zero defects and a good assembly quality.

Zero defects

VPS Academy presents a number of methods to ensure that products are designed and manufactured with a good assembly quality with zero defects.

Autonomation

Autonomation means intelligent automation (Jidoka) and is derived from the words “autonomous” and “automation”. When a defective part or equipment malfunction is discovered, the machine automatically stops, and operators stop work and correct the problem. This enables operations to build-in quality at each process and to separate men and machines for more efficient work.

The biggest value of autonomation is that it eliminates the need for an operator or operators to watch over each machine continuously.

Quality alert systems (Andon)

An Andon system is a tool operators use to signal if they have encountered a problem. The call for help is shown on an Andon board or signalled by a certain sound or tune. People will then come and assist in correcting the problem. An Andon system allows the shop floor team leaders to spend more time solving abnormalities since less time and effort is required to monitor the situation.

Poka yoke

Mistakes are avoided by the use of design or process features to prevent errors or their negative impact. Poka Yoke is an inexpensive tool that is very simple and yet very effective. Poka Yoke can be located before, during or after the process.

Common Poka Yoke devices are guide pins, blinking lights and alarms, limit and proximity switches, counters and checklists. Poka yoke systems consist of the three primary methods; contact, counting and motion-sequence.

The contact method functions in the way that it detects whether or not a device makes contact with a part or object within the process. Examples of physical contact devices are limit and toggle switches. Energy sensors are for example photoelectric switches, vibration sensors or pressure transducers.

The counting method is useful when a fixed number of operations are required within a process or when a product has a fixed number of parts that are attached to it. The number of operations or number of times a part is used is counted by a sensor and only allows the process to continue when the correct number is reached. The method can also be used to count the number of parts or components necessary to complete an operation in advance. If parts are left over the operator knows something has been omitted when using the method.

The motions-sequence method use sensors to determine if a movement has occurred or occurred out of sequence. Photoelectric devices that are connected to timers can be used in this method.

Source inspection

Detection is carried out at the error stage before any defects occur. Source inspection is the ideal method for quality control since quality feedback about conditions for quality production is obtained before the process step is performed.

4 Method

This chapter explains how the project has been performed. The chapter consists of a description of the research strategy, the research approach, the data collection and the interview process.

4.1 Research strategy

After that the purpose of the project was determined, a number of research questions were formulated. The researchers had prior knowledge in the field of production but more thorough knowledge was needed to perform the project. Therefore, an extensive literature review was performed. The literature study was complemented with an interview study to get the views and opinions of people experienced in the field of production. Factory visits were performed in connection to some of the interviews to gain further understanding of the subject. The data collected in this project was both primary and secondary. The interviews and study visits were primary data whilst the literature review and the VPS review were secondary data.

The literature review aimed at covering all the necessary areas related to manual assembly in mixed-model environments. The headlines in the literature review were then used as the basis for the rest of the theoretical part and the empirical part of the report. This made it easier to analyze and compare the opinions derived from different sources of information.

The researchers developed a general model valid for VCE operations in Sweden after analyzing the gathered data. The current state at VCE in Arvika was then analyzed and compared to the general model to establish what parts of the model that where most important for VCE in Arvika. The initiative to this project was taken by VCE in Arvika in combination with the department of Transportation and Logistics at Chalmers University of Technology. The guidance from the supervisors at VCE and Chalmers has been valuable. However, the researchers have tried to be as objective as possible throughout the project. Limited time was spent at VCE in Arvika when the general model for mixed-model assembly was developed. This approach was taken to ensure that all important prerequisites were included in the model despite of the effort needed to realize some of them at VCE in Arvika. This ensured that the researches were not influenced by preconceptions.

The research strategy of this Master´s Thesis is presented in Figure 36.

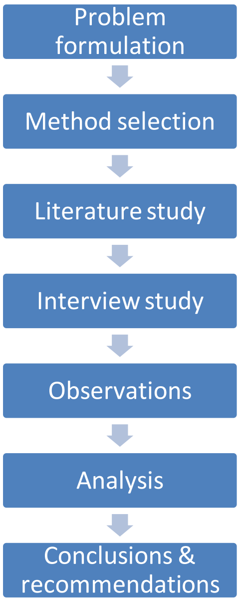


Figure 36 Description of research strategy

4.2 Research approach

One could in general choose between two research approaches; inductive and deductive. The deductive approach was chosen in this project. This project started with an extensive literature review that was later compared to the empirical findings. A lot of the theories described in literature were related to the automobile industry, the researchers therefore found it interesting to investigate if these theories were applicable to the industry described in this project. There was a wealth of literature available within the different areas related to mixed-model assembly from which a theoretical framework could be defined. In this context, which is described by Saunders, Lewis & Thornhill (2009), a deductive approach is more suitable than an inductive approach. The deductive approach seeks to use existing theory to shape the approach that one adopts to the qualitative research process and to aspects of data analysis (Saunders, Lewis, & Thornhill, 2009). The inductive approach is more suitable when specific observations are made to develop broader conclusions, generalisations, and theories about a subject where there is a lack of available literature (Saunders, Lewis, & Thornhill, 2009).

4.3 Qualitative collection of data

The data gathering approach used in this project has been qualitative. A non-participant approach characterized the observations which according to, Glenn (2010), may inhibit the researches´ ability to understand the experiences of a culture. Small but focused samples instead of large random samples have been gathered which is in line with a qualitative study (Glenn, 2010). Qualitative data are according to, Glenn (2010), descriptions of observed behaviours and direct quotations from people about their experiences, attitudes, beliefs and thoughts.

4.4 Interviews

The interviewees are presented in chapter 5.1. They were chosen because of that they had experience from working with mixed-model assembly or because of that they had general experience within the area of manual assembly. The interviewees worked for different companies which are presented below together with a motivation of why they were chosen.

- *Scania* – Have for many years assembled their products on mixed-model lines in a context similar to VCE in Arvika.
- *VCE Braås* – Have recently implemented a mixed-model line in a context similar to VCE in Arvika.
- *Volvo Cars* - Have for many years assembled their products on mixed-model lines. Different context compared to the above mentioned companies.
- *Volvo Technology* – Their input were important because of their knowledge about Volvo's strategies regarding production.
- *Department of Logistics and Transportation* – It was interesting to get an objective academic view of the discussed subjects.

Validation is an important part of a qualitative study which can be established in many ways. One approach is, according to Glenn (2010), interviewer corroboration which has been used when handling the interview material in this project. All interviewees have approved that their opinions are treated non-anonymous. A discussion about the interviewees´ is held to illustrate that their different backgrounds affect their opinions in the discussed subjects. Qualitative interviews can, according to Gubrium & Holstein (2002), be described as guided conversations which have been the interview approach in this project. The interviews were conducted in a semi-structured way with open-ended questions which is described by Gubrium & Holstein (2002). The interviews were handled in this way to ensure that the interviewees could elaborate freely about their experiences and opinions.

The interview process is described below.

- *Preparation* – Several questions were formulated. The questions were formulated to cover the sections in the literature study.
- *Execution* – One person were appointed main interviewer while the other took notes. All interviews were recorded with a tape recorder.
- *Transcription* – The Interviews were transcribed.
- *Summary* – The most important information from the transcribed material was summarized under the same headings as in the literature review.
- *Validation* – The material was sent to all the interviewees for validation. This was done to ensure that their answers where interpreted correctly.
- *Modification* – The material was finally modified after being commented by the interviewees.

5 Empirical findings

5.1 Interviews

Seven interviews with different professionals within the field of production were conducted during the project. The purpose of the interviews was to complement the literature study with the interviewees´ thoughts in the search for the most important prerequisites for a successive mixed-model line. A number of factory visits were made in connection to the interviews to get inspiration to methods and challenges that are related to mixed-model assembly. The findings have been divided into the same categories as in the literature review. Information about the interviewees' is summarized in Table 6.

Table 6 Information about the interviewees

Name	Position	Company
Jim Andersson	Scania Production System Coordinator	Scania, Södertälje
Björn Svedlund	Process Engineer	Scania, Södertälje
Per-Henrik Lenander	Production Engineer	Volvo Construction Equipment, Braås
Sven Olsson	Production Engineer	Volvo Construction Equipment, Braås
Darren James	Volvo Production System Specialist	Volvo Technology, Göteborg
Lena Moestam	Volvo Production System Specialist	Volvo Technology, Göteborg
Lennart Rasmusson	Efficiency Coordinator for Manufacturing	Volvo Cars, Göteborg
Tomas Engström	Associate Professor within Logistics and Transportation	Chalmers University of Technology

5.1.1 Assembly systems

Andersson (2011) and James (2011) mean that one benefit with the changeover from single-model lines to a mixed-model line is that the takt time is reduced. Andersson (2011) argues that shorter takt times make it easier to work after standards, easier to discover problems and that it creates a more distinct flow. Moestam (2011) also mentions the benefits with a shorter takt time. She says that problems tend to reach the surface faster than if one could hide behind long takt times.

It becomes more critical to solve problems fast in a mixed-model environment according to Andersson (2011), Moestam (2011) and Olsson (2011). Moestam (2011) and Olsson (2011) both say that it becomes obvious for the entire organisation if the line stops. They both believe that it becomes more crucial to solve the problem when one mixed-model line stops compared to if one out of many dedicated lines would stop. However, Olsson (2011) mean that it easily backfires if one is not able to fix the problems fast enough and the line is stopped. One has to see the problems as a possibility to improve the process, but he means that it sometimes is hard for the operators to be positive when the "possibilities" pile up (Olsson, 2011).

Olsson (2011) describes that operators working with the assembly of large products such as articulated haulers are often used to long takt times. Operators are often negative of the reduction of takt times because they believe that their work becomes monotonous. It is therefore important to make everyone in the organization aware of what value-added work is. (Olsson, 2011)

Olsson (2011) mentions other benefits such as less duplication of equipment and a better utilization of factory space; the mixed-model line is always running even if the demand for one model is low.

Regarding collective assembly work in parallel flow systems compared to serial flow assembly lines, Rasmusson (2011) prefers the serial flow. The former parallel flow assembly at the Volvo Car plant in Uddevalla is today rebuilt to serial assembly work. Rasmusson (2011) states that:

"For some years we believed in team work, building the product from start to finish and high operator knowledge as a way to improve productivity, quality and ergonomics but everywhere we saw that quality became worse, profitability decreased and ergonomics became worse."

Engström (2011) argues that the quality of cars produced in the Udevalla plant in fact was higher compared to those produced on serial lines. The quality work was successively adapted to the way of manufacturing in Udevalla, but this work was not completed when the plant was closed down. Collective assembly is even more suitable in terms of quality when it comes to the manufacturing of low volume products with many product variants such as for example trucks. This is because such products are difficult to assemble because little product development and manufacturing engineering time have been spent on preparing them for manufacturing (lower "degree of design") which make them less suitable to assemble on serial lines.

Rasmusson (2011) mentions an example where the work in a pre-assembly station was designed so that the operator had total responsibility of assembling objects from start to finish in one station. Rasmusson (2011) states:

"*Everyone talked about "the good factory". After a while even the union started to question the assembly system. Because of the freedom given to the operators there was a possibility to work ahead to create more free time instead of working in an even pace. This created high absence due to illness, injuries and a stressful work environment. When switching to a serial flow in the pre-assembly station; quality, delivery and absence due to illness directly became better and the operators are happy with the situation."*

This way of working is, according to Engström (2011), however not a necessary effect of the assembly system design, but rather due to lack of appropriate norms and rules in the daily work.

Parallel flow systems have always shown to cause higher assembly times, for example more man hours than the serial flow assembly systems even if they handle time losses better. On the whole, parallel systems have shown to increase man hours and increase tied up capital compared to parallel flow systems. (Rasmusson, 2011)

On the other hand, Engström (2011) argues that the assembly time for a model assembled in a plant with collective assembly is in fact significantly lower than if it would be assembled on a serial line. He refers to the Volvo plant in Udevalla that worked with collective assembly during the nineties. He explains that the collective assembly approach in Udevalla was rejected in favour of a serial flow due to a number of unfortunate circumstances.

5.1.2 Standardised work

Andersson (2011), James (2011) and Olsson (2011) mention the importance of standardised work tasks to be able to run an efficient mixed-model line. Andersson (2011) argues that standardisation is a prerequisite to achieve levelled production and to balance a mixed-model line. Both Andersson (2011) and Olsson (2011) argue that well-established practices regarding standardised work should be in place before the transition to a mixed-model line.

The work with the determination of standards and accurate operation times has to be prepared well in advance of the transition to mixed-model assembly, according to Olsson (2011). This is because of that some methods used in this work may face stiff opposition from the operators and the union.

Using accurate operation times is crucial to obtain good standards. (Olsson, 2011) Correct input data is important when standards are to be developed (James, 2011).

Correct operation times should be gathered by the operators performing the assembly, they should also write the standards that are to be followed because they have the best knowledge about the work. The improvement work should be driven by the operators so that they feel that they can influence their work which increases their commitment. It is not a good idea for the production engineers to decide about standards and improvement work. The operators should strictly follow the standards when they are doing assembly work. It is therefore a need of scheduled time for improvement work where they can work more freely with creative tasks. (Svedlund, 2011)

Svedlund (2011) explains that a 30 minute stop of the entire line is planned each week where all the improvement groups are working with improvement activities. The improvement groups are organised so that one extra operator, beyond those who is needed to perform the work, is planned for each improvement group per day. The extra operator is supposed to cover if someone is absent from illness. However, if no one is absent, the extra operator works with improvement work the entire day. Consequently, the time spent on improvement work could theoretically be 30 minutes per week plus 40 hours per improvement group per week. Svedlund (2011) also mentions that because that they only produce to order and want to avoid overproduction, it sometimes leads to that the line is stopped before the shift is supposed to end. In these situations the operators spend the remaining time on improvement work instead of going home early. Svedlund (2011) explains that their final assembly is divided in ten assembly areas; each assembly area consists of two improvement groups with ten to twelve operators each.

Good standards are, according to Olsson (2011), important to be able to avoid that the operators make mistakes. Mistakes will eventually be made by the operators if there is any room for misinterpretation. (Olsson, 2011)

Rasmusson (2011) and James (2011) argue that standardised work and 5S work is extremely important to reduce variability in the assembly system and a prerequisite if many models are to be assembled on the same line.

5.1.3 Product design

Product architecture

Moestam (2011) and Olsson (2011) mention that it becomes easier for the production engineers to influence the product designers in a mixed-model environment. They can argue for the importance of using the same parts in different models and the design of models with similar assembly sequence. Those aspects become more important when several models are to be produced on the same line because of the increased number of constrains. (Moestam, 2011; Olsson, 2011) Moestam (2011) also believes that having one mixed-model line will improve the production engineers´ ability to communicate the issues regarding product architecture to the designers.

Updates to products are a prerequisite to stay attractive on the market, but the introduction of new product generations often causes problems in final assembly. One approach to decrease the disturbances caused by new product generations is to make continuous updates instead of introducing all updates at once. The updates can be gathered and marketed as a new generation to the customers even if they were introduced in assembly at different times. (Svedlund, 2011)

Products may differ between industries; there is for example a big difference between cars and wheel loaders. However, Rasmusson (2011) and James (2011) mean that the same basic principles can be applied when assembling many models in one flow independent of industry. The same principles are used to handle the differences. Common product architecture is, according to Rasmusson (2011), important to be able to have the same assembly sequence between models, and a common assembly sequence is the most important factor for efficiency when assembling many models in the same flow.

Working with the product development department to achieve common product architecture is hard and often a journey of about ten years. But still, it is not possible to just wait for common product architecture from the product development department to solve the problems. Rasmusson (2011) argues that there are methods to solve the problems and that they must be attacked from, in the long term, the product developers and, in the short term, the production engineers.

According to Rasmusson (2011), a difference in product design of two models may cause huge costs related to transportation of equipment in the factory as well as equipment in the automated stations. The conveyor belt must be modified to handle several product designs in the same flow.

5.1.4 Planning and control

Line balancing

Olsson (2011) mentions that the use of buffers between stations is possible even in the production of large products such as articulated haulers. The idea is to decouple parts of the line to make it less sensitive to disturbances. If the downstream section from the buffer gets problems, the upstream section can continue working until the buffer is full. To achieve decoupling from two directions, a second buffer can be introduced in the downstream section. This buffer should store one unit so that the downstream section can continue working even if it is problems earlier in the process. (Olsson, 2011)

Andersson (2011) argues that it is better to have utility workers handling ”heavy” models instead of balancing the entire line after those time consuming models if they appear quite seldom. He sees utility workers as a prerequisite for an efficient line balance. (Andersson, 2011)

According to Rasmusson (2011), balancing the line to the most time consuming model is devastating for the time losses in the system. In the car industry high balance losses on one model can result in zero profit of that model.

Sequencing of models

Andersson (2011) and Moestam (2011) mention the importance of using sequencing rules in mixed-model environments. The idea is that one should impose a limit of how many “heavy” units that may come after each other. (Andersson, 2011; Moestam, 2011)

Andersson (2011) argues that sequencing rules are crucial to be able to plan the utilisation of the utility workers. The utility workers should perform improvement work and supporting task when they are not performing assembly tasks.

Levelling

Svedlund (2011) mentions that it is sometimes better to produce in the sequence that customer ordered instead of levelling out the production based on forcasted volume and mix on a longer time horizon, even if it causes some problems in the production. This is to ensure that delivery dates are kept. He means that it is better to do so than to put products that customers did not order on stock. He means that levelled production in the future will not only be about mixing variants of different models. He argues that companies will have to be able to handle one hundred per cent customer order driven production through a number of tools and techniques. James (2011) argues that levelling the production on a longer time horizon is crucial to handle mixed-model production.

5.1.5 Time losses

Causes of time losses

Rasmusson (2011) mentions two basic principles important for the understanding of how to handle different models in the same assembly line. Both problems are caused by time losses in the assembly system.

According to Rasmusson (2011), the first basic principle is how to handle the difference in assembly sequence between the products that are to be assembled in the same flow. The assembly sequence is derived from the product architecture of the different products. Making the assembly sequence similar between models by working with common product architecture, or common platforms as it is called in the car industry, is a way of handling this issue. As long as the assembly sequence is the same between models, the differences are easier to handle. A difference in assembly sequence for one model can drive man-hours for all the other models because it requires duplication of stations. It is not desirable to have different work content on the same station because it influences assembly quality negatively, so instead, the stations could be duplicated where it fits into the assembly sequence. Consequently, a different assembly sequence for one model may cause time losses for all models. (Rasmusson, 2011)

The second basic principle when assembling many models on the same line is, according to Rasmusson (2011), the difference in work content between models. The assembly sequence may be the same but one car model may for example lack a roof hatch making the operator not doing anything when that car model is assembled on the roof hatch station. This creates another type of time losses on that station compared to the time losses derived from a difference in assembly sequence.

According to Rasmusson (2011), the problem most important to handle is the difference in assembly sequence. Handle differences in assembly sequence is according to Rasmusson (2011) more important for efficiency than differences in assembly time between models. Differences in assembly time between models also create time losses but they are not as severe for the overall efficiency of the system. The time losses caused by only a difference in assembly time per model can, according to Rasmusson (2011), be handled with different methods in the production system. The time losses caused by difference in assembly sequence are handled with common product architectures. One could also think that it could be handled by having one station performing different work tasks depending on which model that is produced. However, this approach is, according to Rasmusson (2011), very bad for assembly quality and must be avoided as far as possible.

