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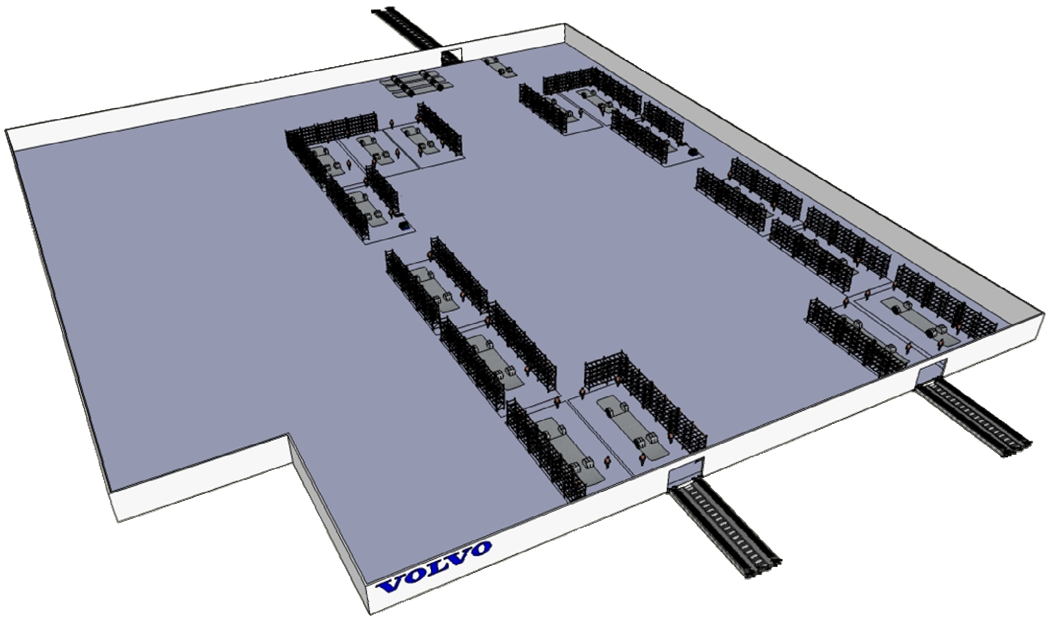

Production system design and optimization

Optimized two-line production system for bus chassis assembly at Volvo Buses Borås factory

Master of Science Thesis in the Master Degree Programme, Automation and Mechatronics

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Preface

This report is the result of a master thesis made in the autumn and winter of 2007 at Volvo Buses Corporation in Borås. The master thesis is the conclusion of the Master of Science in Automation & Mechatronics education at Chalmers University of Technology.

We want to extend special thanks to Torbjörn Nilsson and Hans Sjöberg at Volvo Buses Corporation for giving us the opportunity to do this project and also for all the support they have provided during the project. We also want to thank Bertil Gustafsson at Chalmers University of Technology, who supervises the project, for valuable thoughts when discussing ideas and methods. We also want to thank Christofer Åkerström and his co-workers at the Manufacturing and Logistics development section at ÅF Engineering for providing us with software and support during the project. A big thank you to Kim Gustavsson at Scania Chassi for a very interesting visit. Finally, we want to thank the Volvo technicians; Dan Jernheden, Niclas Hedström and Anders Flodin for all valuable input data they have provided for the project.

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Abstract

Volvo Buses Corporation is one of the world's largest bus manufacturers. They produce about 9 000 buses worldwide each year. Volvo is assembling most of the chassis in Borås, Sweden. The production site handles approximately ten models of chassis with a wide range of variants. The production consists of four lines and each line handles two to four models.

What this thesis project has analyzed is if it is possible to reduce the number of lines to two, and if possible, what effects that will have on the production organization. Through a detailed analysis of the assembly tasks, using methods such as structured balancing, it has been possible to redesign the production into a two-line system.

The two lines has been set to handle a range of models each; one handling more complex models and one handling less complex. This makes it possible to balance each line with a minimum of losses. To handle variant losses variant operators are used for helping out on the most complex variants, like when a third axle is mounted. The output will be 24 chassis on a day-shift of 8.6 hours divided on 13 low complex and 11 high complex chassis.

This new system has proven itself to have a series of advantages:

- A 40% productivity rise is possible to gain.
- With two lines instead of four, a large area has become free in the factory, making it possible to have pre-assembly closer to line.
- Planning department will not have restrictions on the sequence as it is today. Making the production system more flexible.
- Due to shorter takt times learning time for new operators will decrease.

The production system has been verified by a dynamic discrete event simulation. The simulation result showed that the balanced takt and cycle times are possible to use without having any complications such as line stops due to heavy workload.

The project has also presented three ways of making the factory layout; one that is easy to implement on a short term and two that require more fundamental rebuilding. The short term proposal has been used in the simulation and is at the moment the most suitable way of arranging the factory. The layouts have been made with stations that can handle full length chassis, making the production sequence easier for the planning department to set. The new layout will require sideways movement which means that on those stations the material facades will be limited.

Further, more detailed analyzes concerning material handling and layout rebuilding must be done in the near future to come to a point when this system is possible to implement.

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1 Introduction

This section contains the project directives, scope and aims

1.1 Background

The chassis assembly today at the Volvo Buses plant in Borås is based on four parallel assembly lines to be able to handle all the existing models. The nearby planned changes at the factory are to make due with one assembly line less, a total of three assembly lines. As a future possible scenario, a two-line structure is of interest to evaluate. An earlier statement at Volvo Buses is that "buses are to complex and come in too many variants to be able to assemble on one single line". With this background the company asks for detailed analysis of the possibilities of assembling chassis on a reduced number of lines, this thesis work will go deeper in the case regarding two lines.

1.2 Scope

The primary scope is to evaluate how to assemble bus chassis on two assembly lines. This includes analysis of the impact on production planning and resource utilization. Volvo demands that 24 chassis per shift must be built. All existing models are to be assembled in the new layout, no outsourcing is possible. The new layout must also be able to fit inside the current factory walls.

1.3 Aims

The main objective for this project is to make a thorough analysis of the production at the Borås plant chassis assembly which should result in a recommendation how to build chassis on two lines instead of four. This includes how to handle the big variety of models and the effects on production planning due to different assembly times of the models.

1.4 Objectives

The aim is sub-divided into a number of objectives which specify and complement the statement of the main aim.

1. *Present a way of building chassis on two lines.*

2. *Present what effects this way of building has on the production organization. Analyses of what impact this have on production output and optimize the production layout.*

3. *Present theory about production system development.*

4. *A short glance on a single line production system will be made if a two line system shows itself possible.*

1.5 Delimitations

The project will not look into methodology on lower level than existing task times, and will therefore see the given times as an optimized way of assembly. Neither will this project look at any pre-assembly or internal logistics connected to the new production layout. The special flow (flow F) will not be included in the thesis. No economic effects will be analyzed.

1.6 Project organization

This master thesis project is made by two students from Chalmers University of Technology. Supervisor of the project is lecturer Bertil Gustafsson at the department of product and production development at Chalmers University of Technology and Torbjörn Nilsson at Volvo Buses' department of process development.

In addition to this, the consultant firm ÅF Engineering supports the project with the software packages ProPlanner and Automod. All output from the project will go to the process development department at Volvo Buses.

2 Corporate presentation

Volvo Buses is a part of the Volvo Group. Volvo Group also includes Volvo Trucks, Volvo Construction equipment, Volvo Penta and Volvo Aero.

The first Volvo bus was built on a truck platform in 1928 and 1934 was the first bus chassis introduced. Up until 1968 buses were in the hands of the truck production but in 1968 Buses became an independent company within the Volvo group.

The Borås plant that this thesis work considers was built during 1976-77. Today the plant has a capacity of 4300 chassis per year and an additional 4200 CKD kits per year (Completely knocked down, chassis sold in parts) Total area of the factory site is 170 864 m2 of which 28 375 m2 is factory and warehouses. The plant employs 406 people of which 10 % is women.

Volvo delivers buses in three categories; city buses, intercity buses and coaches. With this product mix Volvo is one of the strongest brands on the bus market. The biggest market in 2006 was China followed by Great Britain and North America. The turnover in 2006 was 16859 MSEK and the profit was 633 MSEK.

The Borås plant will further on also be referred to as VBoF.

3 Theory

This chapter will present the theory that has been used during this master thesis. To make the understanding of this report easier, some common keywords and phrases will be explained.

Line = A set of stations that a product goes through during assembly.

Task = A task is a part of a set of actions that forms an operation.

Operation = A set of tasks. See above.

Throughput time = The total amount of time for a chassis to go from intake to completion.

Cycle time = The time it takes to finish all tasks (operations, number of tasks) at a station.

Takt time = The maximum time for each station before all work tasks (One work cycle) must be finished. After this time the object is moved into the next station of the line. The takt time is the same for all stations of the line.

Flow = The standard name for an assembly line at VBoF.

Station(s) = One or more geographically defined places at the line where one or more tasks are being performed. Will also be referred to as step(s) or stage(s).

Operator = Worker at the line

Variant operator = An extra operator that work when heavier variants is on the line.

Resource = In this report is the operators the resources.

Standard work sheet = Sheet that shows all work tasks for a bus chassis.

3.1 Line assembly

Line production is basically that a product is going through a number of stations in order to be completed. The total work is divided between these stations so each station makes one small part of the total assembly.

3.1.1 Different line assembly methods

Line assembly differs depending on the product that is being assembled, depending if it is a product with only one variant or if the product is available in different variants. At a single product/variant scenario the line will be balanced for this model and the line will look like ‘A’ in Figure 1. This will result in a line without variant losses since there are no variants.

A factory line does usually cope with different variants and that will lead to either a “mixed-model line” or a “multi-model line”. The differences between these are that in the mixed-model line ‘B’ the variants can be randomly assembled and not batched as in the ‘C’ alternative since the later one demands exchange of tools or other equipment.