When a new model generation is introduced the problem of time losses caused by the different assembly sequence is introduced. The reason is basically that the assembly process is built for the previous model generation and that the two generations are to be assembled at the same time. Rasmusson (2011) argues that the problem always exists because models are always updated and new product generations will eventually be introduced. Consequently, working on common product architecture is always important and for the car industry there are always new product architectures introduced to the assembly line causing new problems. (Rasmusson, 2011)

The worst case scenario is when two models with different product architecture, which leads to different assembly sequence, and big differences in work content and assembly time are to be produced on the same line. It happens in the car industry that such models are manufactured and sold without profit due to the large time losses that arises in the assembly system. It can be variety of strategic reasons behind why these types of losses related to certain models are accepted. (Rasmusson, 2011)

Methods to handle balance, variant and system losses

Andersson (2011) believes that one of the greatest challenges in mixed-model environments is the difference in work content between models. He says that utility workers are crucial to be able to handle these time differences. A utility worker has to be highly trained to be able to perform the work tasks at almost every station on the line. The utility worker can follow the "heavy" model along the line and perform the tasks that exceeds the planned cycle time. Andersson (2011) states that some models at the assembly line at Scania includes a work content of over 100 per cent more compared to easier models and that it is possible to handle this in one flow with the aid of utility workers. The method of using floaters or utility workers to handle the time losses has, according to Rasmusson (2011), many disadvantages. One is that they are often unused when easier models are assembled creating losses in the system. The method of sequencing the models released to the line in combination with open stations and pre-assembly stations would be more preferable. However, Engström (2011) argues that the disadvantages of using utility workers are more likely in the car industry where takt times are lower than in industries with longer takt times. Having a flexible workforce is, according to James (2011), always an advantage.

According to Rasmusson (2011), an important method to handle the time losses is to identify parts and work tasks that are independent of the assembly sequence. It is important to identify these work tasks and move them around to even out the work on the different stations. One approach could be to gather all independent work tasks in one station to avoid the losses even more. However, one must always strive to have the same type of work tasks on the same stations. Different work tasks on the same station causes serious quality problems and it drives long material façades and costs in the material handling function. It is therefore important that the work tasks that are moved and collected to one station are easy enough so that quality problems are avoided. Another important factor is to identify those work tasks in the process that cannot be moved. This can be stations with heavy equipment that restricts how the products can be assembled. In an assembly plant for cars, those stations are often called hard points. It could for example be the station where the chassis are married to the car. (Rasmusson, 2011)

Rasmusson (2011) argues for a method that is used to handle the time losses derived from the difference in assembly time between models, often called balance losses. The assembly sequence is in that case assumed to be the same. Sequencing the models released to the line by certain rules and in combination with open stations, where the operators can float along outside the station range, is a way to handle the balance losses. A prerequisite is then that the line is not balanced to the most time consuming model. Balancing the line to the most time consuming model would result in devastating time losses in the system according to Rasmusson (2011). The sequence released to the line would result in that easy models will follow hard models. How long the operator can exceed his/her station range is regulated by contracts with union and physical obstacles. In some cases it can also be possible for the operators to work ahead at the previous station's range. It is also important that the sequence of models is set so that the risk of that the operators collide when exceeding the station range is minimized. (Rasmusson, 2011)

According to Rasmusson (2011), it is important to work intensively with the product development department to diminish the assembly time on the heavy models to even out the assembly time between models.

Another method that can be used to handle the time losses is to offload work to pre-assembly stations or bring in work from the pre-assembly stations to even out the work content between models on the main assembly line. According to Rasmusson (2011), a disadvantage with this method is that it causes costs for the logistics department because of the increased material handling. An advantage of producing as much as possible on the main line is, according to Rasmusson (2011), that it becomes easier to be efficient on the main line, it drives efficiency.

Methods to handle increased learning time losses

Lenander (2011) and Olsson (2011) argue that it is a risk to only focus on the technical details when implementing an organizational change and that one neglects the need of proper education of the operators. Olsson (2011) goes on saying that it is important to find a level of education that actually can be achieved. Olsson (2011) means that training is hard and time consuming due to that the operators is busy performing their day-by-day work, it is therefore important to start the training well in advance of the changeover. Olsson (2011) explains that they performed their changeover from several dedicated flows to one mixed-model line during a period of low business activity, and that they therefore managed to run the line without losing too much, even though they had not been successful in their training of employees. He goes on saying that they probably would have suffered more if the changeover would have been performed during a time of high business activity.

Olsson (2011) argues that it is hard to predict the impact on learning times when going from single-model lines to mixed-model lines. He says that shorter work cycles will probably be easier to learn but the introduction of more models to each station will probably make it more complex. Moestam (2011) says that more models do not necessarily lead to longer learning times. The operator may not experience the increased number of models as an additional, unique working moment if there are similarities between the models.

Svedlund (2011) mentions the importance of having experienced operators working with assembly. It can sometimes pay off to keep excess personal in periods of low business activity to be prepared when the demand is increased again. The short term costs are increased but it may be beneficial in the long run due to that one does not need to put down the effort and money related to training of new employees. He also mentions that keeping experienced operators will ensure the quality and minimize the disturbances when the demand is increased again.

5.1.6 Material handling and supply

James (2011) argues that material handling is one of the most important issues to handle when implementing mixed-model production. Andersson (2011) sees kitting as a better alternative than elongating the line in a mixed-model environment where more components have to be available at each station.

Andersson (2011) believes that the theories developed in automotive industry to some extent are useful in the production of larger products, but he thinks that there are significant differences that companies tend to ignore. He also argues that differences in wage rates between for example Sweden and Japan often is neglected when discussing different methods such as for example kitting. He mentions that material handling personal in Japan has significantly lower wages than the operators on the line. It is therefore easier for them to find incentives for the outsourcing of material handling from the line. (Andersson, 2011)

Lenander (2011) mentions that they had a situation where they had to have a longer line due to that the material façade for each station where longer than the length of each station. They were able to fit all material within each station after introducing kitting at some parts of the line. He mentions that kitting had two main benefits; a reduction of the material façade and that the operators could move the kitting wagon to a convenient location with the material ergonomically presented to them on the wagon. (Lenander, 2011)

Lenander (2011) explains that they were able to reduce the material handling time at the line significantly and that the ergonomics for the operators were improved after implementing kitting. However, the time it took to prepare the kits and deliver them to the line slightly exceeded the time savings at the line. Lenander believes that they will be able to reduce this time significantly by introducing a number of different improvements. (Lenander, 2011)

Lenander (2011) describes that before implementing kitting the operators believed that moving less after implementing kitting would cause a more monotounus work. The operators were complaining about becoming “robots”. However there have not been any complaints about this afterwards.

Rasmusson (2011) mentions that sequencing or kitting the material to the operators on the line is a very good method to use when there are many models with different parts. Sequencing and kitting the material to the line saves space in the material façade as well as it removes unnecessary walking time for the operators. According to Rasmusson (2011), this is achieved by pushing the picking work up-stream in the supply chain. One approach is that the logistics function is responsible for packing the material in sequence another approach which is better, is if the material is supplied in sequence from the suppliers. According to Rasmusson (2011), having one person picking and supplying kits away from the line can lead to that two operators can be removed from the main assembly line. The cause for this is that the walking time is reduced to a large extent. It is easier to be efficient when working with kitting and sequencing of the material than on the main line. Another advantage is that the operators feel that the working environment is improved. Advantages with kitting and sequencing are that it leads to a more efficient assembly system, a smaller material façade and higher assembly quality. (Rasmusson, 2011)

Sequencing and kitting material to the line improves assembly and picking quality because the operators are only exposed to the right part and does not need to think which part to pick. It also improves delivery quality because the lines are more reliable and the risks of stoppage are reduced. One could imagine that the person picking the kit or sequencing the parts can make picking errors, this is of course true but it is important to think from the assembler’s point of view on the main line. Rasmusson (2011) mentions that:

“*One could imagine picking material as a wave. The wave is first pushed to the logistics department and later to the suppliers. Then we are working together with the suppliers to diminish the wave completely*.”

Sequencing and kitting of material must be used for many parts in all areas of the assembly system for the investments to be economically justified. If sequencing single parts it would be hard to justify the investment financially. (Rasmusson, 2011)

Another important material handling method is, according to Rasmusson (2011), downsizing of the material containers to reduce the length of the material façade.

5.1.7 Assembly quality

Moestam (2011) highlights the importance of presenting distinct instructions for the operators, to be able to reduce the risk of confusion, related to the introduction of more models on an assembly line. She argues that the usage of long lists for each model, that the operators rarely read, is not a good idea when the number of variants increases. To be able to avoid assembly and picking errors in a mixed-model environment, one should according to Moestam (2011), choose a system where the operators in fact looks at the instructions.

The use of aids to improve picking quality, such as for example pick-to-light, is effective according to Svedlund (2011). He however argues that it is inflexible because of the need of rearranging the system every time a change is introduced to the material façade.

Rasmusson (2011) mentions pick-to-voice and pick-to-light as two methods used extensively to assure picking quality in manual assembly. Pick-to-voice is not used on the main assembly line but in the logistics centres repacking material in sequences or kits. Pick-to-light is extensively used at both the assembly line and when kitting and sequencing material. At the assembly line there may be some problems when the system are introduced because of that the operators cannot work ahead that much as they may be used to because they need to stay more at their station range. The keeps track of that the right part is picked with the use of buttons or sensors. When it comes to extremely important parts, a barcode can be attached to the part. The supplier can deliver parts with barcodes or the logistics function can attach barcodes to parts after delivery. The operator needs to first scan the assembly object and then the barcode on the part to assure that the right part is used. This can be used in combination with a pick to light system. First the part is scanned and then the pick-to-light shows which part to pick. (Rasmusson, 2011)

Return of investment is achieved fast with a pick-to-light system because it assures the assembly picking quality. Wrong parts can often be assembled and may not be noticed before next part is to be attached or when the function is wrong leading to expensive rework. (Rasmusson, 2011)

6 Development of model for mixed-model assembly line

A model with problems, requirements, methods and solutions related to a mixed-model assembly line is developed by the authors in this chapter. The model is based on information gathered from the literature review, Volvo Production System and empirical findings. The model should be valid for VCE operations in Sweden and therefore this chapter begins with a description of VCE plants in Sweden. Thereafter general advantages and disadvantages with mixed-model lines and serial flows are presented and finally the model is presented.

6.1 Description of VCE operations in Sweden

VCE operations in Sweden

In Sweden the production facilities are located in Hallsberg, Braås, Eskilstuna and Arvika. Different products are produced at the different facilities. There is quite a large difference between the products produced at the different facilities as well as the manufacturing processes. The different products are shown in Figure 37.

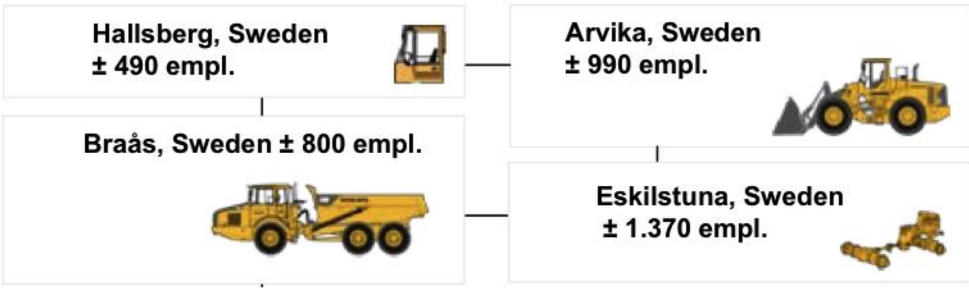


Figure 37 VCE operations in Sweden (Volvo Construction Equipment Global Site, 2011)

VCE production facilities are also located in the US, Brazil, Germany, Poland, France, Korea, China and India.

VCE Eskilstuna

In the plant in Eskilstuna components are manufactured. The two main components are transmissions and axles. The production facility mainly consists of processing and machining but there are also final assembly lines for the axles.

Serial flow assembly lines are used in the final assembly of the axles. The assembly lines are un-paced and the products move from station to station by a carrier that is manually controlled. The final assembly is characterised by few stations and simple flows. Kitting is used as a material supply method for a large number of the parts.

The products have rather few parts and are fairly similar to each other regarding assembly sequence and number of parts. They are also small compared to complete products like wheel loaders.

VCE Hallsberg

The plant in Hallsberg manufactures cabs for the company’s wheel loaders and articulated haulers.

VCE Braås

Articulated haulers are manufactured at the plant in Braås. The final assembly line has a serial flow layout with a few buffers in between the line segments. The last station at the assembly line is designed as three parallel stations with longer cycle times. This is mainly due to lack of space of having them in a serial flow. The serial line is set up as a mixed-model line but basically only two models are assembled at the line so the variability is not very high. The line is operated with takt times that can be categorized as long. Material supply to the line is characterised by regular line side stocking but also kitting to some extent. Some material is also delivered to the line in complete modules, as for example the cabs and axles. The products assembled are large and contains many parts but the number of stations are not that many resulting in long takt times.

Regarding the product architecture, there is a similar assembly sequence between the models. The same items have to be delivered to more than one station, because of a difference in assembly sequence, only on a few places at the assembly line. The assembly times between the models are also fairly similar as well as number of parts. The products are also characterised by having a high degree of modules in the product architecture.

VCE Arvika

At the plant in Arvika, the wheel loader models L60-L350 are manufactured, which means in total ten models. All models except the L350 are assembled in a serial flow assembly system. Two mixed-model lines are already in use for the L60-L120 respective L150-L250. This will be described in more detail in chapter 7.1.1.

The products are characterised by a large difference in assembly time for the model with the least work content compared to the model with the most work content. The work content also depends on optional equipment and difference between the product generations. There is also a difference in assembly sequence between some of the models and between generations.

Conclusion regarding VCE operations in Sweden

The different products that are to be assembled on the same assembly line could be different models; products or model generations but the prerequisites are the same. The prerequisites that decide on what problems, requirements, methods and solutions that will be most important in a model for a mixed-model assembly line is derived from the actual difference between the products that are to be assembled. A basic prerequisite is that it is the same kind of product. It would be hard to assemble a large ship and a car at the same assembly line because there are simply too big differences. In that case the size would be a big problem among others.

Because of the interdependencies between the factors that affects differences between products that are to be assembled on a common line are different depending if it is a wheel loader, hauler, cab, transmission or axle; the model which describes which problems, requirements, methods and solution to focus on must be general. The model must incorporate almost all the problems derived from differences between products if it should be valid for all the models manufactured at each plant.

It should be noted that the question is not whether to assembly a hauler and a transmission at the same line. It is instead whether to assemble all variants of one type of product on the same line and this simplifies the problems that are incorporated in the model.

It has been noted in the literature review and empirical findings that the methods and solutions used to solve the problems and challenges that arises at a mixed-model line can be the same, regardless which type of product that are to be assembled. Often the same methods and solutions can be used. However, there may be many different methods and solutions that can be used to solve the same problem and the choice of which to choose may be dependent on the context and type of industry.

6.2 Model for mixed-model assembly line

6.2.1 Advantages and disadvantages with mixed-model lines and serial flows

A mixed-model line is per definition a serial flow line where many different models are to be assembled. The scope of this master's thesis is to investigate prerequisites, problems, challenges and methods and solutions with mixed-model lines but the serial flow as well as the assembly system is not questioned per se. It could be interesting also to include pros and cons of mixed-model lines as well as the serial flow it operates under to be able to conclude if it is a preferable system.

Advantages and disadvantages with serial flow assembly lines

The main advantages and disadvantages with serial flow lines that are presented here are based on the empirical material and literature reviews. Two assembly systems that traditionally have been used are the serial flow assembly system and the parallel flow assembly system. Serial flow assembly lines are here compared to parallel flow assembly systems.

One of the main advantages that have been identified is that few serial lines uses shorter cycle times than a number of parallel flows. The benefit with this is first of all that the learning time loss decrease. Each operator only needs to learn the work content on his/her workstation within the cycle time. Another benefit with a shorter cycle time is that problems tend to reach the surface faster than if one could hide behind long cycle times. Short cycles are therefore believed to better help monitor quality problems from upstream deliveries and suppliers. A disadvantage with very short cycle times is that it causes monotonous job content and poor job satisfaction. But involving the operators in problem solving and off-line responsibilities can compensate poor job satisfaction in short cycle time jobs.

Another advantage with serial flow systems is connected to resources and capital investment. In a parallel system each flow requires all tools, fixtures and equipment resulting in higher capital investment compared to if it is only needed at one place as in a serial flow system. Parallel systems also drive logistics costs because the same type of part needs to be delivered to several places causing advanced material handling systems.

Balance, variant and system time losses are a large problem in serial flow systems and one of the main disadvantages. The time losses are better handled in parallel flow systems because they are non-existent by definition. There are opinions stating that even if parallel systems absorb time losses in a better way they still require more man-hours.

Another disadvantage with serial flow systems is its vulnerability to disturbances. Machine breakdowns and quality problems may stop the entire system. This is also connected to the performance regarding flexibility.

Serial flow systems are less flexible with regard to production volume, product mix, product changes and introduction of new product generations because of the high specialization of the assembly line. As a note one will see that serial flow mixed-model assembly lines may increase the flexibility compared to traditional single model flow assembly lines.

Regarding floor space there are different opinions. There are opinions that a serial flow causes either less or more floor space. The reason why serial flow assembly lines would require less space is that it requires less space for storage and material movement.

Advantages and disadvantages with mixed-model assembly lines

Here advantages and disadvantages with mixed model assembly lines are compared to single-model assembly lines. Both types are serial flow systems. The comparison is between having several single-model lines or few mixed-model lines.

The main benefits VCE hope to gain if implementing a mixed-model assembly line are the following:

- Reduced surface need.
- Reduced investments.
- Increased volume flexibility.
- Increased variant flexibility.
- Shorter learning times.
- Shorter lead times.
- More consistent quality.

Regarding the need for floor space it cannot be concluded that mixed-model lines requires less floor space than single model lines from the research in this thesis. However, one could think that operating several single-model lines would require more space because it requires more space for storage and material movement the same way as in parallel flow systems compared to serial flow earlier discussed.

A reasoning regarding investments can be made the same way as when comparing parallel systems with serial systems. The conclusion is that mixed-model assembly lines require less fixed investments and thereby reduced product-dedicated costs.

Both volume and mix flexibility will increase when using a mixed-model line instead of many dedicated single-model lines. Volume and product mix can be changed in a mixed-model assembly line without risking than any of the dedicated lines gets idle.

There are several different opinions regarding the belief that mixed-model lines will result in shorter learning times. On the one hand, mixed-model lines will result in shorter cycle times, which will result in shorter learning times as previously discussed. On the other hand learning times will increase because of the increased number of unique operations performed derived from the increased number of variants. At the same time it is not entirely clear that more variants will result in longer learning times. It depends on how similar the variants are to each other and how the operators perceive the similarities. Another factor that can affect not the actual learning times, but the time losses that are caused by learning time is employee turnover. A high employee turnover can cause large learning time losses in total even if the learning time for each employee is small and employee turnover can be affected negatively by short cycle times. Having short cycle times may result in high employee turnover caused by poor job satisfaction, which will result in high learning time losses in the system.

Shorter lead times are not connected that much to mixed-model assembly lines but more dependent on the increased number of sub-assembly lines often used. The increased use of sub-assemblies is utilised to avoid and handle the increased time losses in mixed-model assembly lines.

A more consistent quality can be derived from shorter cycle times earlier discussed when comparing parallel systems to serial systems. Another factor that can affect quality is that if having several dedicated lines, a greater number of operators need to perform the same type of tasks at several locations. In a mixed-model line operators only need to perform the same type of tasks at one location.

Product design, product architecture, number of parts and number of common parts are important factors for the efficiency of the manufacturing of the products. Having one flow will make it easier to influence the product design department for designing the products so that they are easier to assemble. At the same time product design will be more important when assembling the product in one mixed-model line than in parallel flow systems.

Assembling products in a mixed-model line instead of many dedicated lines have many disadvantages and causes a number of problems. One of the main disadvantages is the increased time losses and the problems in absorbing them. The reason for the increased time losses is the variability between the models regarding different aspects. This will be developed further in the next section.

Another disadvantage is the increased vulnerability to disturbances because problems that arise may stop the entire production instead of only the dedicated line.

The prerequisites, challenges, problems and possible methods and solutions regarding mixed-model lines and how to solve them will be presented in the following chapters.

Summary of advantages with mixed-model assembly lines:

- Increased volume flexibility.
- Increased mix flexibility.
- Reduced product dedicated costs.
- More consistent quality.
- Shorter takt time.
- One assembly flow is a driver for commonality and common product architecture.

Summary of disadvantages with mixed-model assembly lines:

- Difficulties in handling the increased time losses in the assembly system.
- Increased sensitivity to disturbances.

6.2.2 Presentation of model for mixed-model assembly line

A model has been developed where prerequisites, problems, challenges, and methods and solutions have been mapped with regard to a well functioning mixed-model assembly line. The model is presented in Figure 38. The differences between models and product generations are dependent of the prerequisites and can be seen in the top square. The differences cause five main problems from which the challenges that are most important are derived. The challenges are all equally important and some of them are dependent of each other. Each part of the model will be explained in respective sections below. The methods and solutions that can be used to solve the challenges will be presented under each section for each challenge. A compilation of methods and techniques can also be found in Appendix C.

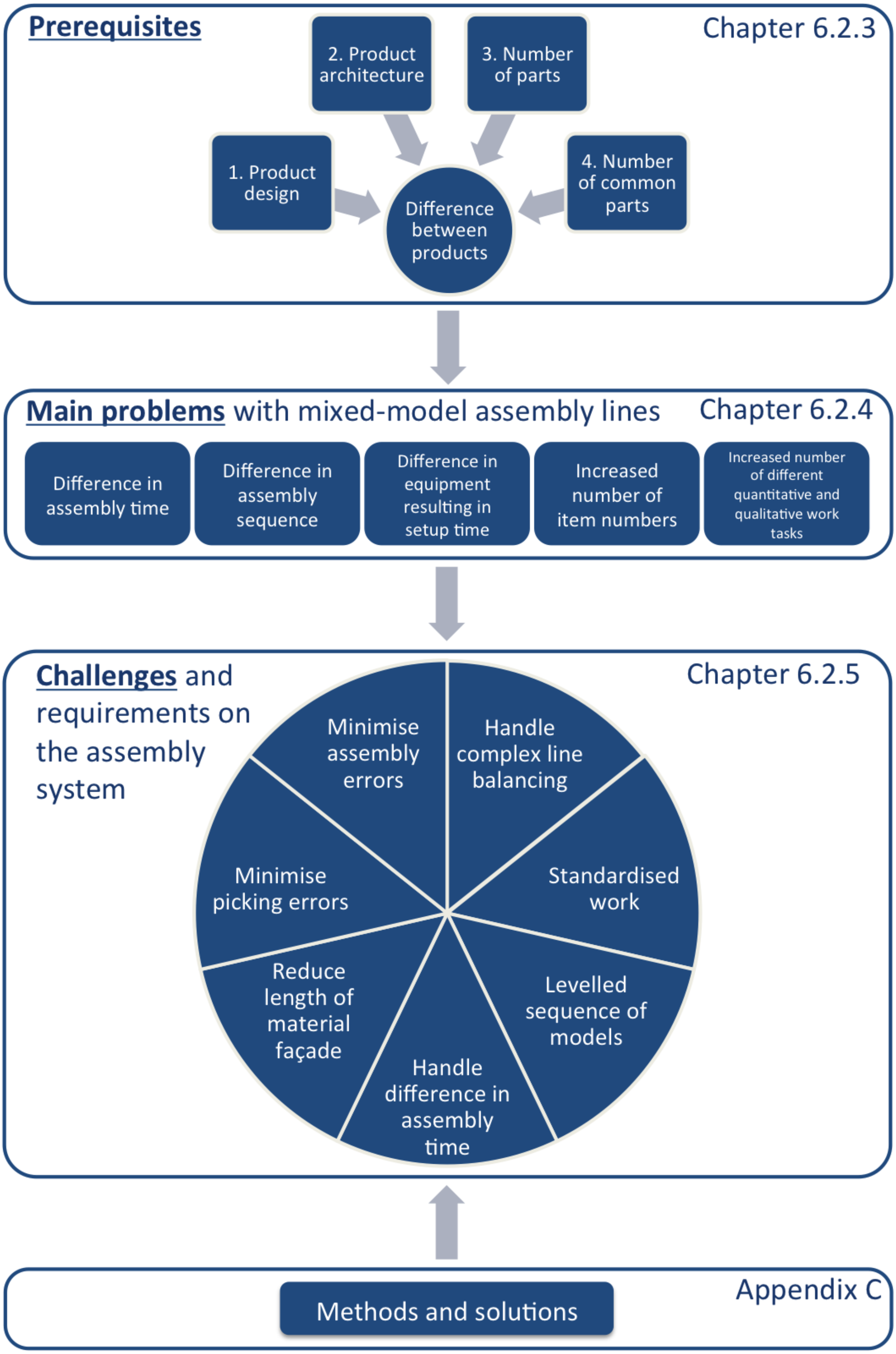


Figure 38 Model for mixed-model assembly line

6.2.3 Prerequisite that causes difference between models and product generations

What causes problems in mixed-model assembly lines are the actual differences between the products and this could be seen as the general prerequisite. The prerequisite determines which problems that will be most important, and as a consequence, which challenges that will be most demanding and what methods and solutions that should be used. The prerequisites are derived from the actual difference between the products that are to be assembled. As earlier discussed in chapter 6.1, the basic requirement is that the products that are to be assembled on the same line are of the same *type.* Size would be an important factor here. It would be hard to assemble a ship and a bicycle at the same line.

Furthermore the prerequisite for mixed- model assembly line are dependent on four factors:

1. Difference in product design between models influencing how the parts are connected to each other.
2. The difference in product architecture deciding the difference in assembly sequence between models.
3. Difference in number of parts influencing the difference in assembly time between models.
4. Difference in number of common parts for each model.

The smaller the differences within each factor, the smaller the problems of assembling the models at the same line will be. Engström, Jonsson & Medbo (2004) mention that different assembly systems need different "degree of design" of the products. Assembly lines need a high "degree of design" of the products meaning that it requires extensive product design and manufacturing engineering to function properly. (Jonsson, Medbo, & Engström, 2004) A conclusion that can be made, because of that the four factors above are important in mixed-model assembly lines, is that mixed-model lines require an even higher degree of design than single-model lines to function in a proper way. Product design and development processes to change the four factors so that the problems diminish are often considered in a time span of ten years or more. Because the degree of design cannot be affected in the short term, methods and solutions to handle the problems in the present assembly system must also be developed. Those challenges, methods and solutions are presented in the following chapters. As a note, Engström et al. (2004) mentions that alternative assembly systems with parallel flows can handle products with a much lower degree of design than serial flow assembly lines.

An important issue is that there may not only be differences between models and their variants, there may be even larger differences regarding the four factors above between different product generations that are to be assembled at the same line. There will always be new product generations for some models and often they will be assembled at the same time as previous product generations for the same models resulting in that the problems always exist. New product generations can be introduced in small steps in the production to avoid causing too much disturbances. Many small changes can be gathered and marketed to the customers as a new product generation.

Each problem derived from the four factors will be further developed in chapter 6.2.4 below.

6.2.4 Problems with mixed-model assembly lines derived from the prerequisites

The problems in assembling many models on the same assembly line can be derived from five main problems. The five main problems can be derived from one or several of the four factors in the previous chapter. The five main problems in mixed-model assembly lines are presented below.

Difference in assembly time

Difference in assembly time between models can be derived from the difference in total number of parts between models. A model including more parts than another will demand a longer total assembly time than a model with fewer parts because of the higher work content.

This main problem will cause large variant time losses if not handled in a suitable way. The challenges will be to handle the difference in assembly time by various methods in the assembly system, to use complex line balancing methods and to use levelled production plan and a levelled sequence of models released to the assembly line. Another challenge that must be addressed to handle the variability is to work with standardised work methods and accurate operation times. Included in standardised work is also 5S work that will reduce the effect of the variability.

Difference in assembly sequence

The difference in assembly sequence between models or product generations can be derived from that there may be a difference in product architecture.

Problems that arise from this are that there may be a need to create several stations where the same kind of work tasks are performed depending of the model that comes down the line. This will cause the following problems:

- Increased lead-time for all models if the duplicated station is placed in the main flow.
- The same equipment regarding tools, fixtures etc. must be available on several stations increasing investment cost.
- The same parts need to be delivered to several stations resulting in higher logistics cost, longer material façade and increased risk of picking errors.

The alternative is to have certain stations to include different type of work tasks but this is directly bad for assembly quality because the increased risk for assembly errors when an operator needs to perform different type of work tasks depending on the model.

The only way to actually avoid this problem is to change the product architecture so that the assembly sequence between models is more similar.

Difference in equipment resulting in setup time

It may be necessary to use different tools, fixtures and equipment for different models derived from the difference in product design, product architecture and number of common parts. Therefore when a new model comes along the line there may be a need for setup time.

The setup time causes problems because a mixed-model assembly line must be free from setup time by definition. A way to handle this problem may be to include the setup time in the line balancing but this of course adds non-value adding time to the assembly process.

Increased number of item numbers

This problem can be derived from the fact that there may be a difference in number of common parts between models. If all parts were the same between models there would not be an increased number of unique item numbers.

An increased number of unique items numbers will result in challenges regarding increased risk of picking errors and an increased length of the material façade as well as extra handling of components.

Increased number of quantitative and qualitative work tasks

A product design that will result in that the parts fits together in different ways will increase the number of different work tasks that has to be performed by the operators. Difference in product architecture may also increase the number of different work tasks that has to be performed.

The increased number of different tasks can be divided into increased number of qualitative tasks and increased number of quantitative tasks. An increased number of quantitative tasks mean that only the number of different tasks is increased causing problems with increased learning times and an increased risk of assembly errors.

An increased number of qualitative work tasks means that different tasks may demand different competence from the operators. This can result in that different work knowledge is needed at different stations as well as at the same station. One model may be very demanding regarding operator knowledge and competence and the next model may not require that much of the operator. This will result in the problem that all operators may need to be trained for the hardest model causing learning time losses.

6.2.5 Challenges and requirements on the production system

The most important challenges and requirements on the production system have been derived from the main problems based on the frame of reference, the empirical findings and the study visits conducted by the authors. Each challenge can be handled with different methods and solutions. The challenges that are presented here are considered the most important ones to be able to assemble different models, variants of models and product generations on the same assembly line. Of course the different challenges may be more or less important depending on which problem is the most important derived from the prerequisites.

Handle complex line balancing problem

The line-balancing problem is always existent in a serial flow assembly line. When it comes to balancing the line in the single model case it comes down to distribute the work tasks evenly among the stations. In the mixed-model case one must also balance the line in a good way with regard to that different models require different assembly times. The difference in assembly sequence will make it even more difficult. This is discussed in chapter 2.4.3. Using advanced balancing methods will help to handle the main problem of difference in assembly time between models.

It is not very uncommon that the assembly line is balanced according to the most time consuming model if assembling many models. This would in most cases cause too large time losses in the system for a mixed-model assembly line to be economically justified. One must use other methods to balance the line.

The most important challenge would be to not balance the line according to the most time consuming model with different balancing methods. Some of them are presented in chapter 2.4.3. VPS Academy proposes a method in chapter 3.2.2 where the line is balanced according to a weighted average cycle time based on demand for each model. This would be a good starting point but there are more advanced methods that can be used according to the literature review.

Time losses will always exist in the system even if it is not balanced according to the most time consuming model. See chapter 2.5. Not balancing the line after the most time consuming model is a prerequisite to be able to use some of the methods to handle the balance, variant and system losses.

Standardised work methods and accurate operation times

Standardised work methods are extremely important to reduce the actual variety in assembly time between different operators. It ensures that the one best work method currently available is followed and that the measured time for that method is correct. If each operator can follow the same method, the time to perform the work will be more consistent and this is very important in a mixed model environment. Accurate operation times are thereby a prerequisite that must be fulfilled before balancing the line and thereby a prerequisite for the other methods that are used to handle the balance, variant and system losses in the assembly system.

Standardised work may be difficult to achieve when having long cycle times in a mixed model environment but it is in that case even more important to combat the large variability.

The 5S methodology in standardised work is also directly important to reduce assembly errors and assembly picking errors because it reduces the variability in the material façade and in the assembly work.

As a conclusion, standardised work can be used to diminish the effects from the following main problems: difference in assembly time, increased number of item numbers and increased number of qualitative and quantitative work tasks.

Levelled sequence of models released to the line

Levelled sequence of models released to the line is a method that can be used to handle the difference in assembly times between models and thereby handle the balance, variant and system losses. The method is further described in chapter 2.4.5. There may also be different goals for sequencing models to the line not directly connected to handle balance, variant and system losses. This is also further explained in chapter 2.4.5.

The sequencing objective of levelling out the workload at every station is considered a key if to assemble many models in the same flow. This sequencing objective can only be achieved if the line is also not balanced to the most time consuming model. If the line is balanced to the most time consuming model the sequence of models released to the line would have no impact in reducing time losses in the system. The interconnection between sequencing models and the line-balancing problem is further described in chapter 2.4.4.

The use of a levelled sequence of models to diminish the time losses is affected on whether the stations are open or closed. If the station ranges were not open then high work content models would result in unfinished products or line stoppage. The sequencing rules must be set in the context that the operators are allowed to depart from their stations. See Figure 23 for a description. If the stations are closed, a levelled sequence can be used to even out the workload of the utility workers.

A prerequisite for having a levelled sequence of models is that the aggregated production plan also is levelled. This is discussed in chapter 2.4.2.

Handle difference in assembly time

The difference in assembly time between models will cause variant time losses. This is the main effect that is caused by the main problem, the difference in assembly times. Three of the methods to handle this problem have already been discussed; complex line balancing, levelled sequencing of models released to the line and standardised work. A complete description of methods that have been identified is presented in chapter 2.5.2. The different methods can be used in combination with each other. Some of the methods are required to be used in combination with others. The methods presented will decrease the balance, variant and system losses, not just the variant losses.

Different methods may be more appropriate to use depending on the products that are to be assembled. For example it can be concluded from the empirical material that levelled sequencing of models released to the line is used in an automotive industry while utility workers are instead used extensively in the truck industry. The best methods to chose depends on the prerequisite in the model, which problems becomes the most important to consider and the context of the assembly system.

Reduce length of material façade

This challenge is derived from one of the main problems that there may be an increased number of unique item numbers that is needed. A basic requirement at a mixed-model line is that all parts must be available at all times at the line if traditional material supply is used.

The length of the material façade may be the limiting factor for the entire assembly line. The line may be too long regarding limits in floor space. A key challenge is then to reduce the length of the material façade.

Apart from that an increased number of parts will cause a long material façade, it also causes another problem. The handling time losses will increase the longer the material façade is because walking time for the operators will increase. Consequently, by improving the material façade with the methods presented below the handling time losses and learning problems in the system will decrease.

Generally a method that can be used to reduce the length of the material façade is the use of just-in-time concepts in combination with using smaller bins. That is, parts should not be provided before they are required and the output should be matched with the demand eliminating the need to keep inventories in the material façade. The application of the just-in-time concept is only possible to achieve if the usage rate of all parts are kept constant. This is mentioned as one of the main objectives when levelling the sequencing of models released to the assembly line. The challenge of levelling the sequence of models released to the assembly line will consequently be a key challenge regarding to reduce the length of the material façade. The objective of having even parts consumption when sequencing models to the line is discussed in chapter 2.4.5.

More specific methods used in the context of just-in-time to reduce the length of the material façade that has been identified are the following:

- Sequencing of parts to the line.
- Kitting parts to the line.
- Repacking to smaller packages.

Reference material regarding material handling and supply methods are presented in chapter 2.6.

Minimise assembly picking errors

Another challenge that is derived from the increased number of unique item numbers that needs to be presented at the assembly line is the increased risk of picking errors. More parts presented to the operators will simply increase the risk of them picking the wrong part or omitting a part. This will result in defective products.

Methods to minimise the risk for assembly picking errors that have been presented in the literature are located in chapter 2.7. As a conclusion from the empirical material and the literature review the following methods can be used:

- Automatic identification devices.
- Kitting.
- Sequenced delivery to line.
- Mistake-proofing line side picking by simple methods.
- Pick-to-light and pick-to-voice.

Minimise assembly errors

This challenge is derived from the problem that there may be different qualitative and quantitative work tasks for different models, model variants and product generation. The challenge involves choosing the correct tool, fixture and assembly procedure for the right model.

The main method that can be used to minimise assembly errors is clear and pedagogical work instructions for the operators. This can be achieved with for example visual aids. Kitting and sequencing the material can be also be used as a work instruction for the operators discussed in chapter 2.6.

Standardised work methods and 5S will also decrease the risk of assembling the part in the wrong way. There is a single work method that must be followed and tools, fixtures and parts are located at the same place at all times making it easier for the operator to make the right choice.

Short cycle times may decrease the risk of assembly errors because the work content for the operator is smaller.

Design for assembly (DFA) is another method that can be utilised in the design face reducing the risk for assembly errors. It will be easier to choose the correct assembly procedure if the individual parts only can be assembled in certain ways. Poka yoke also includes mistake proofing the actual products in the design face.

7 Applying model at VCE in Arvika

In this chapter the model developed in the preceding chapter is applied at the VCE plant in Arvika. A description of how different areas of production previously discussed in the report are handled in Arvika is first presented. The description of the production at VCE in Arvika is based on own observations as well as discussion with employees at different departments. Then a suggestion about what parts of the model that is most important for Arvika to focus on is presented after analysing the current state. After that follows the advantages and disadvantages that VCE in Arvika may experience after the transition to a mixed-model assembly line. Finally, a station where assembly quality is low in Arvika is analysed and a solution to the picking errors causing the quality problems is presented.

7.1 Description of production at VCE in Arvika

7.1.1 Assembly system

The two assembly lines in the plant are presented in Figure 39. As seen the medium line has 20 stations. The large line no longer has 11 stations as indicated in Figure 39, but instead 15 stations since it has been rebuilt for the new G generation of wheel loaders.

The largest model, L350, is assembled in a separate flow. That flow is designed for collective assembly of the entire product from start to finish in a few stations. The L350 flow is not paced. The models that are intended to be assembled on a future mixed-model line are the models on medium and large line.