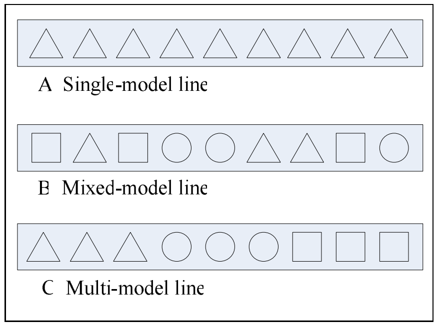

Figure 1 - Different assembly methods (Scholl, A. 1999)

3.1.2 Balancing methods

All kinds of production lines need to be balanced. In order to do so, there are a few things to be aware of. As mentioned before there are different assembly methods. As for the simplest one, the single-model line is the easiest one to balance. In this case the main thing is to even out the work load between all stations so all stations is as close to the takt time as possible. Examples of bad and good balances are shown in figures 2 and 3. (Baudin, 2002)

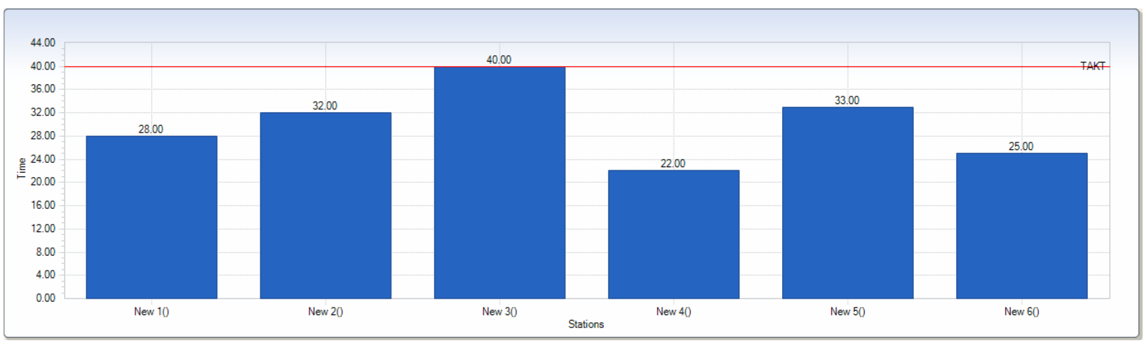

Figure 2 - Example of a poor balance

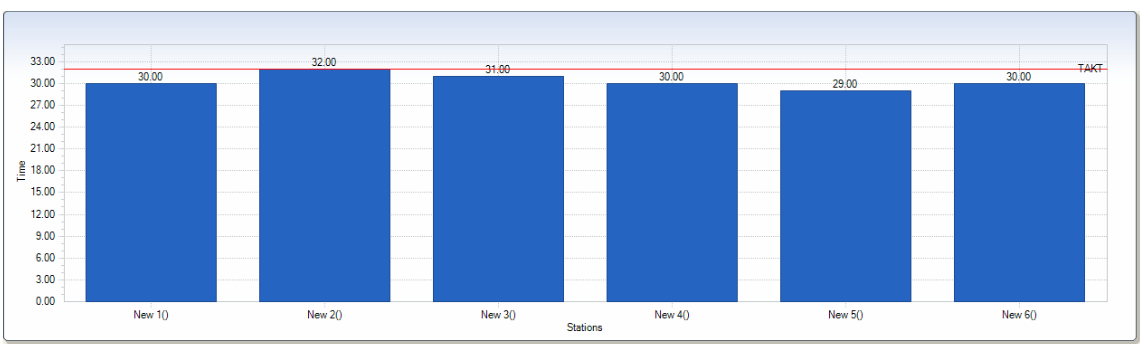

Figure 3 - Example of a good balance

As for the mixed-model and batched line assembly methods there is a few more complications to be aware of. Due to that the line has to manage a range of variants with different assembly times it is up to the process engineer to take away some work on heavier models or put in some work from pre-assembly to line for the easier ones in order to make the amount of work the same for the different models. If this is not made the line will suffer from massive losses due to that the takt time must be set to cope with the heaviest model. That will reduce production capacity throughout the entire production line. (Baudin, 2002)

3.1.3 Balancing losses

A balancing loss occurs because in reality it is not possible to divide the tasks into entirely leveled amount of work. Therefore a balancing loss is the result of line production. (Medbo et al, 2004)

3.1.4 Variant losses

Variant losses is in a way a part of the balancing losses, with the significant difference that the variant loss depends on and increases with the variation in task time, depending on different product variants. This with the difference to balancing losses for a given production system, with certain task times, is constant. (Medbo et al, 2004)

3.1.5 System losses

It is known that operators need a different amount of time to do the same task; a distribution of assembly time is created. This distribution is a loss beyond balancing and variant losses.

Another loss connected to the system is the handling losses. They are such as getting material and tools or reading instructions.

Also outer disturbances affect the losses, such as lack of material, tooling or equipment failure, bad fitment of components and more. Regardless the reason of variation in work time another loss is created, the system loss. (Medbo et al, 2004)

3.1.6 Productivity

Productivity is a relationship between output and input and is usually described this way:

$$Productivity = \frac{Output}{Input}$$

Though it must be mentioned that the above is a general description and that there are far more detailed ways of calculating productivity regarding what type of productivity that is measured. Total productivity is:

$$P_t = \frac{V_s - K_i}{I_a + I_k} = \frac{F_v}{T_r}$$

Pt = total productivity, Vs = value of sold products, Ki = cost of bought goods and services, Ia = effort of labor, Ik = effort of capital, Fv = refining value, Tr = Total effort of resources.

The productivity that is measurable for the process in this thesis is the Work Productivity:

$$P_a = \frac{F_v}{I_a}$$

Pa = Work Productivity, Fv = refining value (no. of chassis built), Ia = effort of labor (no. of operators). (Gustafsson, 2007)

3.1.7 Precedence

The precedence graph is a very important structure to get right when balancing a production line. This graph depicts the order in which the activities (tasks) must to be done. The task assignments are strictly followed using this precedence graph. This is used to limit the possibilities to move tasks between stations. A simple precedence graph is shown in Figure 4.

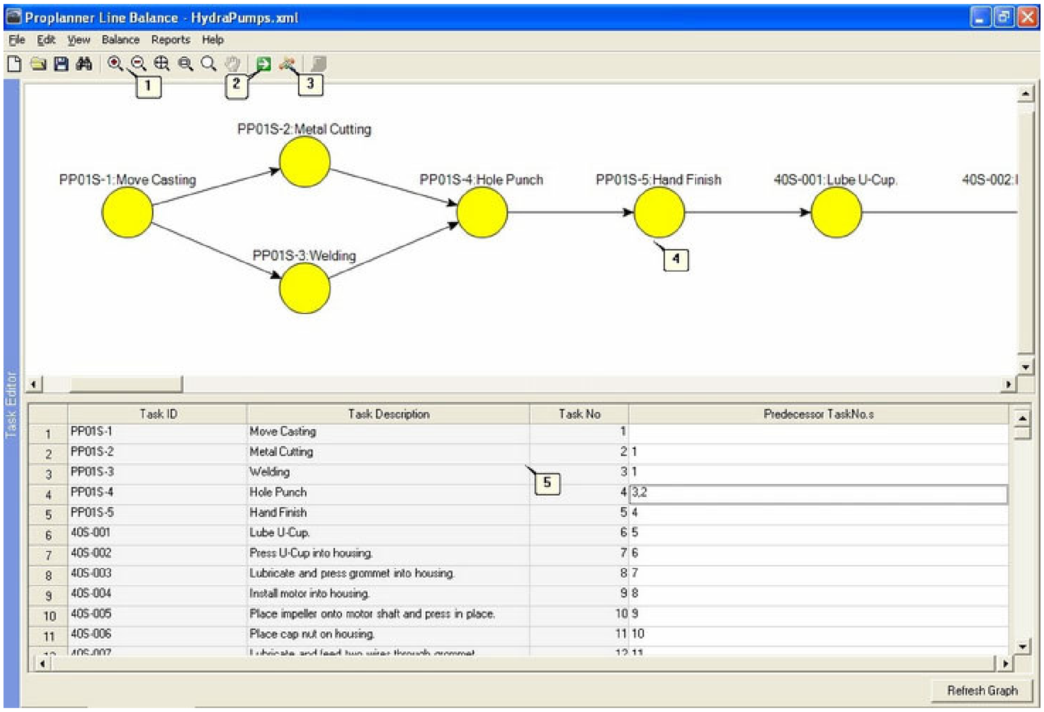

Figure 4 - Precedence graph in ProBalance

3.1.8 Arranging the stages

When the desired output is decided it's possible to obtain the specified output in more than one way. The most common way of arranging the production is to split up the task and put them on a straight thin line. In example; the desired output is 1 item every 15 minutes which makes for a 4 station straight line a cycle time of 15 minutes. However there is also possible to have the same output with a 30 minute cycle time on two parallel two station lines. This means that there are several ways of arranging the process and get the same output. (Slack et al, 2004)

Slack et al, (2004) presents several advantages of the two extreme ways of arranging a process.

Advantages of the long thin arrangement

- *Controlled flow of materials or customers* – Which is easy to manage
- *Simple material handling* – Especially if a product being manufactured is heavy, large or difficult to move.
- *Lower capital requirements* – If a specialist piece of equipment is needed for one element in the job, only one piece of equipment would need to be purchased.
- *More efficient operation* – If each stage is only performing a small part of the total job, the person at the stage will have a higher proportion of productive work as opposed to the non-productive parts of the job, such as picking up tools and material.

Advantages of the short fat arrangement

- *Higher mix flexibility* – If the layout need to process several types of product or service, each stage or line could specialize on different types.

- *Higher volume flexibility* – As volume varies, stages can simply be closed down or started up as required.
- *Higher robustness* – If one stage breaks down or ceases operation in some way, the other parallel stages are unaffected; a long thin arrangement would cease operating completely.
- *Less monotonous work* – Makes the task at the station better to the workers due to longer task times.

3.1.9 Manual assembly constraints

If the takt time is the same as the cycle time it has the effect that operators have to work 100% or close to 100% throughout an entire shift. The human nature does not allow the body and mind to perform at 100% eight hours straight. The highest level of cycle time within the takt time for manual assembly is 85%. (Ortiz, 2006)

This means that the operator have better chances of making a good job which results in less quality problems and a better productivity, if not all of the takt time is filled with assembly. Therefore, process developers should aim to have a maximum 85% utilization of the takt time if dealing with manual assembly. (Ortiz, 2006)

3.2 Layout planning

Simplified systematic layout planning is a method first published in the early 60's by Richard Muther and John D Wheeler. This method is still applicable today when making layout planning of factories and other industrial facilities.

The method is based on six steps in order to get an optimal layout.

1. Map dependencies between resources
2. Establish resource needs (space, water, air, electricity, and more)
3. Make graph of the dependencies
4. Sketch different possibilities
5. Evaluate and choose the best
6. Sketch a detailed layout

Step one

First step is to map the activities, resources or areas to each other. How close they do have to be to each other and the cause for that. Such can be that they share personnel, are noisy or have a great exchange of parts.