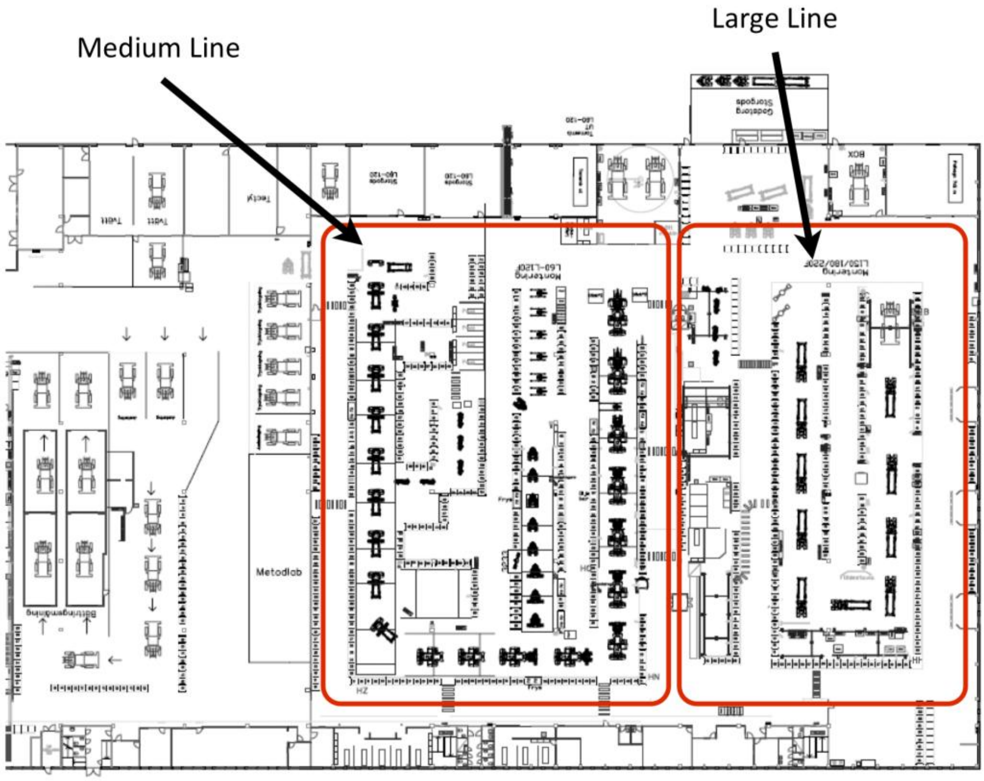


Figure 39 Present assembly line layouts

On both lines, the operators can press an andon button to call for extra personnel if problems occur. The line is stopped until the issues are solved. The work on both lines is paced with the help of large boards indicating the takt time and how long time before moving the product to the next station.

Medium line

The assembly of small wheel loaders takes place at the medium line. At the moment the wheel loaders produced on the medium line are; L60F, L70F, L90F, L110F, and L120F. A new generation of wheel loaders, the G generation, has been developed due to harder emission requirements in Europe and North America. The plan is that all the models of the new generation should be produced on the line in January 2012. The F generation of the small wheel loaders will still be produced and sold to markets other than Europe and North America and consequently both the F and G generation will be assembled in the same flow.

The medium line, which consists of 20 stations, is supported by seven sub-assemblies. The takt time on the line is 46 minutes. The units are moved along the line with an automatic conveyor. The conveyor is placed in the floor and the product is placed on a fixture that is connected to the conveyor. The conveyor belt stands still when the products are operated on and moves when all the stations have indicated that they have completed their tasks. The reason why the medium line is not continuously paced is that the station where the engines are mounted needs to be fixed because of demands from equipment and tools at that station. Of course this induces time losses when the conveyor moves the products from one station to the next. There are two operators on each station on the medium line. There cannot be more than two operators at the same station on the medium line because they will be in each other's way. No buffers are used in between the stations.

Large line

The assembly of large wheel loaders of the new G generation takes place at the large line. The wheel loaders produced on the large line are; L150G, L180G, 180GHL, 220G, and 250G.

The large line consists of 15 stations and it is supported by eight sub-assemblies. The takt time on the line is 78 minutes. The units are moved manually along the line with the help of air pallets. There are 1-3 operators working on each station on the large line depending on the workload. As on the medium line no buffers are used in between any of the stations.

Production volume

According to Baudin (2002), as stated in the literature review, if different models should be assembled in the same flow is based on their similarity in production volume. This is the first step in analysing the feasibility of producing models in the same flow. The production volume for 2010 regarding all models is shown in Figure 40. The division of models to medium line, large line and L350 collective assembly is also seen in the figure. The production volume for each assembly line is seen in Figure 41.

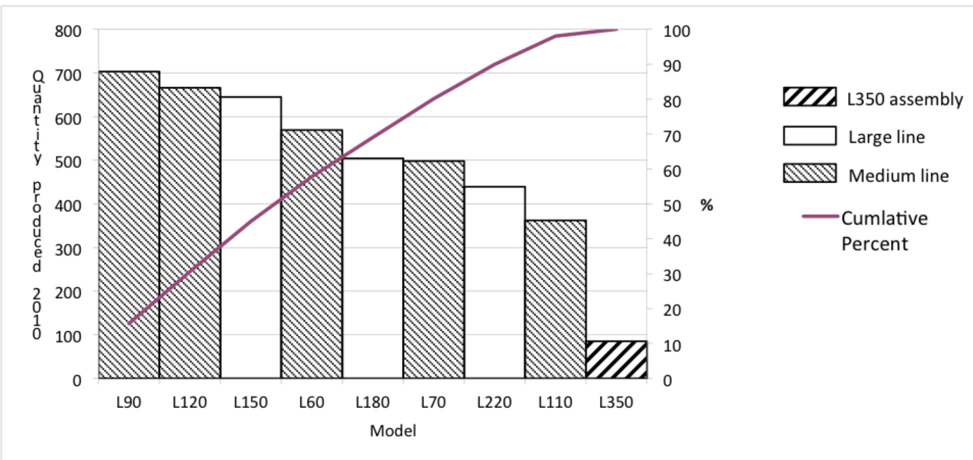


Figure 40 Production volume for each model year 2010

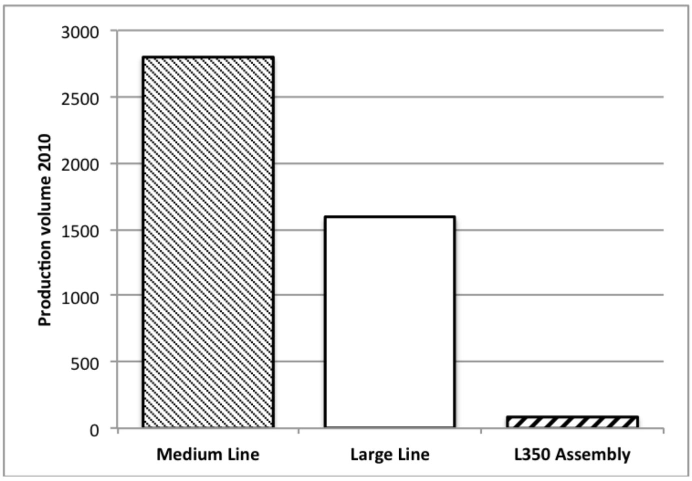


Figure 41 Production volume for each assembly flow year 2010

7.1.2 Standardised work

The operators in Arvika are at the moment undergoing an extensive education effort within the area of standardised work and more than one hundred people have so far been educated. The first priority in the education effort is to make the management of each department aware of the benefits with working after standards so that they are able to motivate their personnel. In the next step the production managers, the group managers, the andon personnel, and the quality representatives are educated. A four day education is followed by a period of four weeks where the newly educated personnel only work with tasks regarding standards at their respective stations.

At present the operation times are based on time studies performed by outside consultants but when introducing standardised work in the factory the timing of the tasks at the stations are to be carried out by the operators under supervision of the production engineers. The standards, which will be written by the group managers, are later sent to the production engineers for approval. Not only will the operation times be developed by the operators but also the work methods. The incentives for the development of standards in Arvika are; quality assurance, productivity precision, delivery precision, and a foundation for accurate input to other activities such as line balancing.

Standardised work has traditionally not been used in the factory. The operators have followed instructions regarding which parts that is to be used and how the finished assembly should look but there was no standard of how the work should be performed.

7.1.3 Product design

Product characteristics

Product data like size and weight is presented in Appendix D. As seen in the table in Appendix D there is a large difference regarding size and weight between the models that are to be assembled in the same flow.

Product architecture

There were significant differences in assembly sequence between the models produced on the medium line and the large line when only the F generation of wheel loaders was assembled. One main focus during the development of the G generation was to achieve a more similar assembly sequence. The F generation of the smaller wheel loaders will still be assembled which will cause some issues regarding assembly sequence. The cab has to be mounted earlier on the wheel loaders of the F generation compared to those of the G generation, which may lead to a duplication of stations.

A big difference in assembly sequence in the current situation is the marriage point of the front frame and rear frame, which takes place at different stations on the medium and large line. In this case it is the process and not the product architecture that sets the assembly sequence. The implication of this is that the marriage point of the rear on front frame can be moved to a common station for all models without changing the product architecture.

There is a project going on in VCE that aims to create a common standard regarding product architecture for all models and thus resulting in a common assembly sequence for all models. The result of this project may not be visible until years ahead in time but it will simplify the assembly process when using a mixed-model line.

Number of items and parts for each model

In the company's ERP system and bill of materials, data for each model can be collected to analyse number of items for each model, number of common items for each model and total number of parts for each model. The information in the bill of materials for different products in a mixed-model line can be used to identify large differences in parts between different models or to quantify part commonality among models. A big difference in the number of parts for each model would indicate that it will be troublesome to assemble them on the same line. Conclusions of problems on running the models on the same line can also be made based on discrepancies regarding number of unique items per model as well as ratios of common part items between models.

The total number of parts for each model is collected from a Gozinto table that is extracted from the ERP system. The figures are presented in Table 7. The total number of parts includes unique item numbers that are needed several times in one model.

Table 7 Number of parts for each model

Model	Number of parts
L60F	3502
L120F	3994
L110F	3994
L90F	3642
L70F	3560
L150G	4660
L180G	4634
L220G	4749
L250G	4911
L350	6561

The number of parts extracted from the bill of material is only made regarding the standard version of each model and not with all possible options and extra equipment. This simplifies the representation without leaving out any clear patterns. Another limitation that has been made is that the data regarding number of items and parts based on bill of materials is not fully extracted regarding some of the modules used. One article number may represent more items than what is shown in the Gozinto table. Because this is evenly distributed between the models the pattern in the data is not affected i.e. the relationship between the models is not affected. Because the number of parts is not entirely correct it may be hard to make any conclusions regarding assembly time for each model based on part numbers for each model. An extract of the Gozinto table can be seen in Appendix A.

It can be seen from Table 7 that L350 contains almost 90 per cent more parts than the smallest wheel loader, L60F. It can also be seen that the largest difference in number of parts for models that are to be produced on the mixed-model line is about 30 per cent.

The Gozinto table has been used to produce a pivot table with each model in the columns and each item number in the rows. If an item is used in a model it is indicated with the digit 1 and the digit 0 if it is not included in that model. An extract from the pivot table is seen in Appendix B. If calculating the scalar product of two columns the number of common parts between the models in those columns is the answer. This data is presented in Table 8. Running down the diagonal shows the number of unique items going into the row's product. The other values are numbers of items in common to the row and column products. It can be seen that it only differs 8 per cent of the number of unique items for each model. The large L350 is excluded from that figure as well as the L180G HL, which is a special version with much extra equipment. Extra equipment for the models is not treated as mentioned earlier but only the standard versions are considered.

Table 8 Number of items and number of common items for each product

	L350F	L150G	L180G	L180GHL	L220G	L250G	L70F	L90F	L110F	L120F	L60F
L350F	1205	326	324	344	326	332	292	298	315	315	292
L150G		921	904	816	800	753	306	310	344	344	305
L180G			919	820	804	755	307	311	344	306	306
L180GHL				1158	738	742	318	324	347	347	316
L220G					920	832	304	308	334	334	302
L250G						929	304	308	332	332	303
L70F							856	808	560	560	791
L90F								870	574	574	769
L110F									896	886	552
L120F										897	552
L60F											864

If considering item commonality regardless of total item count the numbers are normalized into a ratio that is 100 per cent if the two products use exactly the same items and 0 per cent if they have no items in common. This is shown in Table 9. Fields in Table 9 has been assigned colours with regard to which models that are produced on the same assembly line to make it clearer. It can be seen in Table 9 that the big challenge regarding number of parts that needs to be presented in the material façade can be concluded from that a maximum of 37 per cent item commonality is seen in the white area of the table. The mean value for all models that are to be included in a mixed-model line is 57 per cent item commonality.

Table 9 Commonality ratios for each model

	L350F	L150G	L180G	L180GHL	L220G	L250G	L70F	L90F	L110F	L120F	L60F
L350F	100%	31%	31%	29%	31%	32%	29%	29%	31%	31%	29%
L150G		100%	98%	80%	87%	81%	34%	35%	38%	38%	34%
L180G			100%	80%	87%	82%	35%	35%	38%	34%	34%
L180GHL				100%	72%	72%	32%	33%	34%	34%	32%
L220G					100%	90%	34%	34%	37%	37%	34%
L250G						100%	34%	34%	36%	36%	34%
L70F							100%	94%	64%	64%	92%
L90F								100%	65%	65%	89%
L110F									100%	99%	63%
L120F										100%	63%
L60F											100%

7.1.4 Planning and control

Manufacturing planning and control

At VCE in Arvika the manufacturing planning and control are decided and executed at different levels of the planning horizon. This result in a long term production plan often called a master production schedule as well as a detailed planning at a short term planning horizon. The ERP system used at VCE is called MAPICS and is used for the manufacturing planning and control as well as other functions. SAP is a similar system used at other companies.

Long term planning

A master production schedule is created for all models. When deciding the MPS, the demand and forecasts from distributors are matched against capacity and supplier capacity. The MPS has a time horizon of 16 months. It is revised every month to make adjustments and match demand and forecasts from distributors against capacity. The MPS says what to produce each day 6 months in advance and thereafter what to produce each week.

One goal with the long term planning is to make the MPS levelled with regard to product and volume mix for each day. At present, the demand is very high so the customers accept the levelled plan regardless. The MPS is synced with sales through that the dealers can book free slots in the MPS.

The free slots in the MPS are almost always booked in advance because of that the demand is often the same as the forecasts. If free slots are not booked the production rate is lowered so that no models are built to stock.

Medium term planning

The MPS is frozen ten days ahead so as to secure that all parts and material is available when the model is released to the line. There is in some cases a possibility to change the order inside the frozen 10 days depending on which parts are involved in the change. Some parts have shorter delivery times than others.

Short term planning

In the short term planning the sequence of models released to the line is decided inside each day based on what to produce that day according to the MPS. The sequence of models can only be decided among the models planned for one day. The sequence is decided in the MAPICS planning system and in Excel. It is not until the sequencing of models that the extra equipment is taken into account for the different orders. The sequence of models released to the line for a day is decided ten days in advance i.e. when the schedule is frozen.

It is also checked in the short term planning that all parts is available for the models that are to be produced that day. If some articles are missing the product is removed from that days sequence and delayed until the parts arrive.

Models that are behind production schedule cannot be scheduled in a certain sequence but are instead prioritized. One example could be if a part is missing for the L70 model. The system may then be behind of four L70 when the parts arrive. The sequence schedule for that day then prioritizes the four L70 models so the sequence will by L70-L70-L70-L70 and then the rest of the day's production is scheduled. If no models are behind, the sequence is decided with regard to models with the most time consuming equipment to even out the workload. Easy models follow heavy models and so on. The levelled sequence is also used to achieve even part consumption.

No mathematical algorithms or mixing rules are used to decide the sequence of models. Instead guidelines are used of which parts and equipment that results in the highest workload. The sequence is then decided manually by rules of thumb among the models that are planned for one day.

Since the line is balanced for the most time consuming model the line balancing does not restrict in which sequence models can follow even if the guideline is to even out the workload. The restricting factor for the sequence is instead often availability of parts for the models produced that day. Often there is a problem with parts delivery or defect parts so that the sequence has to be changed.

Conclusion regarding manufacturing planning and control
The MPS is fairly levelled with regard to the model and volume mix since the demand is currently high. The intention is that the sequence within each day also should be levelled but no forcing or hard rules are used. Often the lack of material is the obstacle for having a levelled sequence each day. This is because the different variants of models (where extra equipment are included) are not taken into account until the sequence is to be set ten days in advance. The consequence of this is that the assembly system must be planned for any models at any time.

Line balancing
Balancing of both assembly lines is today carried out with input from time studies. The time studies have resulted in a division of operation times from 30 seconds to 15 minutes that has to be divided evenly among the stations.

There is no system for keeping track of the exact assembly sequence of all the parts. The assembly sequence is restricting the line balancing by the production engineer's knowledge and experience of which parts that need to be assembled before others.

The lines are balanced in the computer software Excel. The lines are balanced to the highest work content product as previously mentioned on both assembly lines. This is illustrated in Figure 42 as an example on how the situation can be on the medium line. No models are allowed to exceed takt time resulting in large variant time losses.

The medium line is balanced according to a takt time of 46 minutes and the large line is balanced according to a takt time of 78 minutes.

If the takt time is exceeded for some reason, the andon button can be pushed so that utility workers can help out. A team of utility workers are also available if models with some extra equipment are assembled. This is not to be able to finish the work on a station within takt time; they are instead used since special competence is needed to assemble certain equipment. The line is still balanced for the most time consuming model including extra equipment.

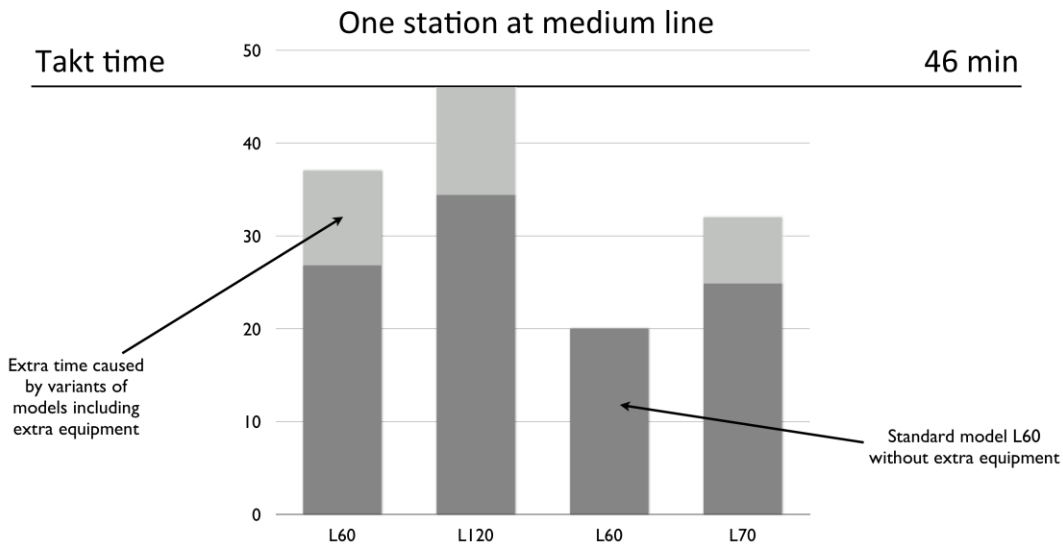


Figure 42 Example of a line balancing on medium line for one station

7.1.5 Time losses

There are today large time losses on both medium and large line. The number one cause for the large time losses in the system is that both lines are balanced for the most time consuming model resulting in large variant time losses. There are variances between models, different variants of the same model caused by extensive extra equipment as well as different product generations. All of these factors result in variant time losses.

Large balance time losses are caused by the low degree of standardisation of work and low quality of time studies as input to the line balancing. Because of that standardised work have not been introduced in the factory the time it actually takes to perform an operation may vary depending on which operator performing the task because different operators use different work methods resulting in that the balancing of the line becomes inaccurate.

It can also be concluded that there are large system time losses on both assembly lines. This is always present because different operators perform tasks at different speed as discussed in Chapter 2.5.1. This problem is worsened because that the operators also use different work methods for the same tasks.

The time studies have been performed by outside contractors. The time studies have resulted in a division of operation times from 30 seconds to 15 minutes and have been performed both on standard wheel loaders and wheel loaders with different types of extra equipment. Because standardised work has not been introduced in the factory, the time it actually takes to perform an operation may vary depending on which operator is performing the task as previously mentioned.

The results from the time studies are seen in Table 10. The G generation of the models that are to be assembled at the same time are not included because the time studies for those models were not available at the time for this thesis. The time has been indexed with regard to the highest work content model. Total time including maximum extra equipment has only been found for the L220 model. As seen in the table there is a large cap between the models assembled on the medium and large line.

Table 10 Indexed assembly times for all models

	L60	L70	L90	L110	L120	L150	L180	L220	L250
Standard model	51,12 %	51,12 %	51,12 %	52,97 %	52,97 %	94,42 %	94,42 %	96,28 %	100,00 %
With extra equipment								128,25 %	

Methods to handle balance, variant and system losses

VCE in Arvika is already using some methods to reduce balance, variant and system losses. Five models are assembled on each line so the variability is already quite large on the respective line. Of course the variability will increase even more if all nine models are moved to one line. Other factors that will increase variability are the extensive equipment options for each model and that both F and G generations are to be assembled at the same time.

The method that is used on both the medium and large assembly line is the use of pre-assembly stations to even out the workload among the stations on the main line.

The intention is also to even out the sequence of models released to the lines. Because of the fact that the lines are balanced for the most time consuming model, sequencing have little effect in reducing the variant time losses. There are no hard or forcing rules regarding which models to assemble in what sequence. The feeling in the production engineering department is that they always have to plan and balance the lines to be prepared for any model.

7.1.6 Material handling and supply

Most items used at the assembly at VCE in Arvika are delivered by external suppliers. Some exceptions are for example the front and rear frames and the booms that are manufactured at VCE in Arvika. Examples of components delivered from external Volvo factories are cabs from Hallsberg and axles and transmissions from Eskilstuna. Deliveries from the suppliers are spread over the day; there are for example approximately five delivers a day from Hallsberg. Some of the larger articles are delivered a day or two ahead of when they are needed in assembly.

The supply of material to the assembly line is mostly done by forklifts carrying pallets. Kitting-racks are tested in a smaller scale but kits in pallets are used at some stations. When pallets at the stations are empty and need replenishment, the operators scan a barcode signalling to the truck drivers that new material is needed. This is also done when the pallets with kits are empty, a barcode is scanned and a truck driver place the next pallet with a kit at the station and the pickers get a signal to prepare the next pallet. Most empty packings are sent away from the factory to be reused but some is scrapped due to the high costs of returning them.

When a truck driver receives an order it is displayed on a screen, the system selects the oldest pallet according to the first in first out principle to avoid material getting old in the warehouse. The truck driver handles the orders in the order they are received with the exception if a priority order is made. Approximately four smaller trucks and one big truck per assembly line are used to supply the material needed. Inside the factory electric trucks is used and outside diesel trucks are used.

Smaller articles for example the so called fix, are placed in smaller boxes and are ordered when empty. There are no large buffers for some small articles, for example screws are ordered directly from the supplier and delivered the next day. The logistics is responsible for replenishing some of the smaller boxes as well as the racks for hoses.

The factory has a warehouse in the basement where some kits in pallets are prepared. A large part of the buffers are stored in pallets above the material façade. Some large parts are stored in sequence in a buffer next to the first stations. There are also warehouses outside the factory in tents and smaller buildings and an external warehouse in for example Hallsberg with engines and some parts from Brazil and Japan intended for the L350.

The total number of unique articles that have to be stored in the material façade is according to calculations about 3162. This is a bit low because in the data from the ERP system and the BOM, many articles can be treated as one in a few cases on every model. As earlier described the fix can be sorted as small articles. Articles can also be sorted as M, L and XL.

7.1.7 Assembly quality

No major efforts have until now been done in the factory in Arvika to reduce the picking errors done by the operators. Articles that are rarely used or belong to stations where the material façade is full are prepared in kits that are sent to the line. However, the picking quality of the kits is not ensured because they are picked after a list without any supplementary aids. Articles that are almost impossible to differentiate by the operators are as far as possible assembled on different stations.

7.2 The model applied at VCE in Arvika

7.2.1 Prerequisites

The analysis that is performed in this chapter is connected to the prerequisite of using a mixed-model assembly line. Different factors will affect which problems will occur and which challenges will be most important in the model for mixed-model assembly line at VCE in Arvika.

Takt time

The value of the takt time affects many key design choices for the assembly system and will influence that some parts of the model will be more important than other. The first step when designing the assembly system is to calculate the takt time. To do this the following assumptions have been made:

- The demand for models produced at the large and medium line for the year 2010 was 4386 units.
- The assembly system in Arvika is operated in two shifts.
- The working hours per day for an operator are assumed to be eight hours.
- Total downtime including scheduled and unscheduled maintenance, set-up times, breaks, lunch etc is one hour per day.
- Number of working days for the year 2010 was 253 days.

The takt time for a future mixed-model assembly line can then be calculated with Equation 7.

$$Takt\ time = \frac{Net\ availible\ working\ time\ per\ day}{Avarage\ demand\ per\ day} = \frac{840}{4386/253} \approx 48\ minutes \qquad (7)$$

If the demand is assumed to increase with 15 per cent in the year 2011 because of the good economic conditions the takt time is calculated to 42 minutes.

The planned cycle time will be lower based on that there are inefficiencies regarding manpower issues and overall equipment effectiveness. According to Volvo Production System, as a rule of thumb, the planned cycle time should in the worst case be calculated according to Equation 8 if the above-mentioned factors are taken in account. The rule of thumb proposed by VPS is a way to handle a difference in assembly time between models. It is used here as an example but we will see that there are other methods to handle the difference in assembly time between models at VCE Arvika further below.

$$Planned\ cycle\ time = 42\ \times\ 0{,}9\ \times\ 0{,}8\ \approx 30\ minutes \qquad (8)$$

A planned cycle time of 30 minutes can be categorised as a long cycle time job. There are numerous problems that arise with long cycle times as described in chapter 2.1.8. When having long cycle times, standardised work becomes extremely important to handle the increased variability, especially in mixed-model environments. A cycle time of 30 minutes is very long but an advantage is that it is shorter than the present cycle times of 46 and 78 minutes. Problems will reach the surface faster and it will be easier to create standards compared to the present situation even if the cycle time still is long. Another part of the model that will be important because of the long planned cycle time is to minimise assembly errors. There is a risk that the operators forget where they are and skips steps in the assembly sequence.

Two factors will decide if the line length will be longer or shorter than the present line lengths; demand and amount of work on the main line. For example if all models are to be assembled on the medium line the demand on that line will be increased with 57 per cent. The number of stations would then need to be increased approximately with 57 per cent if the same amounts of assemblers are allowed at each station and no more work are offloaded to sub-assembly lines i.e. the same amount of work are to be carried out on the main line. The stations will then be increased to 31 stations instead of 20 at the present line. But if a large amount of work is offloaded to sub-assemblies the number of stations on the main line may actually decrease.

It is also possible to calculate the minimum number of required assemblers. The takt time is assumed to be 30 minutes as earlier and the weighted average time to assemble a model is assumed to be 36,3 hours. The minimum number of assemblers can then be calculated with Equation 9.

$$Minimum\ number\ of\ assemblers = \frac{Total\ assembly\ time}{Takt\ time} = \frac{36{,}3 \times 60}{30} \approx 73 \qquad (9)$$

If using two operators per station the number of stations will be approximately 37.

The most probable scenario at VCE in Arvika is that offloading work to sub-assemblies will be used extensively to handle the difference in assembly time between models. Volvo Production System also promotes this way of designing an assembly line. The length of the line will then probably be longer than the present lengths but will not require as much as 37 stations in the main flow because the sub-assemblies will absorb a large amount of work. Another factor that will influence if the stations can be fewer than 37 is if the amount of assemblers per station can be increased.

Difference in production volume

A first step when analysing if different models are suitable to assemble on one line is to look at the production volume for each model. Baudin (2002) argues that models with similar production volume should be categorized in the same flow. The models that may be feasible to assemble on one line with regard to production volume are highlighted in Figure 43. The production volume is fairly evenly distributed among the highlighted models. It can also be noted that the production volume for L350 is much lower compared to all the other models. This is one argument for why the L350 should be separated from the future mixed-model line based on production volume data.

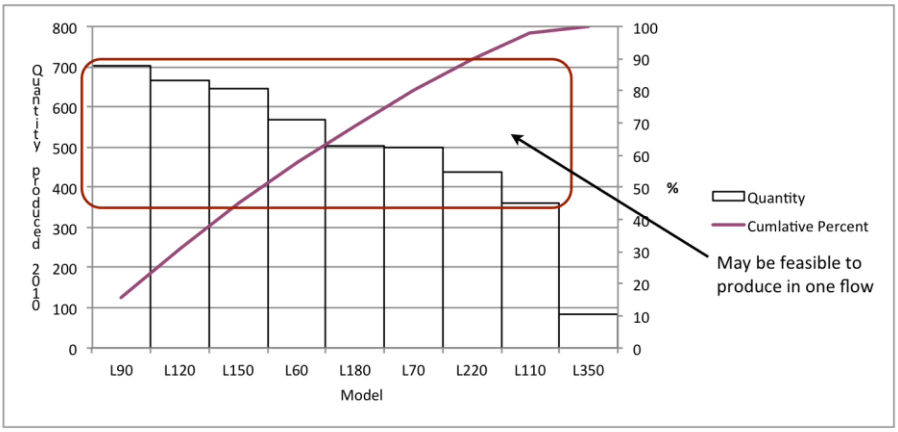


Figure 43 Models that may be feasible to assemble in the same flow based on production volume

Difference in product architecture

There are differences in assembly sequence because models of both the F and G generations will be produced at the same time. When it comes to that the cabs need to be mounted earlier for the F generations than for the G generations the suggested solution is a duplication of station for that assembly operation. The alternative of having one station performing different work tasks depending of which model come along is not a good solution because it will create quality problems. In the long term the product architecture should be changed so that all models, variants of models and product generations have the same assembly sequence. None of the challenges in the model addresses the difference in assembly sequence because it is a prerequisite that must be addressed in the long term.

It is important to make the assembly sequence similar because duplication of stations has severe negative effects on the assembly system regarding increased lead-time and more complex line balancing.

Difference in number of parts for each model

A large difference in number of parts between wheel loader L60-L250 would signal a problem of running them on the same line. A big difference would signal that there would be big differences in assembly time. One could think that because the largest difference in number of parts for the models is about 30 per cent the assembly time should not differ that much more than 30 per cent either. Of course some parts will take longer to assemble because that they may be larger in size or they may require a more complex assembly procedure. As a note the 30 per cent difference is only based on standard versions of the models. If variants that contain optional equipment are included then the difference becomes larger.

A 30 per cent difference in number of parts will cause the challenge in handling difference in assembly time between models becomes important but it is not that large that the models is unsuitable to assemble in one flow. When investigating the difference in number of unique item numbers the difference is about eight per cent which is even smaller.

Difference in parts commonality

The more items that the models have in common the easier will the challenge of reducing the length of the material façade and minimising assembly picking errors will be.

The mean value of parts commonality for the models that are to be assembled in one flow is 57 per cent. This suggests that the length of the material façade may be an issue in a mixed-model line. The material façade will be 43 per cent longer approximately. This figure can be more or less depending on how large in size the unique items are.

The material façade will also not only be longer but also wider because the consumption rate becomes higher. If this becomes an issue the replenishment rate in the material façade must be increased to keep the present width.

The commonality between the models that presently are assembled in the medium and large line is at maximum 37 per cent. The most important issue to deal with if to make the parts commonality higher is to focus on to make the items between the models currently assembled on the large respective small line more common.

The 43 per cent difference in parts commonality will also make the challenge of minimising assembly picking errors important.

7.2.2 Handle complex line balancing problem

It has been concluded throughout the report that the line balancing of the line will become more complex after the transition to a mixed-model line. The introduction of all models on one line at VCE in Arvika will increase both station and model variability leading to difficulties balancing the line. The fact that the lines today are balanced after the most time consuming model leads to huge time losses which will increase even more when all models are to be produced at the same line. VCE in Arvika have to work hard to achieve a decent balance of the work at the line. This can be done when the standards are in place and when correct operation times are available.

VCE in Arvika should focus on the following areas to achieve a decent line balance:

- The exact assembly sequence must be known for each model.
- The line should be balanced according to a weighted average cycle time based on demand for each model.
- The line should be balanced slightly faster than the takt time to be able to compensate for operator fatigue and variations in work content between products i.e the line should not be fully utilized.
- The work tasks independent from assembly sequence should be identified which will create more alternatives for a final line balance.
- If balancing the line to an average focus should be on how to handle differences in assembly times between models due to that some models will exceed the planned cycle time. The methods that are most suitable for VCE in Arvika are presented in in 7.2.5.

Balancing an assembly line can be done with the help of mathematical algorithms calculating an appropriate balance. However, less complex approaches may be used such as to balance the line in Excel or by placing the various tasks on a whiteboard. Despite of what approach that is chosen at VCE in Arvika, they should involve the operators when balancing the line. The operators are familiar with the various work tasks and the problems that may occur with specific balances. They may also be more motivated when they have participated in the decision-making concerning their work situation.

7.2.3 Standardised work methods and accurate operation times

It has been concluded throughout the report that standardised work is a prerequisite to be able to run a successful mixed-model line. Standards have to be in place at VCE in Arvika before the transition to a mixed-model line. The shorter takt time achieved at the plant will make it somewhat easier to follow standardised work instructions at the stations. The fact that the work is carried out at only one flow instead of two will make it easier to develop the best assembly method. The importance of standardised work and accurate operation times will increase at VCE in Arvika after the transition to one mixed-model line due to the following reasons:

- More models on one line will make it harder for the operators to remember how the different models should be assembled.
- The work method that is best at the moment should be standardised and followed to ensure that the assembly time is the same despite of which operator that performs the work.
- They need to standardize the best approach in the current state throughout the factory in order to achieve continuous improvements.
- Line balancing becomes more complex which leads to that the need of correct operation times becomes more crucial which will be easier to achieve if there is only one method to perform the same task.
- The risk of picking errors leading to quality issues increases when handling more models without standards.

Education within standardised work which is underway should, if possible, be accelerated due to the fact that it is an important input to handle the other challenges presented in the mixed-model assembly model. When standardizing work tasks, VCE should involve the personnel working with the tasks every day in the process. It is recommended that the operators themselves write the standards they are to be working according to. This will increase the personnel's empowerment and commitment. The operators at the line may experience that their work becomes a bit more repetitive due to the shorter takt time. Even if variety in terms of more models will be the case in a mixed-model environment, there is no guarantee that the operators feel that their job becomes more enriching just because they, for example, mount several wheels of different sizes. Consequently, it is important that the operators are trusted with different responsibilities within the work with continuous improvement. Offering the operators job assignments that include responsibility and creativity will lower the employee turnover and it will make it easier to recruit new employees. Standardised work is also one of the methods used to handle differences in assembly times between models which is described in 7.2.5.

7.2.4 Levelled sequencing of models released to the line

When balancing the line after an average cycle time, which is recommended to VCE in 7.2.2, producing after a levelled sequence becomes important. Sequencing in itself is a method to handle differences in assembly times between models, which is described in 7.2.5.

VCE in Arvika have to work with their planning system to achieve a levelled sequence. The aggregated production plan has to be levelled to achieve a levelled sequence of models assembled on the line and it is already today fairly levelled. What must be done is to include more details regarding variants of models in the MPS so that the parts availability is secured when the sequence is to be set. In this way the sequence of models can be better followed than today where models that are to be released to the line must be postponed because of lack of material.

The arguments for why achieving a levelled sequence at VCE in Arvika is important are the following:

- It must be used if to balance the line to a weighted average as described in chapter 7.2.2.
- It is a prerequisite to be able to plan the utilization of the utility workers, which is described in 7.2.5.
- It is a prerequisite to use enlargement of cycle time with open stations as described in chapter 7.2.5.
- It is important to control the consumption of parts used on the line.
- It is a prerequisite to reduce unevenness and overburden of equipment and personnel.

VCE in Arvika have to analyse how strictly they should follow a levelled sequence. Producing wheel loaders that are behind schedule in batches to ensure delivery dates creates disorders on the line which may cause stops at the line or unfinished products. However, the cost of that the line is stopped must be balanced against the impact of not delivering wheel loaders on time. High demands and competition regarding delivery dates makes it harder to follow a levelled sequence. Currently the demand is very high so it should not be a restricting factor.

7.2.5 Handle difference in assembly time

The difference in number of parts suggests that there could be a difference of about 30 per cent between the models in assembly time. This figure is regarding the standard versions with no extra equipment. The largest difference is between the L60 and L250. The result from the time studies performed for the same models is shown in Figure 44. The time studies show a difference of about 50 per cent in assembly time for standard versions or that the L250 takes almost 100 per cent longer time to assemble than the L60. The difference between the time studies and what is stipulated from the parts analysis can be explained by that there may be a difference in size of parts and the product as well as the for the ease of assembling the individual parts for the L250. Another explanation could be the low quality of the time studies.

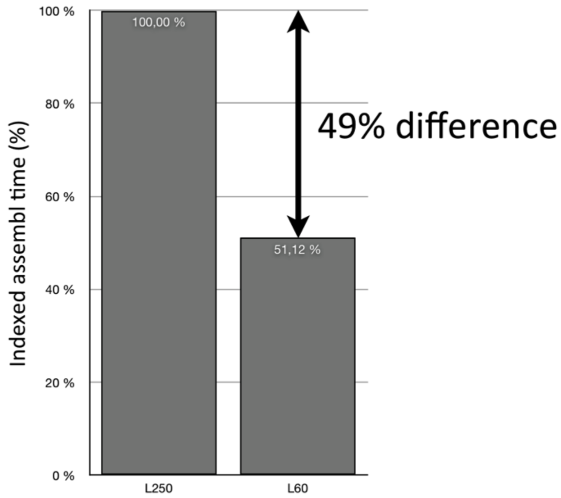


Figure 44 Difference in assembly time between L60 and L250 in standard versions

The L220 has almost the same standard operation time has the larger L250. When comparing a standard version of the L60 with no extra equipment with a version of the L220 with maximum extra equipment the result would be the maximum difference in assembly time that can arise in the assembly system. This is shown in Figure 45. The difference is approximately 60 per cent or that the L220 with equipment will take over 100% longer to assemble than the L60 standard.

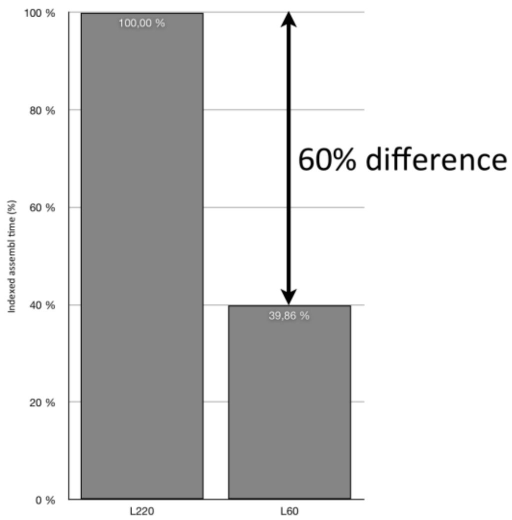


Figure 45 Difference in assembly time between L60 standard and L220 with max equipment

The difference in assembly time between models, variants and model generations in VCE in Arvika is large, as shown above, and consequently one of the most important challenges is to handle this difference in the assembly system. In this chapter all of the methods to handle balance, variant and system losses will be discussed to see if they are suitable for VCE in Arvika. Advantages and disadvantages will be presented for each method.

Two of the methods have been considered more important than the others because they also affect other parts of the assembly system; standardised work and sequencing of models released to the line. They have therefor already been discussed in earlier chapters. They will still be presented here but only with regard to the current subject.