Step two

Every resource needs space, service, and other arrangement to fit in the layout. This step maps the needs and how it affects the layout.

Step three

Making a graph on the dependencies brought up in the first stages. Important connections are shown by thick lines and weaker connections by thinner lines. This is used to make the first initial layout sketch.

Step four

Use the graph from step three and put the areas for all stations within the factory walls. Make different solutions to evaluate.

Step five
Evaluate the different layouts made in the step above. Evaluation can be made with aspect to different relations and needs. Finally one layout is modified to be the optimal one.

Step six
Make a detailed layout planning of the chosen sketch.

(Muther & Wheeler, 1962)

3.3 Simulation

A simulation is made as a reflection or imitation of a real world system. In the simulation model all things are called entities. The relations between entities are expressed in a mathematical, logical and symbolic way to obtain a valid behaviour of the model. To be able to set up a valid model, data collection is of great importance since the simulation must behave as the real world system. Once the model is validated it is used to answer a series of questions, in example potential changes in the real world system can be implemented in the model and the impact on the system can be measured without having to interfere with the real world system. (Banks et al, 2001)

3.3.1 Advantages and disadvantages of simulation

Johansson, B. (2002) presents a series of advantages and disadvantages concerning simulation.

Advantages

- A way to evaluate changes in a system without interfering with daily work
- A complex and dynamic system which is difficult to analyze in a static model is possible to analyze.
- Time can be compressed which allow analysis of phenomena that appear over an extended period of time. Also things that happen during extreme short time can be seen when runtime is extended instead of compressed.
- Obtain understanding of what impact different variables have on the system and also understand the interaction in between variables.
- Identification of flow bottlenecks can easily be done in order to deal with the resources that set the pace of a flow.
- “what-if” scenarios can be answered. This comes in handy when developing new systems.

Disadvantages

- Simulation projects are expensive and time consuming. To “cut corners” in the modeling process will eventually turn out as bad or incorrect output from the model.
- Simulation is sometimes used when static methods are better suited.
- The interpretation of the result can be difficult due to random input data. Output can therefore be tricky to evaluate if it depends on randomness or input variables.
- To build a model takes lots of practice and a made model is only applicable to a certain problem.
- Simulation does not optimize the solution. The analysis has a trial and error approach which gives different output from one run to another.

3.3.2 Areas of application

Simulation is used widely and can be applied on many different systems. Manufacturing systems has complex value streams with a lot of material handling. To be able to handle all this complexity and interactions in the system, simulation is most often used. Another area connected is logistics where different system approaches can be evaluated. Simulation of human behavior has also been done. This kind of simulation is hard due to a human does not always follow a logic sequence of actions.

3.3.3 Discrete event system simulation

The technique used in this kind of simulation is discrete event system (DES) simulation. A DES is basically a set of entities that can have different settings, every combination of settings makes a state of the system. As an entity changes its settings the whole system changes its state. This means that the model only changes states when an event occurs.

3.3.4 Distributions

In a simulation that is random statistical distributions are used. By doing this the model will behave a bit different depending on which random number set that is used for a run. Models run several times with different number sets to get the average values over a series of runs making the results statistically approved. Simulation software can handle many distributions; however some are more often used and therefore are the normal, triangular, exponential and uniform distributions presented more in detail.

Normal distribution

The normal probability function is a bell-shaped curve of the characteristics shown below. In general, the normal distribution is used to represent any symmetrical random variable with limited variability. Examples include processing times, repair times, and time until wear-out failure. The normal curve is symmetrical about its mean, so values are equally likely to occur over as under the mean value. The characteristics of the normal probability function are shown in figure 5. (Automod manual/help file)

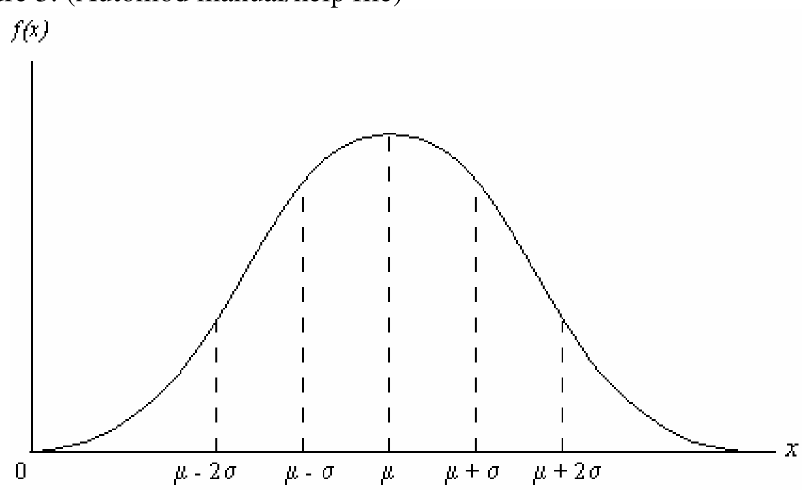

Figure 5 - The characteristics for the normal probability function (Automod help file)

Triangular distribution

A triangular probability function is most often used when having finite maximum and minimum value. As in the example below; the mode (the most probable value) is 2 and lower and upper limits are 0 respective 10 meaning that over a longer period of time the mean value will close up to 4. The triangular distribution is used when the approximation is rough so no other distribution is better suited. The characteristics of the triangular probability function are shown in figure 6. (Automod manual/help file)

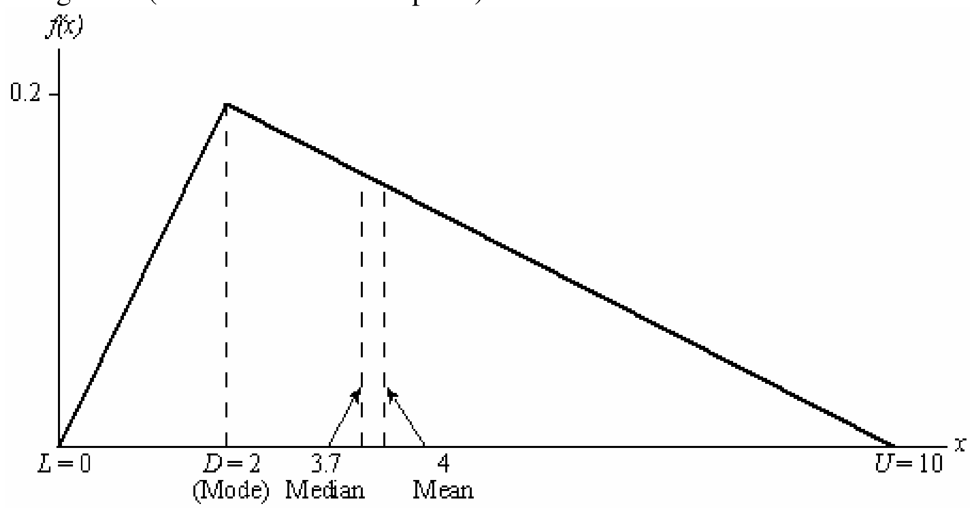

Figure 6 - The triangular probability function (Automod help file)

Exponential distribution

This highly asymmetric distribution is often used to model completely random events having high variability. It is commonly used to model time until failure for a resource or random arrivals. The characteristics of the exponential probability function are shown in figure 7. (Automod manual/help file)

- 63 percent of the data values are less than the mean
- 37 percent are greater than then mean
- 14 percent are greater than 2 times than the mean
- 5 percent are greater than 3 times the mean
- 2 percent are greater than 4 times the mean

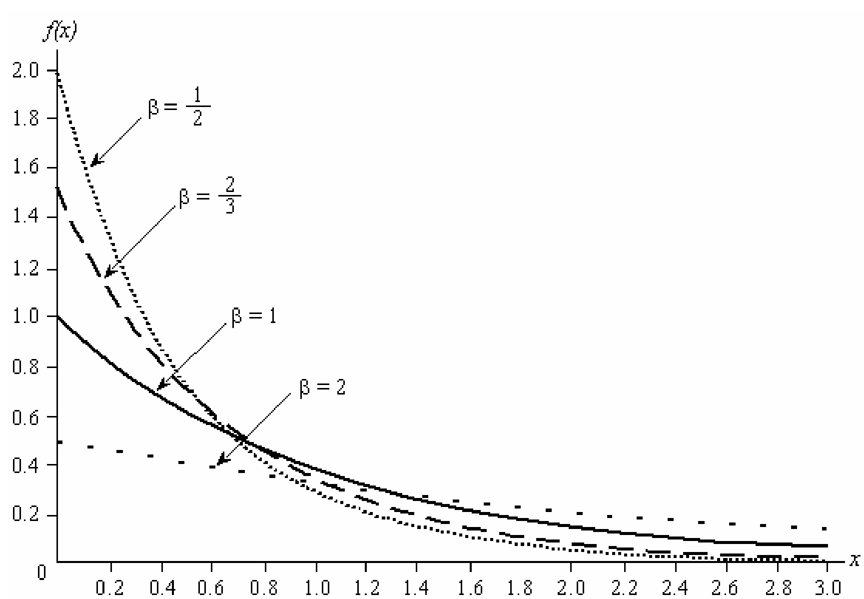

Figure 7 - Characteristics for the exponential probability function for some values (Automod help file)

Uniform distribution

A uniform distribution is the simplest one. The probability is equal that an event will occur throughout the whole range. The mean and the offset are specified as in the example; 5 and 3. The characteristics of the uniform probability function are shown in figure 8. (Automod manual/help file)

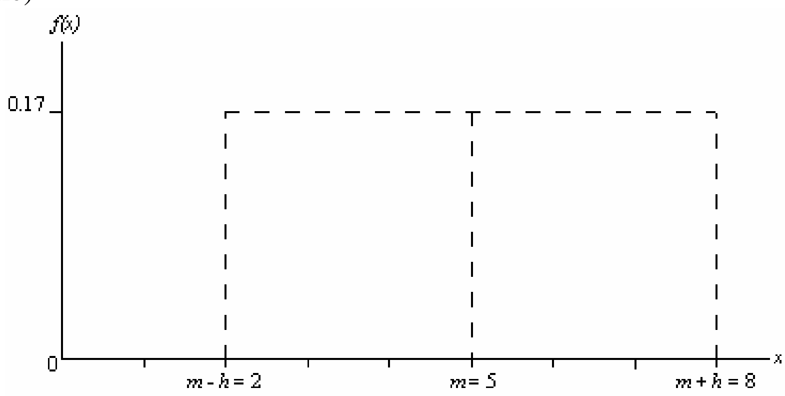

Figure 8 - Uniform (5, 3) probability function (Automod help file)

4 Methodology

This chapter will summarize the methodology of the different tasks that this project contains.