A precondition is that the line is not balanced according to the model with the highest work content. Balancing the line to the highest work content model would result in time losses that couldn't be handled by any of the methods presented below. It is a precondition to try to handle the remaining balance, variant and system losses that will arise.

The following assumptions have been made when analysing the methods:

- The planned cycle time is categorised as long, about 30 minutes.
- Nine models, L60-L250 are to be assembled in the same flow.
- Different product generations will be assembled in the same flow.
- Different variants of the models will be assembled in the same flow.
- There is a large difference in assembly time between models, variants and product generations.
- There is a difference in assembly sequence between some models, variant and product generations.
- The products are very large.
- Space is considered a limiting factor.
- The assembly line is to be paced, either at a constant speed or incrementally.

Offload work to assembly lines

This method is considered as a key for avoiding variant, balance and system losses and handle large variances in assembly time in a mixed-model assembly line in Arvika. It is already used in the current lines so the methodology is not new.

\+ Already in use at current assembly lines.
\+ Promoted by Volvo Production System with the fishbone factory.
\+ Reduces lead time.
\+ Evens out the workload on the main line.

– Increased material handling causes increased logistics cost.
– May create long cycle times in the sub-assembly lines.
– Work on the sub-assembly lines becomes dependent on the model sequence.
– Dependent on the assembly sequence.
– It is often easier to be efficient on the main assembly line than in the sub-assemblies.

Bypass line with different takt time

Using a bypass line for models, variants and product generations requiring long man-hours would be a problematic method in the Arvika plant. The bypass line would require large extra floor space because of the large products. Because of the large products will also make the offloading and on loading to the main technically problematic. Since floor space is considered a limiting factor at VCE in Arvika this method is not recommended.

\+ Evens out the workload on the main line.

– Requires extra floor space.
– Problematic in offloading and on loading the wheel loaders to and from the main line because of their size.
– Requires extensive planning of the model sequence.

Buffer stocks

The use of buffer stocks in between stations or line segments is considered inappropriate in the assembly of wheel loaders because of the large size of the products and the amount of tied up capital that would be created.

+ Reduces the system time losses caused by line stoppages and disturbances.
+ Reduces the need for adjustments caused by uncompleted products.

– Increases work-in-progress tied up capital.
– Increases the need for space.
– Increased handling of the products.

Alternative buffers

This method is achieved by increasing the amount of products available to work at for example by having more stations than is actually needed. Because of the size of the wheel loaders this would cause too much increased tied up capital. If instead increasing available work positions by including pre work/sub assemblies the method could be achieved by not increasing that much tied up capital. The way to use this method in Arvika would be to include positions in the sub-assembly lines for operators that are place on some of the stations on the main line. Those operators could then work in the sub-assembly lines when low work content products appear on the main line

+ Decreases balance and variant time losses that are existent on the main line.

– Increases tied up capital.
– Requires that some operators are highly trained and flexible creating higher training costs and learning time losses.

Utility workers

The possibility to use utility workers in the assembly system is dependent of the value of the cycle time. It may be hard to use utility workers when having short cycle times because it may be hard for the utility workers to quickly switch to stations and work for example only one minute on each station and then move to the next. When cycle times are longer the use of utility workers can be used to handle the times exceeding the takt times and consequently the line could be balanced so that the variant and balance losses are minimised.

Utility workers are used extensively at Scania where cycle times are relatively long but are not used at all in the short cycle time line at Volvo Cars. The method is considered to be a suitable method for a mixed-model line in Arvika because the cycle times are quite long.

An example of how to lower the variant time losses by adding utility workers is seen in Figure 46. As a note, balance the line according to the model with smallest work content in Figure 46 is an extreme case that is used to clarify the purpose.

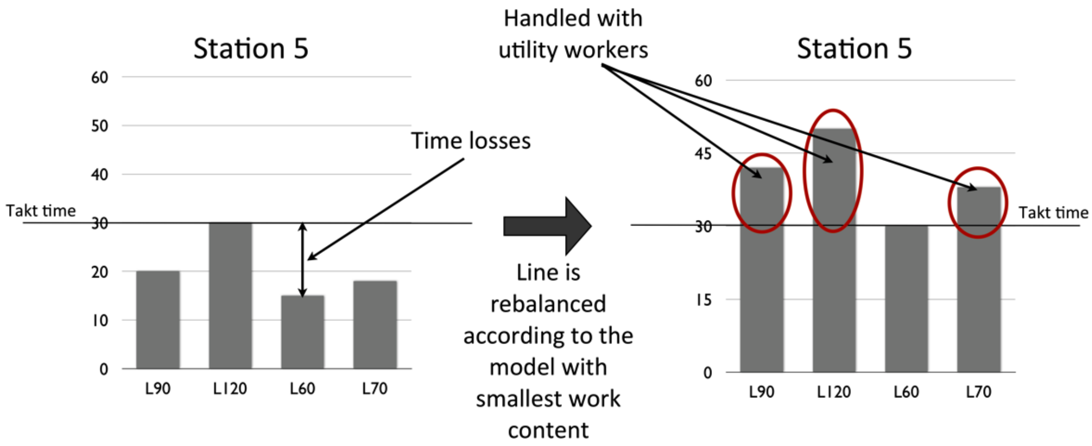


Figure 46 Lower the variant time losses by adding utility workers

+ Is used to handle models, variant or product generations that exceeds takt time allowing for the line to be balanced so that the variant and balance time losses could be minimised.

- The scheduling of the utility workers is dependent on the model sequence and consequently the utilization of the utility workers is dependent on a levelled sequence of models.
- The utility workers must be highly trained and flexible creating learning time losses.
- If used as the only method the costs are higher because of that the utility workers have to be cross-trained.

Enlargement of cycle time

To be able to depart from the one assembly station to the next is in combination with levelled sequencing of models a good way to keep the balance constant even though the man-hours differ. It must be used in combination with sequencing rules so that an easy wheel loader follows a high labour intensive wheel loader to allow the operators to catch up.

Because of that the assembly line is paced but the conveyor moves in intervals a restriction is that all tools, and equipment may not be available at the next station. Another problem is that there may not be space for more than two operators at each station. The problems can be diminished if the line speed is constant instead of incremental so that there may be an overlap space in between stations. Therefore, a continuously paced line may be a requirement at VCE in Arvika and consequently the tools and equipment must also support a continuously paced line.

+ Evens out the workload and handles the variant time losses if used in combination with sequencing rules of models released to the line.

- Operators may be in each other's way.
- All tools and equipment must be available at the subsequent station.
- Dependent on a sophisticated sequence of models released to the line resulting in more advanced planning and control.

Flexible division of work between operators

The operators have a flexible and overlapping knowledge of the work that enables them to help each other if a high work content model appears in one station. A baton touch zone can be used as described in chapter 2.5.2. The strengths and weaknesses for this method in VCE's case are summarized below:

+ Is used to handle models, variant or product generations that exceeds takt time so that the line could be balanced so that the variant and balance time losses could be minimised
+ This method is a prerequisite for some of the other methods.
+ Results in a cross trained workforce with a high understanding of the process and product which could have other benefits such as better quality and process improvements.
+ Possibility for the operators to have a more varied work leading to higher job satisfaction.

– There is a risk that the operators will be in each other's way.
– A baton touch zone requires a continuously paced line.
– Increases the learning time losses and cost for training the operators.

Because of the above mentioned advantages it is recommended that it should be implemented in VCE in Arvika.

Increase the indirect work

Increase the indirect work will, in contrast to increasing the number of products available to work at (direct work), not cause more tied up capital. Indirect work could in the Arvika assembly line be maintenance, 5S work, material handling, improvement work or administrative tasks. It is recommended that this method should be implemented.

+ Handles the balance and variant time losses by that the operators are engaged in other work tasks when idle times occur at the line.
+ Increases responsibilities for the operators resulting in higher job satisfaction.

– Sufficient amount of indirect work may not be available in Volvo CE in Arvika.

Parallel flows

Assembly flows with a completely different assembly layout is not considered an alternative in Arvika even if a parallel flow layout would eliminate the time losses in the system completely. What can be considered in Arvika is the use of parallel stations on the main line, parallel work/collective assembly in pre-assembly stations or the material handling function.

Another way to use parallel work is if the work content in one station exceeds the planned cycle time the use of two stations in parallel would enable to even out the workload among the stations. The use of parallel stations on the main line is not considered to be possible. It would be technically difficult to achieve with a paced conveyor belt the same way as a bypass lines earlier discussed.

+ Parallel flows could be used to decrease the time losses in pre-assembly stations.

– Increased cycle times in parallel work.
– Collective assembly in sub-assemblies need to be paced in a way so that the operators cannot work ahead for example by sequencing delivery of material.
– Increased learning times.
– Higher material handling and logistics costs.

Standardised work
Standardised work will be important in many ways at VCE in Arvika. Regarding time losses standardised work in the assembly system will decrease the actual variety in assembly time between different operators and thereby enables stable station times and reduced assembly time losses. It is therefore considered a key method that must be used.

+ Reduces the variability and thereby the time losses in the system.

Sequencing of models released to the line
One of the sequencing objectives is to level out the workload among the stations. The method is a prerequisite for using the method enlargement of cycle times with open stations as well as to even out the workload for the utility workers if used. It is recommended that it should be evaluated if a levelled sequence could be used in combination with open stations as well as utility workers.

This method is further discussed in Chapter 7.2.4 as a main challenge.

+ Enables the line to be balanced according to a weighted average to diminish the time losses.
+ Diminish the variant losses if used in combination with open stations.
+ Enables an even work distribution for the utility workers.

– Requires that the master production schedule is levelled.
– Increases the requirements on production planning and control.
– High demand on parts availability.

Varying the takt time
Reducing the variant losses can be achieved if releasing the models to the line with different intervals. Varying the takt time can also be achieved if the line speed is adjusted depending on if high or low work content models are currently assembled on the main line. Dividing the line into segments with buffers in between can make it possible to vary the speed in the different line segments.

Assembling models in a multi-model mode with a certain takt time and then flush the line and then adjust the line speed to the next assembly batch is not considered as an alternative because it would result in too high time losses before the line is flushed and refilled.

One could also think that Arvika instead could choose the Automated Guided Vehicle (AGV) concept and get an even higher flexibility. The method is currently considered a bit too advanced for VCE Arvika. It requires advanced manufacturing planning and control and investments in the conveyor system.

+ Enables a highly flexible production.
+ Diminish variant time losses.

– Requires very advanced manufacturing planning and control.
– High investments if AGVs is chosen.
– Technically advanced.
– High tied up capital if line segments with buffers are used.

Methods recommended to VCE in Arvika

Based on the analysis above, a number of methods have been chosen best suited to handle balance, variant and system losses at a mixed-model line at VCE in Arvika:

- Standardised work.
- Sequencing rules of models released to the line.
- Utility workers.
- Off load work to sub-assemblies to even out the workload on the main line.
- Enlargement of cycle time enabled by open stations.
- Flexible division of work.
- The use of alternative buffers.
- Increased indirect work.
- Collective assembly in sub-assembly stations.

The method flexible division of work between operators is considered a method in itself but is also required by some of the other methods. The use of utility workers, alternative buffers and increased indirect work can only be used if the workforce is cross trained and flexible.

The use of the methods open stations in combination with a levelled sequence and flexible division of work with the baton touch zone has a better effect if the line is continuously paced. Advantage with a continuously moving line is also that the time losses when the line is moving are eliminated. A continuously paced line may also make the pacing of work clearer for the operators. The workpace becomes more critical. Today the marriage point between the engines and vehicle limits the possibility of having a continuously paced line. The investments that have to be made to eliminate this limiting factor must be compared to the costs saved due to the decreased time losses in the system derived from the continuously paced line.

The takt time decreases when running only one line compared to several lines as mentioned earlier. This leads to that the handling time losses in the system become larger, i.e. the handling time losses will increase when using an incrementally moving line. This would be another incentive for using a continuously moving line compared to an incrementally moving line in addition to the ones earlier mentioned.

7.2.6 Reduce length of material façade

In the factory today pallet racks are extensively used. Both assembly lines are almost completely surrounded by pallet racks used as material façade on the bottom and as storing only reachable for the forklifts the rest of the height.

Today most components are presented to the operators in pallets or for components such as screws in smaller boxes. To be able to fit all components on the same station lengths when building a mixed-model assembly line some measures has to be taken. Even though there are common components between the models that are to be assembled on the same line one could expect that there will be space problems in the façade at some stations. One obvious example of a station that could get a space problem is the station with the freezers. Large freezers are used to cool down parts so that they could be assembled when using very narrow tolerances. The freezers are very bulky and inflexible.

If using a traditional material supply a basic requirement at a mixed-model line is that all parts must be available at all times. This may not be feasible. When implementing a single mixed model line a larger use of kitting, sequencing and repacking must be used. This requires that parts to a larger extent are delivered Just-in-Time and altogether this will put more strain on the logistics as well as give the logistics more responsibility.

Kitting, mainly in pallets, is already used in a small scale in Arvika where there today is space problems. This must be taken a step further with for example kitting-wagons that also give the possibility of guiding the operator in which part to take next.

Sequencing of parts, particularly large ones, become important when it no longer is possible to store all variants in the façade. This is today already done but may have to be taken further.

Implementing a system such as a 2-bin system may be good in the future but put even more strain on the logistic department.

Another benefit with implementing Just-in-Time together with kitting, sequencing and repacking is that the material façade probably will be less filled with components. The pallet racks may not longer be necessary and the flexibility in rebuilding the façade when rebalancing increases.

In conclusion Arvika must focus on:

- Piloting and then implementing kitting at some stations.
- Repack into smaller boxes.
- Sequence large components to the line.

7.2.7 Minimise picking errors

VCE in Arvika have no overall strategy to minimize picking errors in the assembly. Kitting is used in a small extent. They should develop a strategy to handle picking errors that is applicable on their entire assembly line. Some areas of the assembly line are more troublesome and will require more actions to reduce picking errors. One part of the assembly where picking errors are more frequently occurring is analysed more thoroughly in 0. Finding root causes to solve quality issues in a large organisation such as VCE are troublesome and it is not the scope of this Master´s Thesis. However, ensuring that the right parts are picked and assembled by the operators is one part of the quality puzzle. VCE in Arvika should focus on to identify where picking errors are most common and analyse the impact of the quality issues that occur to find the right solution to the problem. Despite of what method that is chosen, VCE should choose a proactive approach where picking errors are detected and solved at the source.

7.2.8 Minimise assembly errors

Today quality problems arising from assembly errors are costly and often unnecessary. When all models will be assembled on the same line action to prevent assembly errors increases must be taken. Costly rebuilds or line stoppage due to assembly errors must be avoided when all models are built on one line.

In Arvika today on the two lines there are varying degrees of action taken to prevent assembly errors. Each wheel loader has a list with components that should be installed but it is up the operators to read and interpret the list and this open up for mistakes. On the stations there are different lists showing in more detail with for example exploded views how some or all parts should be installed.

In the short perspective visual aids could be used to show how assembly should be done. Implementing standardised sheets showing the work tasks will minimise the risk of operators assembling parts wrong or omitting parts.

Today the factory has begun implementing 5S-work at the stations on the lines. This not only helps the workers picking the right parts but also assembling the right components. To continue the 5S-work is an important step in assuring the assembly quality.

The cycle times are rather long which requires the operators to have a big knowledge of the products. The cycle times can be expected to be lower when combining the lines to a single mixed model line but on the other hand the number of models on the line increases and variety is one of the biggest issues in creating assembly quality problems. With increasing variety the number of mistakes such as omission, incorrect installation, installing the wrong part etcetera may increase. Challenges today include for example choosing the correct tool, fixture and assembly procedure for the right variant. As an example the same parts may be installed on many models but in different places etc and this requires the operators to have a lot of knowledge of different models.

Andon is today used in the factory and should also be used when rebuilding the line. To immediately ask for help when a problem occurs with assembly is in line with the literature and VPS Academy and is something to strive for when rebuilding the line. Poka Yoke is another tool that could be used to minimise problems with assembly. In the longer perspective products should be designed according to for example Design for Assembly (DFA) to ensure good assembly quality.

7.3 Advantages and disadvantages related to mixed-model production at VCE in Arvika

The advantages and disadvantages that are valid at VCE in Arvika due to the transition to mixed-model assembly line are summarized in Table 12 and Table 11. Some of the advantages are directly linked to the implementation of mixed-model assembly line discussed in preceding chapters, while others are a result of the actions that have to be taken to make mixed-model assembly line possible. The same is valid for the disadvantages.

Table 11 Disadvantages due to the transition to mixed-model assembly at VCE in Arvika

Performance objective	Disadvantage
Quality	Increased learning time losses because of increased number of models Risk of that more operators are needed per station
Speed	
Dependability	The system become more sensitive to disturbances
Flexibility	
Cost	Investment because an elongation of the assembly line compared to present lengths Increased risk for time losses due to differences between models, variants and product generations Increased costs in the material handling and logistics function

Table 12 Summary of advantages gained due to the transition to mixed-model assembly at VCE in Arvika

Performance objective	Advantage
Quality	Reduced picking errors Reduced assembly errors Easier to create one best assembly method Solid base for continuous improvements Smoother workload on staff and equipment Reduced learning time losses because of shorter cycle times
Speed	Decreased lead time Shorter takt time Reduced handling time losses at the line Improved efficiency in the assembly work due to that the one best standard is followed
Dependability	Increased delivery accuracy Decreased percentage of orders delivered late caused by less adjustments are needed
Flexibility	Increased volume flexibility Increased variant flexibility Possibility of modularisation Flexible material facade
Cost	Shift trade-off between economics of scale and variability Higher resource utilisation Reduced product dedicated costs Reduced balance, variant and system losses if methods to handle them are used Improved ergonomics Driver for commonality and common product architecture Reduced fork lift traffic

7.4 Prevent picking errors at engine and transmission sub-assembly at medium line

7.4.1 Present situation

It is crucial to reduce picking errors in manual assembly to ensure the overall quality of a company's products. This becomes even more important in a mixed-model assembly line due to the increased number of components which, if presented poorly, will lead to an increased risk of part confusion which causes defect products.

Part confusion occurs too often at especially one section of the medium line at VCE in Arvika. The section is the sub-assembly of motors and transmissions supporting the main line. The sub-assembly consists of three stations with the same takt time as the medium line. There are one, two and three operators working at the stations respectively. The hydraulic work and fan pumps are assembled at the first station. Other components that are assembled on the sub-assembly are; generators, handbrakes, inter cooler pipes, air condition, and cable mats. An overview of the sub-assembly is shown in Figure 47.

Figure 47 Overview of the motor and transmission sub-assembly

The problematic task is the assembly of hydraulic work and fan pumps. The main issue is that all pumps have the same interface which means that they can be assembled on all the motors and that the pumps only differ slightly in appearance. All pumps except two are presented in pallets next to the line, the more rarely used pumps, which are the ones for L60F long boom and L70F HDLS, are instead ordered when needed. The material needed on the sub-assembly is placed in pallets on both sides of the line. Eight pallets are stacked on top of each other in racks of which four are storage. A part of the material façade can be seen in Figure 48.

Figure 48 Picture of material façade at one side of the engine and transmission sub-assembly

The units that are defect due to the assembly of the wrong pumps are discovered at different stages in the manufacturing chain. The defect can be discovered on the line, at the quality control or by the customer. The worst case scenario, when a defect wheel loader is sent to the customer, leads to significant costs for VCE.

The risk of installing the wrong pump is more commonly occurring for certain variants. Two of the pumps look different compared to the other which means that the risk of confusing them is low.