4.1 Time studies

Time studies for the assembly times are provided by Volvo which already made video analysis. In those cases that video analyses haven't been made task times will be provided by Volvo as older time studies made with stopwatch.

4.2 Line balancing

To balance a line is a continuous work where all tasks continuously are put together in different ways and on different stations in order to minimize the losses. All the tasks that are required to assemble a bus are put into the software ProBalance (which is a part of the ProPlanner package) which will be used to obtain good balanced production lines. The program ProBalance is provided by ÅF Consult and is described more in detail below.

4.3 ProPlanner® Line Balance (ProBalance)

The tool used in this project for static line balancing is ProBalance by ProPlanner which is a big manufacturing management system. The balancing tool used in this project is a part of the package. The balance module contains an auto balance tool which is a helpful algorithm to gain the best possible balance in just seconds. In order to use this algorithm is it important to have all data correct, especially the precedence as shown in the theory chapter. Another important thing to consider is tools that are connected to different tasks. ProBalance has a feature that can handle situations where tools are not possible to move. This makes the program easy to use to try out different setups for the production line in a fast and efficient way.

4.4 Factory layout

After the lines are balanced, the work with fitting the new assembly lines inside the factory begins. As described in the theory chapter is the method simplified systematic layout planning used as a foundation to get ideas for the factory layout.

4.5 Simulation

The simulation will follow a method developed for discrete event simulation by Banks et al (2001). The complete work routine is shown in figure 9.

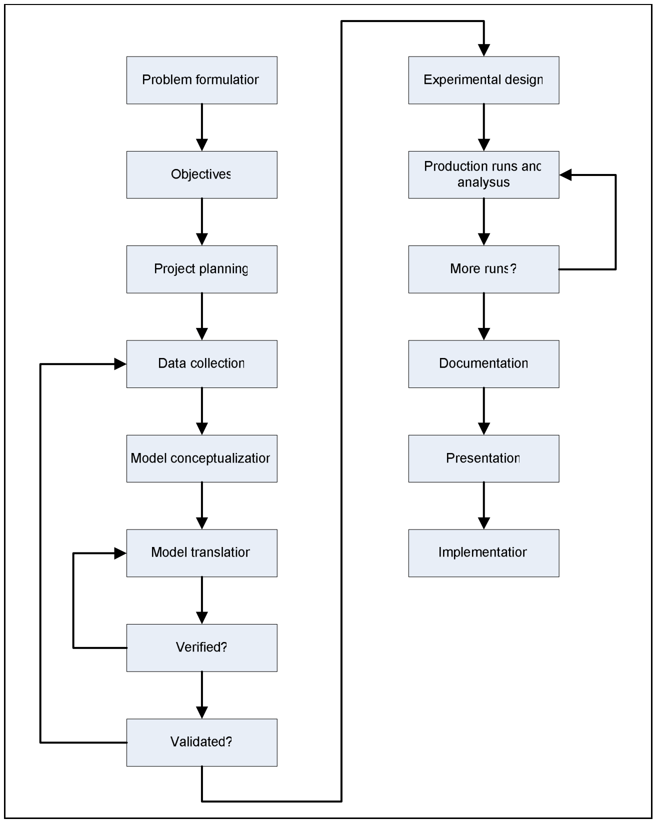

Figure 9 - Steps in a simulation study (Banks et al, 2001)

The objective of the simulation is to visualize the output from the static balancing in a dynamic model in order to get a deeper understanding of how a two-line production process would affect the VBoF chassis assembly.

The code for the simulation will be continuously verified according to the figures given from the balancing output. This simulation model can not be validated (compared to a real world system) since it is not a model of an existing system.

4.6 Simulation in Automod® 12.1

This project will use the program package Automod by Applied Materials to simulate a production system. The program uses DES simulation to run the simulation of material flows. Automod uses modules for resources, loads, conveyors and so forth. This means that it is relatively easy to make the basic settings for a system without writing too much code. Automod also has a good 3D interface that helps out with visualization of the simulation. Instructions to the program are written in an internal programming language especially developed for this kind of modeling. To be able to handle different data in and out of the model, the package contain features like interaction with excel-sheets and also an optimization tool called AutoStat.

5 Current state analysis

This chapter presents the current production at VBoF which is to assemble a range of bus chassis. These chassis are assembled and delivered to Volvo bodybuilders throughout the world. The current layout is displayed in figure 10. Areas to the left and in between lines are used for preassembly and storage.

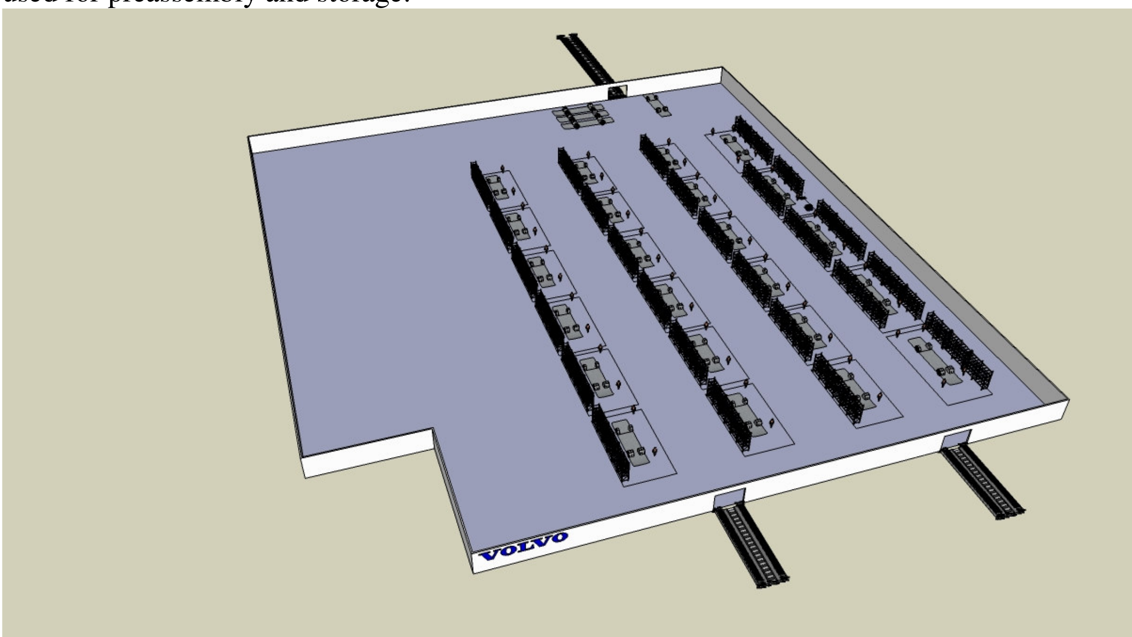

Figure 10 - Layout of the current production. From left are the lines in order C, B, A and D

5.1 Products

The Borås Factory (VBoF) produces approximately ten models of chassis with a wide range of variants. Here follows a short description of each model. B stands for "BUS" in all models. The following number is the volume of the engine and the last characters is explained in detail in table 1.

Model	Description	Bus Type
B9L/LA	**9-litre 6-cylinder diesel engine, L stands for Low floor and A stands for Articulated.**	**City**
B9S	**9-litre 6-cylinder side mounted diesel engine. S stands for side mounted.**	**City, intercity**
B12M/MA	**12-litre 6-cylinder mid-mounted diesel engine, M stands for mid-mounted. MA is the articulated model.**	**Intercity, coach**
B7R	**7-litre 6-cylinder rear mounted diesel engine, R stands for rear mounted.**	**City, coach**
B7RLE	**7-litre 6-cylinder rear mounted diesel engine, R stands for rear mounted. LE stands for low**	**City**

	entrance.	
B9R	**9-litre 6-cylinder rear mounted diesel engine, R stands for rear mounted.**	**City, intercity**
B12BLE, 4x2, 6x2	**12-litre 6-cylinder back mounted diesel engine, LE stands for Low entrance, two or three axles.**	**City, intercity**
B12B, 4x2, 6x2	**12-litre 6-cylinder back mounted diesel engine, two or three axles**	**Intercity, coach**
B12BLEA	**12-litre 6-cylinder back mounted diesel engine, Low entrance, Articulated**	**City, intercity**
B9TL	**9-litre 6-cylinder transverse mounted diesel engine, Low floor**	**Double deckers**

Table 1 Model range at Volvo Buses

5.2 Production system

The current production system at VBoF is based on four production lines that handle a series of models each. This is shown in the table 2 by a X. Where lines are situated is presented in Figure 10.

Chassis\Line	A	B	C	D
B9L/LA	**X**			
B9S	**X**			
B12M/MA	**X**			
B7R		**X**		**X**
B7RLE		**X**	**X**	**X**
B9R		**X**		
B12BLE, 4x2, 6x2	**X**			**X**
B12B, 4x2, 6x2	**X**			**X**
B12BLEA				
B9TL			**X**	
% of tot prod.	**23.45**	**27.11**	**22,67**	**26.77**

Table 2 Correlation between flows and models

The lines consist of five assembly stages (except line D that has four) and one control stage. The four lines have a takt time of 82 minutes with a cycle time of 60 +-5 minutes depending on model. This means that 67 % - 80 % of the takt time is for assembly and the rest is to

handle disturbances, allowance and time losses due to the balancing. The throughput time is 492 minutes (including control step). These four lines end up in a common line that fills fluids, mounts tires, runs final tests and starts up the bus.
There is also a flow F which is not included in the scope of this project. Flow F handles extreme models that just don't fit in the other flows due to extreme throughput time. That could be the B12BLEA or chassis with unique customization. The rear part of the articulated buses is also assembled in flow F.

Each stage has two or three operators depending on stage. Stage 0, 1, 2 and 3 usually has two operators and stage 4 has three. For the more complex models an extra operator is used to help out during assembly in the first stages. There are today a total of 61 operators in the assembly area.

The factory runs one shift per day and assembles approximately 22 chassis per day.

5.3 Assembly process

The assembly on one line is made in five steps. This section presents the basic operations when assembling the B7R model that is very common, on each stage in order to give an understanding of the assembly process.

Stage 0
This stage handles the intake of the frame and applies beams and crossbars to the frame. Also prepare attachment points for the engine and mounting of steering beams.

Stage 1
Stage 1 consists mainly of assembly of valves, cables and tubing. Also gear shifter and fuel filter is fitted on the frame.