The greatest confusion risk occurs when a model with special equipment that is uncommon is assembled. This is the case when L110F with long boom is to be assembled. Two work pumps and one fan pump is used in the standard version of L110F. In the long boom version, one of the standard work pumps is replaced with a work pump used on the standard version of a L120F. The pumps used on the standard versions of L110F and L120F are also easy to confuse due to their appearance and the way they are presented to the operators.

Another frequent error occurs when the work pumps for L60F long boom and L70F HDLS are assembled. Those variants require pumps different from the standard case and there is therefore a risk that the standard pumps are assembled instead of the pumps that have to be ordered.

There is no significant confusion of fan pumps because all variants of the F generation uses one type of fan pump and another type of fan pump is used on all the variants of the G generation. The models and their respective pumps are presented in Table 13. The squares that are marked red in the table represent scenarios where confusion risks occur. The squares that are marked green represent low confusion risk scenarios.

Table 13 The wheel loader models and their respective work and fan pumps

	Model									
***Pump name**	L60F	L70F	L90F	L110F	L120F	L60G	L70G	L90G	L110G	L120G
FP1	x	x	x	x	x					
WP1	x (long boom)									
WP2	x					x				
WP3		x					x			
WP4		x (HDLS)								
WP5			x							
WP6				x						
WP7				x						
WP8					x					
WP9				x (long boom)	x					
FP2						x	x	x	x	x
WP10								x		
WP11									x	
WP12									x	
WP13										x
WP14										x
Note	Risk of using std WP when long boom	Risk of using std WP when HDLS	Low confusion risk	Risk of using std WP when long boom	Confusion risk with L110F's std WP's			Low confusion risk		
***WP = Working Pump; FP = Fan pump**										

At the sub-assembly, the operators are presented with a list of components and parts for the model that is to be assembled. The list tells the operator what parts to assemble and their respective item number. The operator also have special instruction sheets for each variant that show in more detail what parts that should be used. The assembly sequence is not specified in the lists or the sheets. As shown in Figure 49, there is a small sign in front of each pallet that indicates which model the pump belongs to in the standard case. A label with the item number of the pump is also attached on the pallet rack.

Figure 49 Example of part presentation at the motor and transmission sub-assembly

7.4.2 Analysis of station

The perfect scenario would be if one standard work pump could be developed and used on all the wheel loaders. However, this is hard to achieve because of that the different variants require pumps with different performance. The difference is sometimes small; it can for example be that the oil pressure in one pump is the only parameter that differs from another pump with different item number. However, these small differences are crucial for the function of the wheel loader.

Using modules with the same interface is often a preferable way to be able to offer more variants of a model without adding too much complexity to the manufacturing system. However, in the case with the hydraulic pumps, the similar interfaces adds more confusion and errors in the production due to that only one specific pump can be used on each variant. The pumps are bought from an external supplier that delivers the pumps to other companies as well. It may therefore be hard for VCE to influence the design of the pumps. If the design could be influenced; simple Poka-Yoke solutions could be implemented to ensure the quality. Some kind of physical constrain could for example be added which would make it impossible to install a pump on the wrong engine or transmission.

The marking of pallets with signs showing what model each pump belongs to could be a good solution. The problem with this approach is that it only shows what pump to use in the standard case. This becomes problematic when a standard pump for one variant is used in a special variant of another model, as in the case of L110F long boom mentioned earlier. This approach then becomes more confusing for the operators than if only the pallets would have been marked with the item number.

The way the pumps are presented in pallets today is quite space demanding and will be more so when more models are to be produced on one line. The situation at the corresponding sub-assembly at large line is similar to the one at medium line.

The work instructions only show what parts that are to be assembled at a station which is not informative enough. There is no follow up on that the operators are looking at the instructions. It is not highlighted enough in the work instruction when unusual models, such as long boom or HDLS, are to be produced. The absence of distinct assembly sequences and information in the instructions lead to that the operators have to rely more on experience.

The plant in Arvika is at the moment undergoing an extensive education effort within the area of standardised work. However, it has not yet reached the sub-assembly at medium line. The work with standards will probably improve the overall situation at the sub-assembly to some extent.

The main problems that lead to quality issues at the engine and transmission sub-assembly can be summarized as follows:

- Similar interface and appearance between the different work pumps.
- Signs at the pallets in the material façade are confusing.
- Work instructions are not sufficient.
- Lack of standards.

7.4.3 Possible solutions

Quality issues that occur due to the installation of wrong hydraulic work pumps are costly and it may affect VCE's reputation negatively. Consequently, it implies that an investment of time and money to solve these quality issues is economically viable.

When looking at possible solutions for the situation at the engine and transmission sub-assembly at medium line one has to have in mind that the conditions will change after the transition to a mixed-model line. An overall approach could be used on the entire line to handle the quality issues when the layout is changed. The overall approach could involve that the entire logistic chain is revised. The solution presented for the present situation could though still be valid after the transition to a mixed-model line, especially at stations where the risk of picking errors is more likely.

VCE should work with standardisation as one part of the solution to achieve better assembly quality. The standardisation process should involve the development of clear work instructions and a system that ensures that the standards are followed. The development of standards should be done in cooperation between operators and production technicians. The method that is chosen to increase the assembly quality should be used in combination with a source control approach that demands immediate action which ensures that no defect items leave the sub-assembly.

The methods available to overcome quality issues due to picking errors differ when it comes to complexity and cost.

A simple, yet effective solution to ensure that operators are taking the right pump is to tag the pallets in a more clear way. This could be done by enlarging some digits in the item numbers. One work pump used in the standard version of L110F has 15079526 as item number and another work pump used in the standard version of L120F has 15079525 as item number. The two last digits in the item number, both in the work instruction and on the pallet where the pumps are presented, should be enlarged. This means that the operator only has to memorize two digits instead of eight which will lessen the risk of item number mix up and it will reduce the time spent on double-checking that the right item has been picked. An example is illustrated in Figure 50.

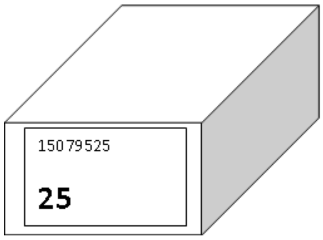


Figure 50 Example of item number presentation

Kitting is a material supply method that increases the picking accuracy at the line. If the kits with only the set of parts for one assembly object are sequenced to the line, it will lead to that the operators do not have to choose between different pumps. It also reduces the risk of omitting parts because they will notice if there are parts left in the kit when they have finished assembling. It is though crucial when working with kitting that the picking quality is ensured upstream the chain. If picking errors are made when the kits are put together the company will continue produce defect products. Kitting in itself does not include source inspection because it does not alert if incorrect parts are installed or if parts are omitted. Parts could also be delivered to the line in the right sequence as a method to make sure that the right part is picked.

However, VCE have to make sure that they have a well functional planning system to achieve a successful material supply involving sequenced kitting. One can argue that it is not economically justified to change the entire material supply system to overcome quality issues at one station. Because of the increased material handling time that is needed to prepare kits, it will be harder to recoup profit if kitting is only implemented at one part of the line. Kitting will probably be important in many aspects when VCE implements their mixed-model line but at the moment, less complex methods should be used to ensure quality.

A pick-to-light system in combination with barcoding or RIFD is an appropriate solution for VCE to solve the quality issues at the engine and transmission sub-assembly at medium line.

RFID saves, as mentioned earlier, more time because that the operators does not have to manually scan items. However, it is more expensive than barcodes and the time saved represents only a small fraction of the takt time. Consequently, the station should be equipped with a barcode reader connected to a computer. Engine and transmission, pallets and pumps should be tagged with barcodes. The unit entering a station should be scanned so that the lights at the right bins are lit. All the lights could be lit at the same time or one at the time in the right assembly sequence. A touch-free sensor verifies that the correct item is picked and the light turns green. If the wrong item is picked, the light turns red. The computer screen, which is included in such a system, can show the assembly sequence and the theoretical assembly time for each step. The unit and the pumps should be scanned after assembly to ensure that the right pumps have been installed and that no pump is omitted. With this approach the quality control is done at the source and immediate action can be taken if anything is wrong.

A survey of the market was conducted to see if there was any appropriate pick-to-light system of the kind needed at VCE in Arvika. Tenders were taken in to see what such a system would cost. The price of the system depends on the number of components that have to be equipped with sensors. It also depends on how the material façade is designed. The price is also dependent on the degree of extra functions and if it should be connected to the planning system which is preferable in VCE's case. A summary of the tender is presented in Table 14. The price does not include installation.

Table 14 Summary of tender

Description	Cost (SEK, excluding VAT)
Station	45,000 – 62,000
17 x touch-free sensors	
1 x barcode reader	
1 x 19” PC touch screen	
All cables needed	
Two days education	24,000
Customized software	70,000
Total	139,000 – 156,000

The cost of the quality issues that can be derived to the picking errors made at the engine and transmission sub-assembly depends, as mentioned before, on when the defect is detected. The most expensive warranty cost for VCE is when the defect wheel loader reaches the end customer. The cost is then depending on which market the wheel loader is sold on. The average cost is estimated at 100,000 SEK per wheel loader. The cost of the defect wheel loaders that are caught within the factory also differ depending on how much rework that is needed. When a defect wheel loader is caught within the factory it usually takes one operator eight hours to correct the problem. It can also have effects such as line stoppage, late delivery to customer and cost due to tied up capital etcetera. The total cost for the quality issues could not be found. However, as an example, a rough estimation could be done that two defect wheel loaders reach the end customer per year of a total cost of 200,000 SEK per year. The rework cost within the factory could be estimated at a 100,000 SEK per year. The equation below shows an estimation of when a pick-to-light system would be repaid.

$$\frac{Cost\ of\ system\ [SEK]}{Warranty\ and\ rework\ cost\ [SEK/month]} = \frac{156{,}000\ [SEK]}{25{,}000\ [SEK/month]} = 6{,}24\ months \qquad (10)$$

The calculation above implies that the investment of the suggested pick-to-light system would be repaid within approximately six and a half months.

8 Conclusions

In this chapter the conclusions are presented together with a discussion about if the purpose of the Master´s Thesis and the research questions has been answered. The conclusions comprise of three subsections: the conclusions with regard to the research questions, a summary of the contributions of this thesis, and a prospect of future research.

The assembly of many models, variants and product generations on the same assembly line results in many problems. The problem that causes the largest challenges has been found to be the difference in assembly time. It has been concluded that this challenge can be handled with certain methods and solutions. The literature poses that the largest difference in assembly time can be about 30 per cent but it has been seen from the empirical findings that a difference of about 50 per cent can be handled if following the guidelines presented in this thesis. The other problems and challenges can also be handled but the difference in assembly time is the most important issue.

Conclusions with regard to the research questions and purpose of the thesis

RQ1: Which problems and challenges have to be overcome when implementing a mixed-model assembly line at VCE operations in Sweden or in production systems with similar products?

The problems and challenges with a mixed-model assembly line have been mapped in a model. The model with the problems and challenges is presented in chapter 6.2.2.

RQ2: Which are the possible methods and solutions to be able to handle the challenges?

The possible methods and solutions to handle the challenges in the model are presented under each challenge in chapter 6.2.5 and in Appendix C.

RQ3: What challenges will be most important at VCE in Arvika and what methods and solutions should be used to overcome them?

The analysis of which parts of the model that will be most important for VCE Arvika is presented in chapter 7.

Contribution of this Master's Thesis

This thesis is contributing knowledge in the form of a general framework for mixed-model assembly lines that maps the problems, identifies the most important challenges, and suggests methods and solutions. The framework can be used by companies to be able to identify what must be considered when implementing mixed-model lines. The framework is presented in the form of a model in Chapter 6.2. The authors believe that the model considers all relevant aspects regarding mixed-model assembly lines and it is therefore believed to be comprehensive. A similar framework has not been found in the literature as of today.

Further research within the area of mixed-model assembly

The model in this thesis is considered to be comprehensive but each part of the model is not fully explored. When implementing mixed-model assembly lines, each part of the model could be more thoroughly analysed based on the specific company's current prerequisites and context.

9 Recommendations for VCE Arvika

Implementing a mixed-model line at VCE in Arvika will require that numerous methods and solutions have to be utilised to handle the challenges that will occur. The question is whether to implement all methods and solutions at once or start with some of the methods in the present assembly system before rebuilding the plant. It is recommended that standardised work is fully implemented and in place before rebuilding the plant because this challenge serve as a prerequisite for many others. Standardised work can be considered a basic requirement before considering any of the remaining challenges. The methods and solutions that are recommended to implement before or after are seen in Figure 51.

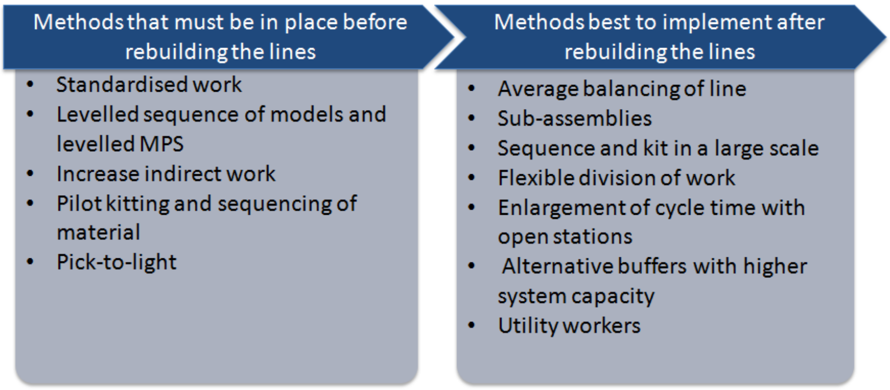


Figure 51 Methods to implement before and after implementing one mixed-model assembly line

Short term recommendations

VCE in Arvika should well in advance of a transition to a mixed-model assembly line develop action plans and strategies of how to handle the challenges presented in this Master's Thesis. Waiting for the mixed-model line to be in place before strategies are developed will cause problems and is therefore not recommended. Pilot projects within each area should be implemented so that any obstacles can be resolved before the new systems are implemented on a larger scale. Mixed-model assembly lines should not be seen as a solution to all problems even if it brings numerous benefits.

Long term recommendations

There are many benefits with mixed-model assembly lines but also numerous problems. The problems must be attacked from two ways as seen in Figure 52. To move towards more similar product architecture is time consuming and it should therefore be handled as a long term issue. Efforts to achieve more similar product architecture, product design, common parts, and number of parts will hopefully be accelerated after the transition to mixed-model assembly, which will simplify the process of managing the other challenges related to mixed-model assembly in the future.

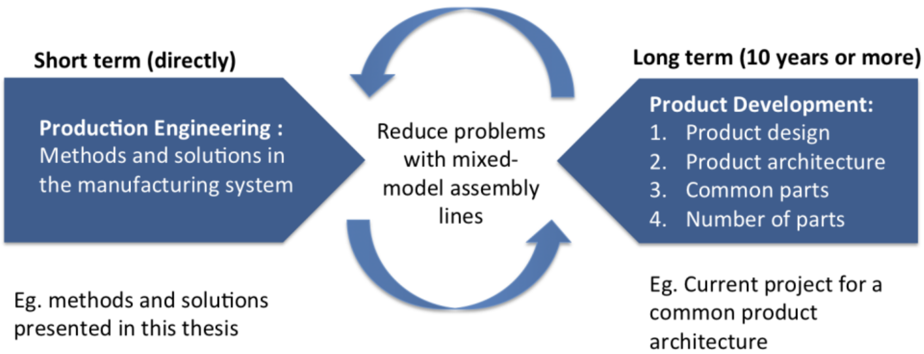


Figure 52 Recommendations to VCE in Arvika

10 Discussion

The researchers believe that the aim and purpose of this Master's Thesis have been fulfilled. However, the different parts of the model could have been analysed more thoroughly in part two of the analysis where the model was applied at VCE in Arvika. The analysis was limited due to the amount of time allocated for this project. This Master's Thesis could, however, serve as a starting point for VCE in Arvika in their desire to achieve a well functional mixed-model assembly line and clarify what should be analysed.

Regarding the empirical material one must bear in mind that the interviewees' have different experiences with regard to the type of products their companies produce. The level of experience from companies with different strategies regarding production may also influence their opinions about how to handle mixed-model assembly. The interview study could have been more extensive to include the views of a larger number of people experienced within the field. However, this was also restricted due to the lack of time.

One of the advantages VCE hope to gain when implementing a mixed-model assembly line is the possibility to get shorter learning times. The conclusions from this Master's Thesis do not confirm that shorter learning times are a result from a mixed-model assembly line. This is further discussed in chapter 6.2.1.

Another of the main advantages VCE hope to gain is the need of less floor space. Evidence that this will be a consequence if implementing a mixed model assembly line has not been found. See chapter 6.2.1.

A noteworthy conclusion that can be drawn is that a mixed-model assembly line would require a higher dependability than the two lines currently operating at VCE in Arvika. This is due to that the assembly system becomes more sensitive to disturbances when having only one flow.

One important issue that have not been addressed much in this thesis because of limited amount of time is work organisation and employee opinions regarding mixed-model assembly lines. Work organisation and employee involvement is considered to be very important when making changes and implementing new systems in a company. It could have been good to include the employees' view of a transition to mixed-model assembly lines in the Thesis. Another important issue not addressed also related to work organization is the top-management involvement.

The aim of this thesis was to develop a model with problems, challenges and methods and solutions for mixed-model assembly lines and then apply the model at VCE in Arvika. This thesis was developed with the intention that one mixed-model assembly line should be used in the future Arvika plant. The result from this thesis can therefore be used to make one mixed-model line in Arvika as good as possible. It could be discussed if the purpose of this thesis also could have included whether one mixed-model line should be used or not used and why it should be used or not used.

There is a risk associated with rebuilding the current assembly system is Arvika to one mixed-model assembly line. There is a risk that the expected benefit is not achieved. If the results from this thesis are followed the risk is smaller than it would have been but nevertheless there is still a risk. The authors believe that there are two options to improve the assembly system. Either follow the model presented in this thesis and implement one mixed-model assembly line or avoid the risk by applying the model to the two current mixed-model assembly lines. The recommendations in the previous chapter is based on that VCE in Arvika already have decided to use one mixed-model assembly line and it is believed that this is possible. But it is also believed that it is possible to apply the model to the current lines and this may be an option worth to consider.

11 References

Aigbedo, H., & Monden, Y. M. (1997). A Parametric Procedure for Multi-Criterion Sequence Scheduling for Just-In-Time Mixed-Model Assembly Lines. *International Journal of Production Research , 35* (9), 2543-2564.

Andersson, J. (2011, March 28). Scania Production System Coordinator. (F. Hellman, B. Lindahl, & J. Malmberg, Interviewers)

Avix Balance: Avix. (2006, 06 09). Retrieved from Hem: Avix: http://www.avix.eu/vaara-produkter/avixr-balance.html

Baudin, M. (2002). *Lean Assembly: The Nuts and Bolts of Making Assembly Operations Flow.* New York: Productivity Press.

Baudin, M. (2004). *Lean Logistics: The Nuts and Bolts of Delivering Materials and Goods .* New York: Productivity Press.

Bayers, P. C. (1994). Using Poka Yoke to Ensure Quality. *Ninth annual Applied Power Electronics Conference and Exposition* (pp. 201-204). Orlando: IEEE Power Electronics Society.

Becker, C., & Scholl, A. (2006). A survey on problems and methods in generalized assembly line balancing. *European Journal of Operational Research* , 694-715.

Blackenfelt, M. (2001). *Managing complexity by product modularisation: Balancing the aspects of technology and business during the design process.* Stockholm: Department of Machine Design, Royal Institute of Technology.

Bozer, Y. A., & McGinnis, L. F. (1992). Kitting versus line stocking: A conceptual framework and a descriptive model*. *International Journal Production Economics , 28*, 1-19.