Stage 2
In this stage the frame is married to axles and engine, more cables and the air suspension bellows are fitted.

Stage 3
This stage applies the radiator and intercooler tubing. More tubes and cables and several other devices such as the fuse box and water divider are fitted.

Stage 4
In this step are three instead of two operators working on the chassis. Here is the dashboard installed, fuel and other tanks are fitted and the battery box is also attached.

Stage 5
All electrical circuits and air systems are checked and a general visual control is carried out.

After this the bus goes to final assembly were fluids are filled and tires are mounted.

5.4 Balancing results

The results of the balancing of the current state at VBof are presented in table 3. What have been analyzed is the average utilization of the operators on each flow. That is how much time of the total workday that is balanced work. These figures will be used for benchmarking the new layout. Details are presented in Appendix 10.1.

Flow	Average utilization
A	**62.38%**
B	**70.15%**
C	**70.57%**
D	**61.02%**

Table 3 - Average utilization

6 New production system

The information used in the static analysis and creation of the new lines is based on existing standard worksheets supplied by Volvo. These times are measured and is in “100-Takt” which means that no task times has been reduced. These task lists have been thoroughly analyzed and the precedence is made together with operators that work with the models on a daily basis. The precedence was made with two criteria; in what sequence parts must be assembled and also that they will be easy to mount. This gives a reassurance that the way of building a bus stated in the new balances really is feasible and also that the times that have been given are applicable on the new task orders.

6.1 The new assembly lines

As stated in the assignment the output is supposed to be 24 chassis per day. The solution that has been developed is based on two lines; one with the more complex and one with the less complex models. It came rather clear after looking at the assembly times that it was possible classify the chassis in the two categories; low complexity and high complexity. This makes it possible to have an uneven output of 11 and 13 chassis to obtain the desired total output. The mathematics behind this decision is presented in appendix 10.2.

6.1.1 Line 1 – low complexity

Line 1 will handle the models of lower complexity. These are the B7R/RLE, B9R/S/L and the B12M. All these models have similar throughput time and are also similar in assembly. The line consists of 7 stations with 3 operators each and the takt time will be just over 39 minutes in order to get the output of 13 chassis on an 8.6 hour workday. This means that the average cycle time on a station is about 29 minutes (movement of chassis not included) which is 75% of the takt time. Since the movement time is not yet known, will the cycle time be around 85% as mentioned in the theory chapter when movement is included. When assembling the B12M 6x2 a variant operator must be used on station two and four. Throughput time will be 313.3 minutes, a 37% decrease from the current production system. Throughput time is measured from intake until buffer before final assembly. A static analysis of this setup of the line gives an average resource (operator) utilization of 71% which gives some room for handling errors and disturbances. As stated earlier is the mathematics behind all this is presented in appendix 10.2. Worksheets for the new stations in the line are presented in appendix 10.3. In figure 11 are the balances presented for three different models, as seen are the times for the different models quite similar. The gap between the columns and the line showing the takt time is buffer time for handling movements and disturbances.

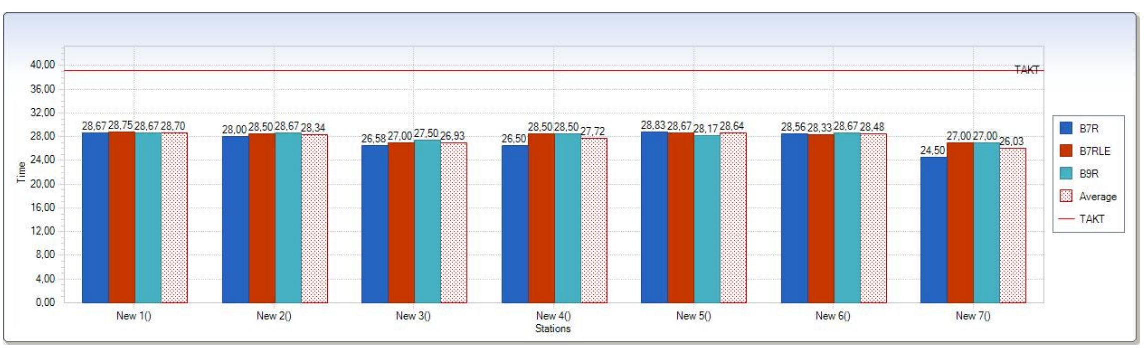

Figure 11 – Line 1 station balance overview

Line 1 in short

Handles models	B7R/RLE, B9L/LA/S and B12M
Maximum cycle time	29 minutes plus movement
Takt time	39.2 min
Throughput time (Including control step)	313.3 min
7 Stations	
3 operators per station – 21 in total	
Resource utilization	*Mean – 71%*

6.1.2 Line 2 – high complexity

Line 2 is a more flexible line that will handle complex models as the B12B and B9TL. The line consists of six stations with 3 operators in each station for the most basic model and will have an output of 11 chassis per shift. The takt time for this line will be set to 46.3 minutes and an average cycle time of 36 minutes (movement of chassis not included). The throughput time is decreased to 324.1 minutes which is a 34% decrease compared with the current production system. Throughput time is measured from intake until buffer before final assembly. The complexity and the big difference in total assembly time for the different models and variants must be handled effectively. The use of variant operators is a must. There will be a need for up to four variant operators on the line when having a complex model (B9TL, 6X2 and full length). Mathematics for this line is presented in appendix 10.2. Worksheets for the new stations are presented in appendices 10.3. Figure 12 and 13 shows the balances for line 2, notice that B9TL has much longer assembly time and therefore is the variant operators used to cut down these times which shows in figure 13.

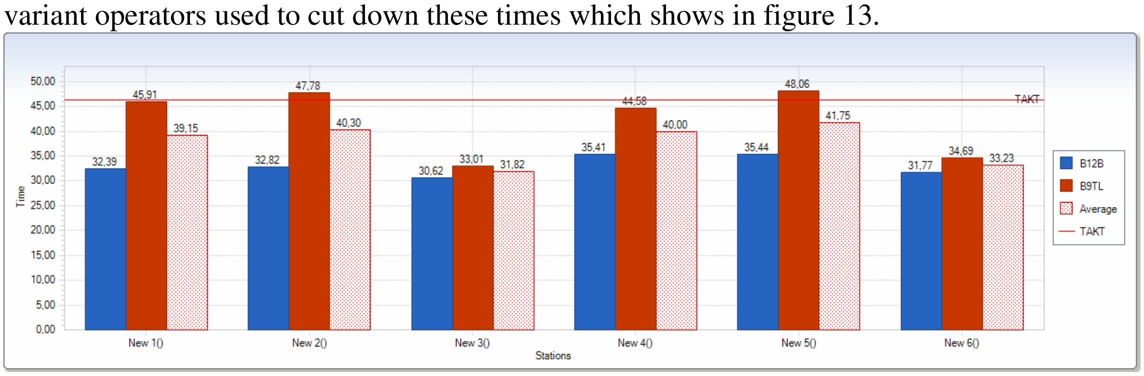

Figure 12 Line 2 balance without variant operators

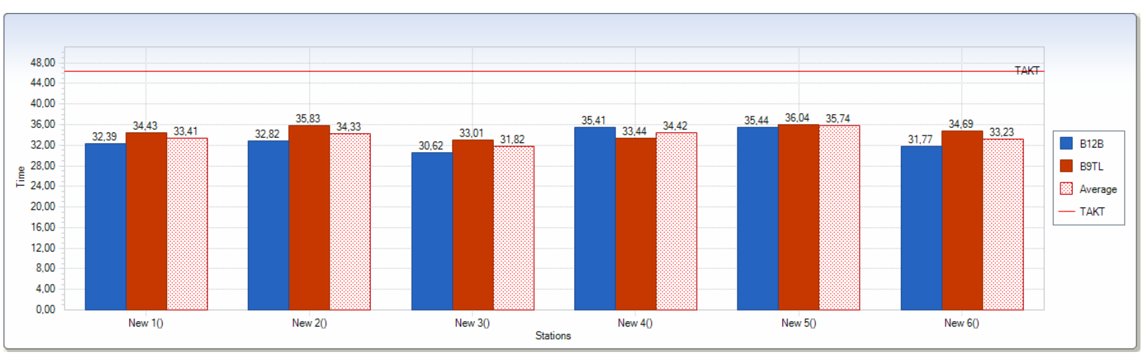

Figure 13 Line 2 balance with variant operators for the B9TL on station 1,2,4,5

Line 2 in short

Handles models	B9TL and B12B/Ble
Maximum cycle time	36 minutes plus movement

Takt time	46.3 min
Throughput time (Including control step)	324.1 min
6 Stations	
3 operators per station and additional 4 variant operators – 22 in total	
Resource utilization	*Mean – 73%*

6.2 Station layout

All stations in the new production design are to be designed with the prerequisite of handling full length bus chassis, which are in total 14.7 m long.
The length of the stations should in addition to the bus length also have 2½m of extra space for the operators to work on. One exception is the station where the engine is mounted; in this station an addition of 6 meters instead of 2½ m is required for the operators to be able to place the engine.

The demands above resulted in a line and station length of:

- **Line 1 – 141.1m**
    - Station 1: 19.7m
    - Station 2: 17.2m
    - Station 3: 14.7m
    - Station 4: 17.2m
    - Station 5: 23.2m
    - Station 6: 17.2m
    - Station 7: 17.2m
    - Control Step: 14.7m

- **Line 2 – 123.9m**
    - Station 1: 19.7m
    - Station 2: 17.2m
    - Station 3: 17.2m
    - Station 4: 14.7m
    - Station 5: 23.2m
    - Station 6: 17.2m
    - Control Step: 14.7m

These station lengths are based on distributing the additional 2½m between the stations.

6.3 Factory layout

The current layout of the Borås Factory is with this new production design not possible to use by different reasons. A prerequisite for the new factory layout set by Volvo was that all stations should be able to work with full length bus chassis, something that is only possible in one of the existing lines. Also the total numbers of stations are different from the today's layout which requires another layout.

The demands for the layout were that no outer walls should be moved and the existing inlets and outlets should be used if possible.

Since the two lines had a total length between 123.9 and 141.1m it came clear in an early point that the building does not allow the lines to be parallel and straight.

Three different factory line proposals have therefore been made and compared to each other. The proposals are as follows:

6.3.1 Layout proposal 1

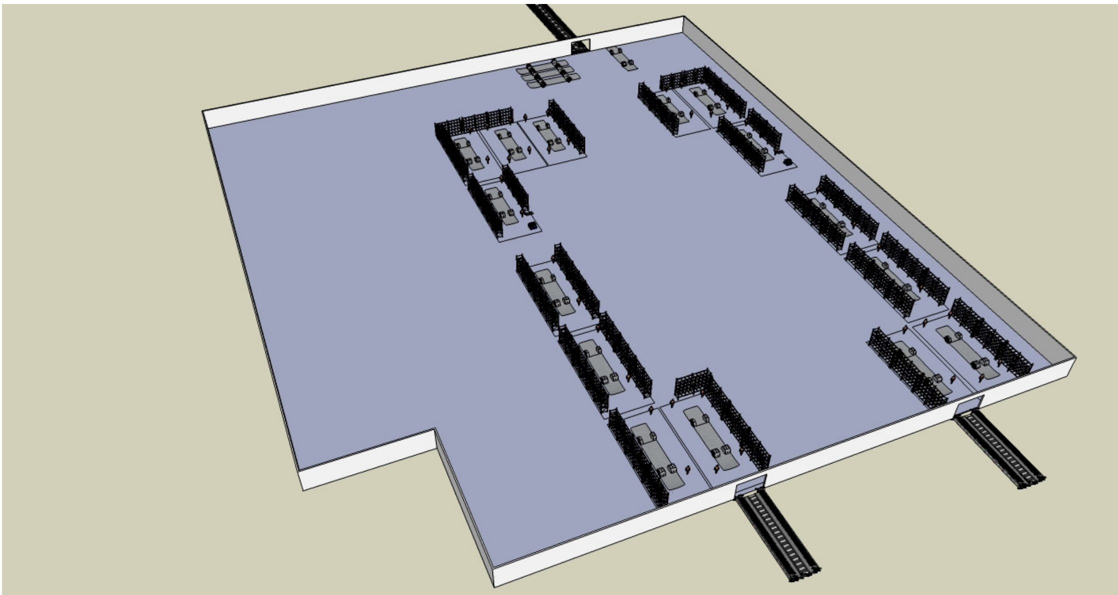

Figure 14 - Layout proposal 1

This layout, as shown I figure 14, is the most feasible and easiest to implement in the current factory in a short term. The two lines are situated where line D and line C is situated today. This has the advantage that no equipment, like intakes or cranes, has to be moved. Parallel stations are used in the beginning and end of each line. These stations are a consequence of the perquisite to fit all necessary stations within the current factory walls. This layout uses sideways movement of the chassis in the parallel stations in order to avoid unnecessary rotations of the chassis. In between the lines, a big area appears that can handle the preassemblies that are currently made on line. The stations that will send or receive chassis sideways will not be able to have material facades on the long side. This problem can be handled by balancing those stations with small or big but few parts to mount.

Profits

- The intakes must not be moved and the cranes that exist can probably be used after minor adjustments.
- No rotation of the chassis will be needed.
- No extra space is needed; the layout uses the same area as is used today.

Consequences

- Due to sideway movements, the amount of material racks and facades in these stations will be limited.
- Kitting and sequencing of material will be necessary.

6.3.2 Layout proposal 2

This layout has two L-shaped lines, creating a square for preassembly in between them as shown in figure 15. This layout demands that one of the intakes is moved as shown in the figure below. Also cranes must be moved because one of the lines will be situated on areas that today don’t have any assembly. This layout also requires rotation of the chassis on two places. In order to do the rotation as easy as possible it is preferable that the chassis already on step one is transported on air pillows.

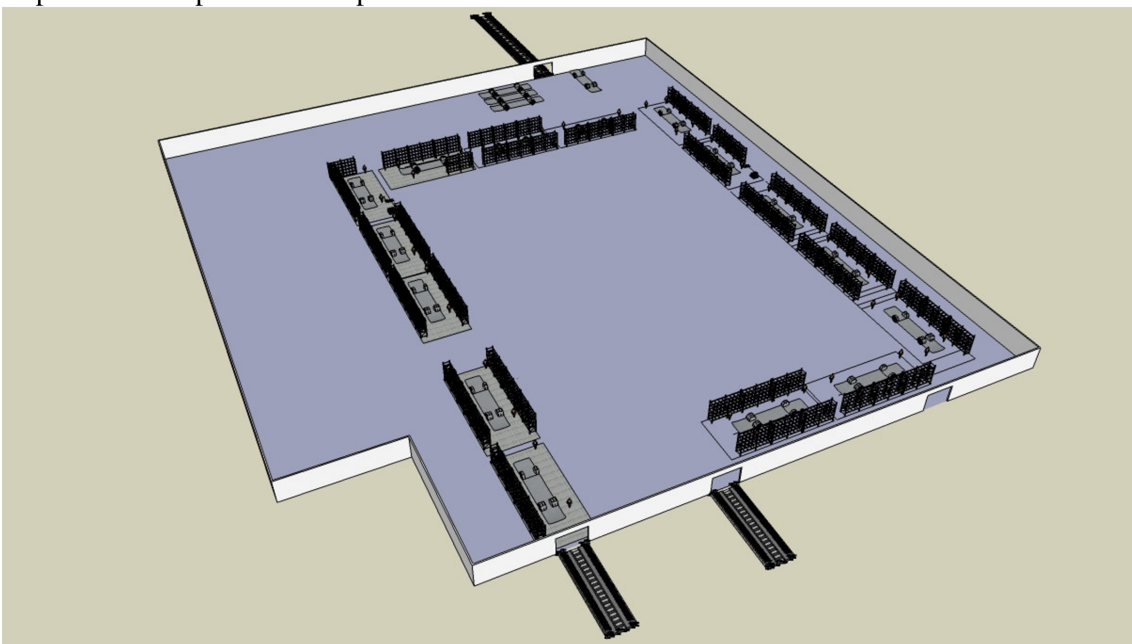

Figure 15 - Layout proposal 2

Profits

- An extremely large area for pre assembly is possible to have in between the lines.
- Much space is available for material facades.

Consequences

- Major reconstruction must be made, such as move of one intake and moving cranes.
- Investment in reconstruction of air pillows will be necessary.

6.3.3 Layout proposal 3

This layout has some similarities with proposal 2, see figure 16. They both have L-shaped lines and therefore a 90 degree rotation in one place. The total area it uses is nearly the same as today. For this layout it is required that both intakes will have to be moved into a common intake. The new intake should be able to move the chassis sideways from the yard to reduce number of rotations of the chassis. The cranes on the other hand will only need slight adjustment to work in this layout. The air pillow solution will also be applicable in this layout.

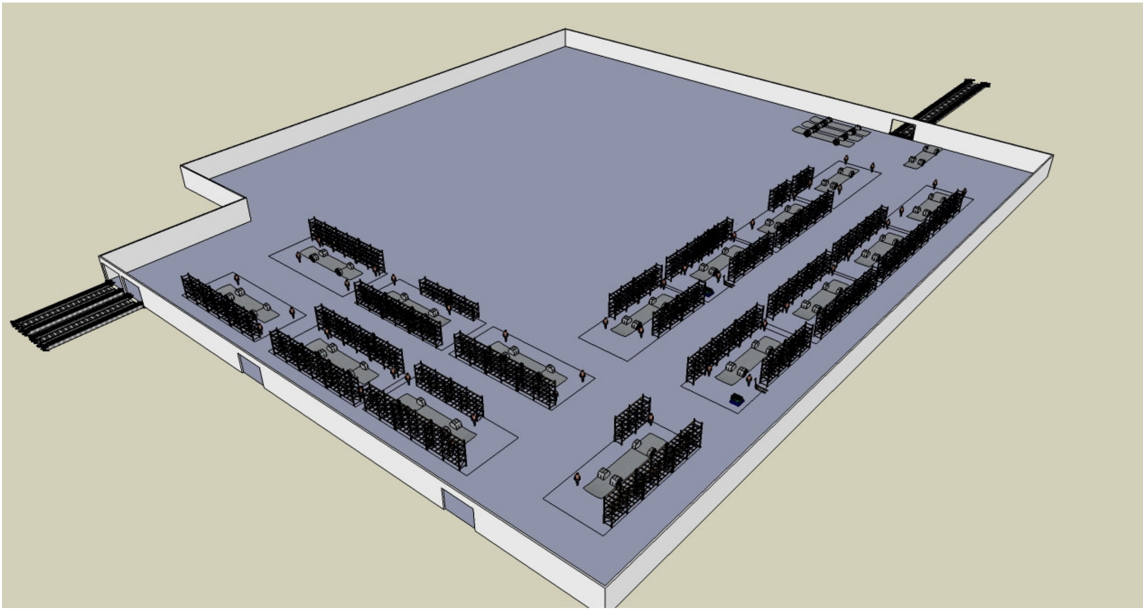

Figure 16 - Layout proposal 3

Profits

- An extremely large area for preassembly is possible because no assembly line shields the preassemblies from the rest of the factory.
- Much space is available for material facades.

Consequences

- Major reconstruction must be made, such as move of the intakes and some cranes.
- Investment in reconstruction of air pillows will be necessary.
- Pre-assemblies must be moved to make space for intakes and beginning of line.

6.3.4 Layout summary

Comparing the different proposals profits and consequences and discussion with Volvo the chosen layout for the discrete event simulation is proposal number 1. This proposal is the most feasible since no intakes have to be moved and the existing lines concerning cranes/air are possible to use without major reconstruction.

6.4 Advantages and disadvantages of the new production system

The presented production system has a number of effects, good and bad, that is worth mentioning.

6.4.1 Productivity and resources

The new system is using fewer resources and also has a higher output which enhances the productivity compared to the current production system. Output goes from 22 to 24 chassis which is a 9% increase. The number of operators needed decreases from 52 permanent and 9 variant operators (52+9) to 39 permanent and 6 variant operators (39+6). This means an increase in productivity with approximately 40%. This increase makes it possible to assemble as few as 16.5 chassis per shift (8.6 hr) with the same productivity as today.

6.4.2 Losses in the production system

The arrangement with two lines has compared to the current system some flaws. Some losses will increase, at least in theory. The theory says that the variant losses increase when a larger range of models and variants are produced at a line. The system and handling losses will in theory increase when having a longer array of stations. Each station has certain reliability and when having them on an array the system reliability will decrease exponentially with every more station that is added.

The increased movements of chassis and longer production lines will increase handling losses. The number of movements on one shift will increase from 138 to 181. Though some sideway movements are used it contributes to a shorter distance of total movement than in a regular line system.

The total reliability and robustness will decrease and make the system loss higher. The system loss will decrease also due to that the current intakes must feed two lines each which create waiting time if the lines are in synchronization. In the new system they only have to feed one line each, which erases the wait time.