Bukchin, J. (1998). A comparative study of performance measures for throughput of a mixed model assembly line in a JIT environment. *International Journal of Production Research , 36* (10), 2669-2685.

Chakravarty, A. K., & Shtub, A. (1985). Balancing mixed model lines with in-process inventories. *Management Science , 31* (9), 1161-1174.

Cheldelin, B., & Ishii, K. (2004). Mixed model assembly quality: An approach to prevent human errors. *2004 ASME International Mechanical Engineering Congress & Exposition* (pp. 1-11). Anaheim, California USA: Stanford University.

Corporate brochures & presentations. (2011). Retrieved April 15, 2011, from Volvo Construction Equipment: http://www.volvo.com/constructionequipment/corporate/en-gb/AboutUs/presentations/presentations.htm

Duggan, K. J. (2002). *Creating Mixed Model Value Streams.* Oregon: Taylor & Francis Inc.

Ellegård, K., Engström, T., Johansson, B., Nilsson, L., & Medbo, L. (1992). *Reflektiv produktion, Industriell verksamhet i förändring.* Göteborg: Arbetslivsutveckling, AB Volvo.

Engström, T. (2011, May 23). Associate Professor Logistics and Transportation at Chalmers University of Technology. (F. Hellman, B. Lindahl, & J. Malmberg, Interviewers)

Engström, T., Jonsson, D., & Medbo, L. (2005). *Alternativ montering – Principer och erfarenheter från fordonsindustrin.* Stockholm: Metall.

Fujimoto, T., Jürgens, U., & Shimokawa, K. S. (1997). *Transforming Automobile Assembly: Experience in Automation and Work Organization.* New York: Springer-Verlag New York, LLC.

Gaukler, G. M., & Hausman, W. H. (2008). RFID in Mixed-Model Automotive Assembly Operations: Process and Quality Cost Savings. *IIE Transactions* , 1083-1096.

Glenn, J. C. (2010). *Handbook of Research Methods.* Jaipur: Global Media.

Gubrium, J. F., & Holstein, J. A. (2002). *Handbook of interview research : context & method.* California: Sage Publications, Inc.

Heike, G., Ramulu, M., Sorenson, E., Shanahan, P., & Moinzadeh, K. (2001). Mixed model aseembly alternatives for low-volume manufacturing: The case of the aerospace industry. *International journal of production economics* , 103-120.

Huttmeir, A., de Treville, S., van Ackere, A., Monnier, L., & Prenninger, J. (2009). Trading off between heijunka and just-insequence. *Int. J. Production Economics* , 501-507.

James, D. (2011, March 11). Volvo Production System Specialist. (F. Hellman, B. Lindahl, & J. Malmberg, Interviewers)

Johansson, E., & Johansson, M. (2006). Materials Supply Systems Design in Product Development Projects. *International Journal of Operation and Product Management , 26* (4), 371-393.

Johansson, M. I. (1989). *Product design and materials handling in mixed-model assembly.* Göteborg: Chalmers University of Technology.

Jonsson, D., Medbo, L., & Engström, T. (2004). Some considerations relating to the reintrodocution of assembly lines in the Swedish automotive industry. *International Journal of Operations & Production Management , 24* (8), 754-772.

Jürgens, U. (1997). Rolling Back Cycle Times: The Renaissance of the Classic Assembly Line in Final Assembly. In K. Shimokawa, U. Jürgens, & T. Fujimoto, *Transforming Automobile Assembly* (pp. 255-273). Berlin: Springer-Verlag.

Koide, K., & Iwata, T. (2007). Kaizen Through Heijunka Production (Leveled Production). *SAE International* , Abstarct.

Lenander, P.-H. (2011, April 6). Production Engineer at Volvo Construction Equipment in Braås. (F. Hellman, B. Lindahl, & J. Malmberg, Interviewers)

Liker, J. K. (2004). *The Toyota Way; 14 Management Principles from the World´s Greatest Manufacturer.* New York: McGraw-Hill.

Liker, J. K., & Meier, D. (2006). *The Toyota Way Fieldbook: A practical guide for implementing Toyota´s 4Ps.* New York: The McGraw-Hill Companies.

M Alper, C. (2008). *An Evaluation of Kitting Systems in Lean Production.* Borås: University College of Borås.

MacDuffie, J. P., Sethuraman, K., & Fisher, M. L. (1996). Product Variety and Manufacturing Performance: Evidence from the International Automotive Assembly Plant Study. *Management Science , 42* (3), 350-369.

Martin, T. D., & Bell, J. T. (2011). *New Horizons in Standardized Work: Techniques for Manufacturing and Business Process Improvement.* New York: Productivity Press.

Medbo, L. (2011, March 16). Förluster i monteringssystem - de finns men går att minska om man känner till dem. *Svenskt Monteringsforum 13:10-13:30.* Stockholm.

Moestam, L. (2011, March 29). Volvo Production System Specialist. (F. Hellman, B. Lindahl, & J. Malmberg, Interviewers)

Monden, Y. (2008). *Toyota Production System: an integrated approach to Just in Time.* Norcross: Chapman & Hall.

Ohno, T. (1978). *TOYOTA PRODUCTION SYSTEM: Beyond Large-Scale Production.* Tokyo: Diamond, Inc.

Olsson, S. (2011, April 6). Production Engineer at Volvo Construction Equipment in Braås. (F. Hellman, B. Lindahl, & J. Malmberg, Interviewers)

Pro Balance. (2011, 06 09). Retrieved from Pro Planner: manufacturing process engineering & management: http://www.proplanner.com/en/products/probalance/

Rasmusson, L. (2011, April 21). Efficiency Coordinator for Manufacturing at Volvo Car Corporation. (F. Hellman, & B. Lindahl, Interviewers)

Rekiek, B., Pierre, D. L., & Alain, D. (2000, June). Designing Mixed-Product Assembly Lines. *IEEE Transactions on robotics and automation , 16* (3), pp. 268-280.

Rushton, A., Croucher, P., & Baker, P. (2006). *The handbook of Logistics and Distribution Management.* London: Kogan Page Limited.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students.* Harlow: Pearson Education Limited.

Scholl, A. (1999). *Balancing and Sequencing of Assembly Lines.* New York: Physica-Verlag.

Shimbun, N. K. (1988). *Poka-Yoke: Improving Product Quality by preventing Defects.* Cambridge: Productivity Press.

Shtub, A., & Dar-el, E. M. (1989). A methodology for selection of assembly systems. *Int. J. Prod. Res. , 27* (1), 175-186.

Sivard, G. (2001). *A Generic Information Plattform for Product Families.* Stocholm: Royal University of Technology.

Slack, N., & Lewis, M. (2008). *Operations Strategy.* Harlow: Pearson Education Limited.

Slack, N., Chambers, S., & Johnston, R. (2010). *Operations Management.* Harlow: Pearson Education Limited.

Sly, D. (2011, 06 09). *ProPlanner webiste.* Retrieved 06 09, 2011, from Line Balancing Technical Presentation (PDF): http://www.proplanner.com/documents/filelibrary/products/probalance/documents/Line_Balance_PDF_EA88A25C4FF47.pdf

Swaminathan, J. M., & Nitsch, T. R. (2007). Managing Product variety in Automobile Assembly: The importance of Sequencing Point. *Interfaces , 37* (4), 324-333.

Swecon. (2011, 06 08). Retrieved from Lastmaskiner - Hjullastare: Swecon Anläggningsmaskiner: http://www.volvo.com/dealers/sv-se/Swecon/products/wheelloaders/wheelloaders/introduction.htm

Svedlund, B. (2011, April 26). Process Engineer at Scania. (F. Hellman, & B. Lindahl, Interviewers)

Thomopoulos, N. T. (1967, October). Line Balancing-Sequencing for Mixed-Model Assembly. *Management Science , 14* (2), pp. B59-B75.

Thomopoulos, N. T., & Lehman, M. (1969). The Mixed Model Learning Curve. *IIE Transactions , 1* (2), 127-132.

Ulrich, K. T., & Eppinger, S. D. (2004). *Product Design and Development.* New York: McGraw-Hill.

Wild, R. (1975). On the selection of mass production systems. *International Journal of Production Research , 13* (5), 443-461.

Wild, R. (1995). *Production and Operations Management.* London: Cassell.

Vollmann, T. E., William, B., Whybark, D. C., & Jacobs, R. F. (2005). *Manufacturing Planning and Control Systems for Supply Chain Management.* New York: McGraw-Hill.

Volvo Construction Equipment Global Site. (2011, 05 17). Retrieved 05 17, 2011, from Corporate brochures & presentations: http://www.volvo.com/constructionequipment/corporate/en-gb/AboutUs/presentations/presentations.htm

VPS Academy. (2011). Volvo Technology.

Xiaobo, Z., & Zhou, Z. (1999). Algorithms for Toyota's goal of sequencing mixed models on an assembly line with multiple workstation. *Journal of the Operational Research Society , 50*, 704-710.

Zhu, X., Jack Hu, S., Koren, Y., & Marin, S. P. (2008). Modeling of Manufacturing Complexity in Mixed-Model Assembly Lines. *130*, 0.

Appendix A - Extract from gozinto table

Table A1 Extract from gozinto table

Utr	Artikelnr	Benämning	Antal per produkt	Förråd	Vikt	Saldo	Ändringsorder frå	Ändringsorder til	Emballag	Antal per em	Station	Tempo	Förb plat
31713	15109083	SLANGLEDNING	1	464	0,67	4	1090323	9999999	K1	10	3020	30353	3030V
31713	4766526	TÄTNINGSLIST	2,7	456	0,4	247,752	0	9999999	L1	200	PROV	30839	3021G
31713	15168018	GIVARSATS	1	456	3	124	1100517	1110426	K1	25	3040	30478	3040B2
31713	15168018	GIVARSATS	1	456	3	124	1100517	1110426	K1	25	3040	30480	3040B2
31713	11171853	LEDNINGSMATTA	1	457	6,3	7	1060929	1110314	L1	6	3490	30147	KC14
31713	949746	KLAMMA 12,7	16	462	0,01	21400	1060419	1110314	L1	4500	3490	30147	3010F2
31713	977599	KLAMMA 22,2	13	462	0,016	11123	1060419	1110314	L1	3000	3490	30147	3010F2
31713	11411896	PLATTSTÅL	6	462	1	507	1051128	1110314	K1	2000	3030	30392	3030F3
31713	11302483	GÅNGJÄRN	4	464	0,7	60	0	1110314	L0	200	PROV	30835	3490B1
31713	11412631	KOMPRESSOR	1	456	8,3	-1	0	1110314	L1	16	3021	30615	KB29
31713	967710	LAMPA 24VX10W	2	462	0,007	921	0	1110314	L0	0	3040	30510	3040F2
31713	977600	KLAMMA 25,4	1	462	0,026	2381	0	1110314	L1	2000	3490	30147	3010F2
31713	15193570	GOLVMATTA	1	465	17	225	1110209	0	G2	15	PROV	30920	KF07
31713	16209870	KLAMMA	2	462	0,47	16	1110117	0		0	3010	30149	3010F2
31713	4880576	KLAMMA	2	462	0,035	130	1110117	0	L1	750	3021	30735	3021F4
31713	16809552	SLANG	1	464	0,838	8	1110103	0		0	3021	30608	3021B3
31713	15063541	ALTERNATOR	1	458	6,8	297	1101206	0	L1	24	3021	30615	KB29
31713	15179652	TRAPPSTEG	2	465	24,6	289	1101206	0	L2	10	3010	30135	KD02
31713	16800487	STÄNKSKYDD	2	465	7,988	22	1101206	0		0	3040	30513	KC45
31713	16800498	SKÄRMBREDDARE	1	465	1,8	12	1101206	0		0	3040	30513	KE53
31713	16800501	SKÄRMBREDDARE	1	465	1,8	12	1101206	0		0	3040	30513	KE54
31713	20523395	KUGGREMHJUL	1	456	0,588	209	1101206	0	K1	0	3021	30615	KB30
31713	930428	DISTANSRING 10X15X6	1	VMI	0,004	54030	1101206	0	L1	60000		0	
31713	945408	MUTTER M6FM M8-8,0	2	VMI	0,008	162047	1101206	0	L1	48000	3040	30513	3040F1
31713	948438	KULLERSKRUV M8X20	2	463	0,02	2318	1101206	0	K1	12000	3040	30513	3040F1
31713	960141	BRICKA 8,4X22X2	2	VMI	0,007	-18653	1101206	0	L1	72000	3040	30513	3040F1

Appendix B – Extract from pivot table

Table B1 Article numbers from pivot table

Count of Artikelnr	Utr											
Artikelnr	L350F	L150G	L180G	L180GHL	L220G	L250G	L70F	L90F	L110F	L120F	L60F	Totalt antal modeller
22560											1	1
22561							1					1
22562								1				1
22563									1			1
22564										1		1
22574		1	1	1								3
22575					1							1
22581						1						1
23967					1	1						2
33016											1	1
33017							1					1
33018								1				1
33020									1			1
33021										1		1
33027	1											1
33170							1					1
33285								1				1
33389									1			1
33390										1		1
33532		1										1
33758											1	1
33860						1						1
33862			1									1

Appendix C – Methods and solutions

Table C1 Summary of methods and solutions for mixed-model assembly lines

Methods	Chapter	Description
Standardised work	2.2	*Using standardised work is important to be able to cope with variations in assembly time between models. In a mixed-model environment with long takt-times it has to done to combat variability. Is a basis for other methods and techniques.*
Correct operation times (MTM or other)	3.3	
Standardised work methods	5.1.2	
5S-work	6.2.5 p82	
Operator involvement	7.2.3	
Handle difference in assembly time	2.5	*The difference between the amount of working time that is needed and the minimum amount of value adding working time is called time losses. Time losses increase as the work content for different models varies. To be able to produce on a mixed model assembly line it is important to consider methods used to absorb the time losses. Different methods may be suitable depending on the context.*
Sub-assembly lines	3.5	
By-pass line with different takt time	5.1.5	
Buffers between stations or segments	6.2.5 p83	
Alternative buffers (high system capacity)	7.2.5	
Utility workers (variantpositioner)		
Enlargement of cycle time / open stations		
Flexible division of work between operators		
Automation		
Increase the indirect work for operators		
Parallel flows		
Standardised work		
Levelled sequencing of models		
Varying the takt time		
Handle complex line balancing	2.4	*Balancing the assembly line in the mixed-model case is more complex than in the single model case. Station variability and model variability must be taken into account. The line must not be balanced after the must time consuming model if to be able to handle the time losses.*
Weighted average cycle time (VPS)	3.4	
Software solutions (AviX and Pro Planner)	5.1.4	
	6.2.5 p81	
	7.2.2	
Levelled sequencing of models	2.4	*The sequence in which the models are fed to the assembly line will affect the efficiency of the line. There are different sequencing objectives. Sequencing to level the work load on each station in combination with appropriate line balancing can be used to handle the time losses.*
Sequencing rules	3.4	
Levelled MPS	5.1.4	
Advanced algorithms (Toyota Goal Chasing)	6.2.5 p82	
	7.2.4	
Reduce length of material facade	2.6	*Increased number of models assembled will, dependant on the degree of parts commonality, increase the number of parts in the material facade. The length of the material façade may be the limiting factor for the assembly line and it creates large handling time losses.*
Kitting	3.6	
Sequenced delivery to line	5.1.6	
Repacking	6.2.5 p83	
Smooth demand of parts	7.2.6	
JIT		
Minimise picking errors	2.7	*Increased number of models assembled will, dependant on the degree of parts commonality, increase the number of parts in the material facade. This will increase the risk of picking errors which will result in quality problems.*
Kitting	3.7	
Sequenced delivery to line	5.1.7	
Automatic identification devices	6.2.5 p84	
Pick-to-light and pick-to-voice	7.2.7	
Poka-Yoke	7.4	
Minimise assembly errors	2.7	*An increased number of models will increase the number of different work task thus increasing the risk of assembly errors. The challenge is select the correct tool, fixture and assembly procedure.*
Clear work instructions	3.7	
Short cycle time	5.1.7	
DFA	6.2.5 p84	
	7.2.8	

Appendix D – Product data for the wheel loaders

Table D1 Product data for the wheel loaders (Swecon, 2011)

	Weight	Width incl wheels (Y)	Width excl wheels (X)	Length excl scoop (B)	Height incl cab (F)
L60F	11,0-12,3t	2440 mm	1900 mm	5990 mm	3220 mm
L70F	12,7-14,0t	2470 mm	1930 mm	6050 mm	3280 mm
L90F	15,0-17,0t	2490 mm	1960 mm	6120 mm	3280 mm
L110F	18,0-20,0t	2670 mm	2070 mm	6470 mm	3360 mm
L120F	19,0-21,0t	2670 mm	2070 mm	6580 mm	3370 mm
L150F	23,0-26,0t	2950 mm	2280 mm	7070 mm	3580 mm
L180F	26,0-30,0t	2950 mm	2280 mm	7170 mm	3580 mm
L220F	31,0-35,0t	3170 mm	2400 mm	7470 mm	3730 mm
L150G	23,6-32,8 t	2960 mm	2280 mm	7070 mm	3570 mm
L180G	23,6-32,8 t	2960 mm	2280 mm	7190 mm	3580 mm
L220G	23,6-32,8 t	3170 mm	2400 mm	7480 mm	3740 mm
L350F	50,0-56,0t	3630 mm	2720 mm	9130 mm	4180 mm

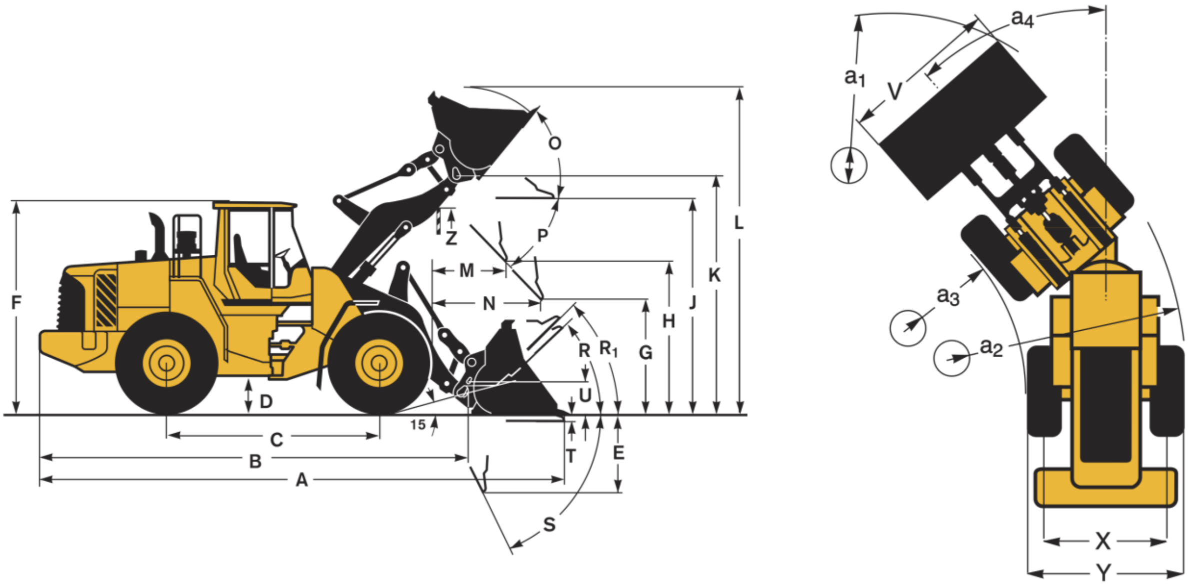


Figure D1 Drawing of a wheel loader (Swecon, 2011)