6.5 Simulation

Simulation in AutoMod has been made by building a model of the static balanced system. This model has been verified to the static balancing by comparing utilization and output in both the dynamic and the static model.

The objectives for the simulation were:

1. *Verify the static balance*
2. *Make an estimation of the need of variant operators*
3. *Estimate the maximum capacity of the production system*

6.5.1 Distributions and deviations

An operator well known with his/her work task is still always performing the amount of work with some variance in time. This means that the same task does not always take the exact same amount of time; sometimes it takes less time but mostly more time. This is in the model presented as a triangular distribution with the balanced time as mean value and the spread set by technicians at Volvo.

Each bus is being built on customer order; this also contributes to that the buses being built have different chosen options, which also affects the assembly time. The chosen way to identify this was to identify the spread of the average time per chassis from the planning department and a distribution was achieved. These distributions are also presented in appendix 10.5

6.5.2 Variant operators

One of the questions the simulation was set to answer, was the need of variant operators in a resource pool. The static need of these are six; a maximum of four on Line 2 due to B9TL, 6x2 and full wheelbase and two on Line 1 due to B12M 6x2. The interesting result was that only a maximum of total four variant operators were needed in the dynamic simulation in order not having to stop the line for a lack of available variant operators. If the number is decreased to tree variant operators both the lines will suffer from takt overdue regularly. Though there is always some absence due to illness to take into consideration. Therefore it is recommended to have all six operators in the resource pool. When these operators aren’t in use on line, they can work with other things like training of new personnel or other tasks.

6.5.3 Resource utilization

The utilization of operators is measured individually due to that each operator has its own spread as mentioned in 6.5.1. The maximum utilization for an operator in the random simulation model is 75.6%. The average utilization is on line 1 73.1%, and on line 2 71.1%.

6.5.4 Takt overdue

There is always a risk of takt overdue; this means that the takt time is not large enough to contain the total amount of labor. After making an analysis of 25 replications it came clear that takt overdue would occur in average of six times per year. The reason that these six times occurs are that on some occasions a complex bus with a lot of options and a slow operator, are combined which results in a takt overdue. This time is mostly very short, between 20 and 270 seconds.

6.5.5 Maximum capacity

The maximum output for the system is 28 chassis per day (8.6 hr). This means that the takt time is the same time as the longest cycle time on the line. This means of course that the utilization is rising for all personnel. This can be applied when having an extreme demand under a limited time instead of working overtime. The output is based on that no disturbances occur such as missing material or other breakdowns as said for the other simulation as well.

6.6 Organizational impact

The new production system will have a series of impacts on the surrounding organization.

6.6.1 Material handling

The material facades on some stations will be limited. The material will have to arrive kitted in sequence to those places. This means that the material must arrive with high precision both in time and sequence to those stations.

6.6.2 Production planning

The planning function will have more freedom than in today's system; the restriction that the 6x2 buses only can come every third is no longer necessary. The only restriction is that the models are dedicated to a specific line.

6.6.3 Operator learning time

Thanks to the decrease in cycle time the learning time for a new operator will be shorter. The savings that come out of this is hard to put an exact number on. However is it for sure an advantage when educating new operators and they will perform at full pace sooner than today.

6.7 Risk analysis

The production system that is presented has some issues that are important to know of.

6.7.1 Input data

Due to that not all models have been analyzed with standard worksheets and task times some assumptions and estimations are made as presented in section. The presented output is therefore not covering all models but the ones where task data is missing estimation to another equivalent or more complex model is made to be sure of that no better times than in reality. The estimations are shown in the table below. This can have the effect that the balancing losses may be a bit larger than the output shows. The translations that are made are displayed in table 4.

B9S	=	B9R
B12M	=	B7R
B9L	=	B9R
B9LA	=	B9R
B12MA	=	B12B

Table 4 - Translation of the not analyzed models

6.7.2 Changes in demand

The production system has two lines with dedicated models. This make the production a bit inflexible if the demand swings between the different models. As an example is the B7RLE and the B12Ble quite similar to the buyer, just engine size differs. These models are assembled on different lines and this can be a problem if the demand shifts from to one of the models. The effect will be under utilization of one line and over utilization of the other. On the other hand is the prognosis of 2008 compatible to the line model mix meaning that the upcoming demand is handled in a good way. A more detailed analysis of the 2008 prognosis is made in appendix 10.5.

6.8 Production system benchmarking

Another large bus manufacturer in Sweden is Scania, based in Södertälje. Their production system has developed a lot in the last years and have the past two years been spoken well about since their productivity have raised much in the latest. After a visit at Scania it came clear that the new production system presented here is quite similar to the one in Södertälje.

The production in Södertälje is based on one semi-parallel line that starts with 3 parallel stations and then a following single line. Their output is 12 chassis/day with a takt time of 36 minutes. The comparison to Line 1 in the presented production system is clear with a takt time and daily output which is similar to Scania's.

A difference between the systems are that Scania sequence their production to at maximum every third bus as a 6x2 to be able to keep the takt time. This is not an issue in the presented production system.

The benchmarking shows that the presented new production system is a one line system, if considering line 1 that has almost the same output as Scania has.

7 Conclusions

The most essential answer this project has given is that there is a possibility of assembling chassis on two lines. Here follows a list of conclusions from the project;

- Setting up a two-line production system can, if correctly implemented, increase productivity up to 40%. This comes of higher output with fewer resources (operators) which became possible after a rebalance made the use of resources better.
- Production planning and sequencing will not suffer from restrictions as is the case today.
- Learning time for new personnel will decrease due to shorter takt time.
- A large area becomes free when reducing the production to two lines that makes it possible to have pre-assembly near line. The stations are possible to make larger to be able to handle full length chassis.
- The requirements will be harder on material handling, sequencing and kitting must in used in some stations where the space for material is limited.

A short glance at a single line system has been made and is presented in appendix 10.6. The conclusion is that the present products are not possible to assemble on one common line in an effective way.

8 Further recommendations

Further, more detailed analyzes concerning material handling and layout rebuilding must be conducted in the near future to come to a conclusion when this system is possible to implement.

The project has also looked into a structured way of working with line balancing. The software ProPlanner Line Balance has shown itself to be of big help when balancing the lines. Volvo can gain great benefits if the balancing work will continue using a structured tool such as ProPlanner. Though this demands a thorough analysis of all models and assembly tasks initially, is it a smart way of having the assembly process in control and be able to adjust balances off-line to analyze the effects before implementing on shop floor.

This structured method is possible to use today also with the four lines. To be able to rebalance the existing lines with ProBalance a significant rise in productivity is most certain possible to gain also in short term.

9 References

9.1 Written sources

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9.2 Interviews

Torbjörn Nilsson, Industrial Engineering, Volvo Buses Borås Plant (VBoF)

Håkan Svensson, Industrial Engineering, Volvo Buses Borås Plant (VBoF)

Niclas Hedström, Operator, Volvo Buses Borås Plant (VBoF)

Dan Jernheden, Operator, Volvo Buses Borås Plant (VBoF)

Anders Flodin, Operator, Volvo Buses Borås Plant (VBoF)

Bertil Gustafsson, Lecturer, Chalmers University of Technology

10 Appendices

In this chapter is all additional details and calculations displayed.

10.1 Balancing of the current lines

The analyse of today regarding the current state line balancing has been made based on the actual Standard Work Sheets (SWS) for the available models. The models that do not have an up to date SWS have been translated in the same way that was described in table 4.

10.1.1 Line A

Shown in figure 17: B12M, B12MA, B9S, Average

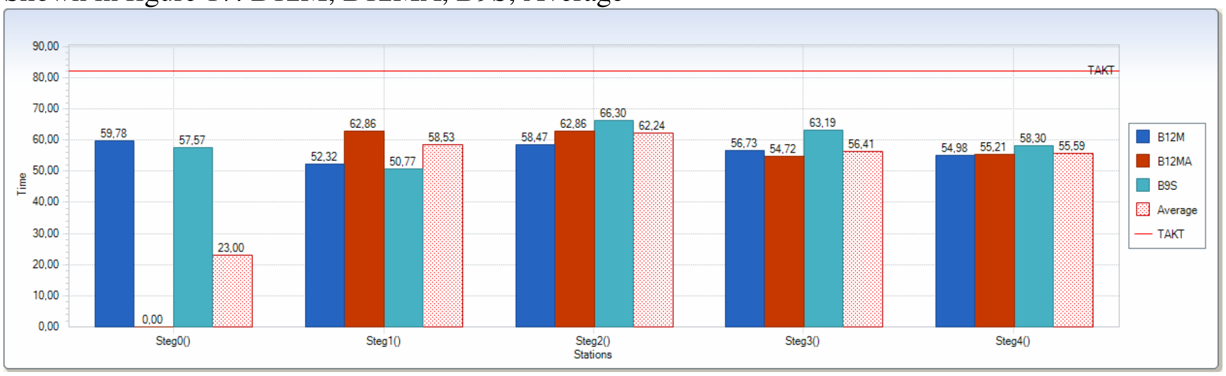

Figure 17

10.1.2 Line B

Shown in figure 18: B7R, B7RLE, B9R, Average

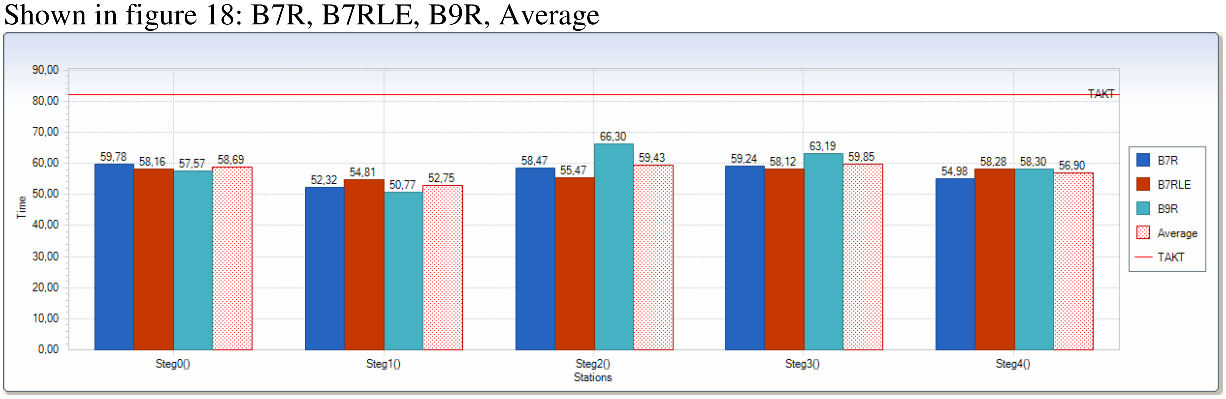

Figure 18

10.1.3 Line C

Shown in figure 19: B7RLE, B9TL, Average

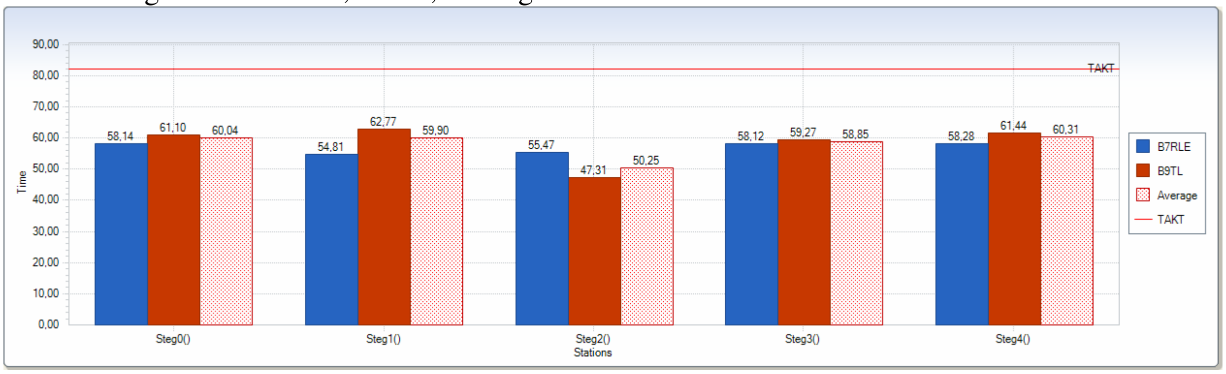

Figure 19

10.1.4 Line D

Shown in figure 20: B12B, B7R, B7RLE, Average

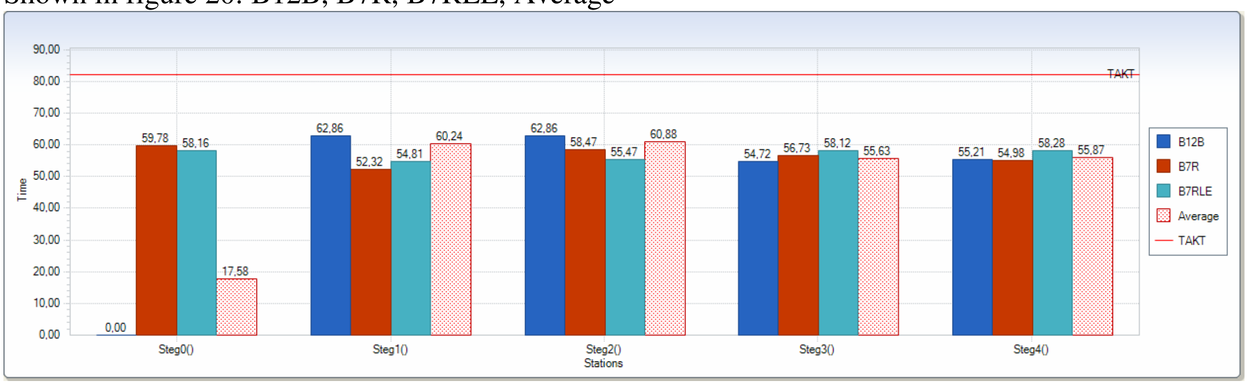

Figure 20

10.2 Balancing of the new lines

To balance the new lines of assembly it was necessary to know the demand. The demand was, by Volvo, assumed to be the same as the production had been so far during the first 33 weeks of 2007. The distribution of the produced models are presented in table 5.

B12B	B12BLE	BLEA	B12M	B12MA	B7R	B7RLE	B9L	B9LA	B9R	B9S	B9TL	TOT
531	213	0	132	11	342	537	28	13	137	54	324	**2322**

Table 5 - Distribution of produced models

The demand was now used to choose which models that was to be produced on each line. The general idea of the distribution between models is one complex and one less complex assembly line. The less complex handles models with shorter throughput times and the complex handles 6x2 buses, full wheelbase and models with long throughput times.

With these delimitations two lines were formed. The complex line is line number two and the less complex is thereby line number one.
To obtain the daily production output from each line the total output (24) was multiplied with each percentage of the total production. That gave 13 respectively 11 chassis per line and day.

Calculating the balance between the outputs, the volumes from the prognosis and outcome where used to gain an equal work load for the lines. The result was 97,1 respectively 96,5 days. A day is a labor day meaning that the total difference in production would only be about 4 hours. This is shown I table 6 below.

Line 1		**Line 2**	
B7+B9R/S/L+B12M		B12B+B12BLE+B9TL	
# chassis	1254	#chassis	1068
%:age of total prod.	54.01%	%:age of total prod.	45.99%
Daily production	12.96124	Daily production	11.03876

	No of days	**TAKT-time**	**Cycle time**
Line 1	96.46	39.23	34
Line 2	97.09	46.36	39.1

Table 6 - Calculations for line distributions

The Takt-time is a calculation between the length of a labor day and the number of chassis produced per day. The Cycle time is the maximum allowed cycle time is 85% of the TAKT-time (Ortiz, 2006).

10.3 Worksheets for the new lines

Worksheets are in Swedish and task times are not displayed.

10.3.1 Line 1 – B7R, B7RLE, B9R, B9S, B9L, B12M

Tasks for B7R:

Station 1

Lyft in ramsidor
Tvärbalkar; reastags fästen,
Cykelram, nedväxling, främre tvärbalk
Dragning av skruv
Lyft in ramsidor
Tvärbalkar; reastags fästen,
Cykelram, nedväxling, främre tvärbalk
Dragning av skruv
Lyft in ram
Montera säkringslåda till ram
Lyft in ram Med kollega
Övre reastag
Montera spwcarr med kollega
Applicera Welding instructions

Station 2

Motorfästen
bälgplattor, konsoler
Crossmemberbalk och motorfästen
Styrväxel
Klämbalkar
Crossmemberbalk och motorfästen
bälgplattor, konsoler
Motorfästen
Klämbalkar
Tryckluftttank fram, Ventiler fram
Pvc-rör, Nylonrör fram
Övre reastag
servorör
Lägg upp kablage vid växel-låda
Vinkelväxel, pedaldurk, konsolprovförarstol,främre servorör
Tryckluftttank fram, Ventiler Fram
Ventiler Bak, lufttankar bak
Montera moppe motor till ram
Montera pingtank till ram
Montera förarplats till ram

Station 3

Fräser Jordpunkter
montera bränslefilter inkl konsol till ram
Ventiler bak, lufttork
Pvc-rör, nylonrör,Bränslerör
Pvc-rör bak, nylonrör, bränslerör
Lägg i och anslut främre modul kablage
drar jordfläta till ram
Montera kylslinga till ram
Anslut kompressor rör, klamma rör till ram
Montera styrkardan till vinkelväxel
Anslut förarplats och elcentral
Montera provförarstol till ram

Station 4

Klamma kablage vid växellåda
Kör in axlar i steget
Montera framaxel inklusive bromsslangar
Montera f-battlåda med kollega
Montera bakaxel ihop med kollega
Montera bälgar fram och bak
Kör in axlar i steget
Montera framaxel till ram med kollega
Montera bakaxel ihop med kollega
Montera bälgar bak och fram
Montera bromsslangar till bakaxel
Anslut batterilåda
Klamma rör vid battlåda
Moment dra kräningshämmare

Station 5

Dockar och åtdrar motor
Bakstam och underbalk
Bandar kablage till bakstam
Dockar och åtdrag motor
Bakstam och underbalk
Montera nedre kylrör på motor
Montera remspännarfjäder
Montera slangar och rör mellan exptank och motor
drar fast servobehållare
monterar klamma till bränslerör
Lägg i och anslut bakre chassie kablage
anslut slangar och rör på vänster sida motor
anslut servoslangar
klamma pluskablar till crossmember balken
koppla in vattenavskiljare
koppla in säkringsdosa
Anslut jordfläta vänster sida
Anslut jordfläta höger sida
inkoppling ebs bak
Lägg i och anslut växellåds kablage
Anslut luftfilter

Station 6

montera kardan till bakaxel
Montera konsoler och kylare till ram
Montera och klamma övre llk-rör
Montera fläktrem
montera ljuddämpare
Montera och anslut urea-tank
Montera värmeskydd till kablage över ljuddämparen
Montera luftdukt
Montera bränsletankar till ram
Anslut bränsletankar
Montera Ac-brygga till ram
Anslut och plasta växel väljare

Station 7

Montera slangar och rör mellan kylare och motor
Montera och klamma avluftningsslangar
Montera och klamma nedre llk-rör
Montera plåt bakkant kyl
Montera rör och slang under motor
Drag fäste för luftdukt samt övre kylarinfästning
Provtryck laddluftsystem
Klamma växellåds kablage
Bandar överblivna rör och kabellängder
Lyfta på verktygslåda

Tasks for B7RLE:

Station 1

Lyft in ramdelar med kollega
Tvärbalkar; reastags fästen, bälgplattor, konsoler

Brotcha jordpunkter
Docka ihop ramdelar
montera skruv i nedväxling samt k-hämmarfäste
Mät in chassiet
Drag skruvförband
Montera klämbalkar
Lyft in ramdelar med kollega
Tvärbalkar; reastags fästen, bälgplattor, konsoler
Docka ihop ramdelar
montera skruv i nedväxling samt k-hämmarfäste
montera konsol till ram
Montera säkringslåda till ram
Klamma kabel matta till ram
montera nivåventil
montera tankar
Häng upp kablage på ram
Montera nivågivare bak
Montera tank till ram bak
Montera durkplåt inkl konsoler
montera främre krets tank
drar jordfläta till ram

Station 2

Montera styrväxel
Montera bränslefilter till ram
montera servorör
montera lufttork
montera abs-ventiler
Momentdra servorör
Montera pvc-rör
montera ventiler till ram
anslut n-rör till ventiler bak
lägg i och anslut främre modulmatta
Montera urea detaljer
Montera servorör och moppemotor
Bandning till konsoler på abs-ventiler
Montera förarplats till ram
Montera styrkardan till vinkelväxel
Anslut förarplats och elcentral

Station 3

Motorfästen
Montera pivot arm
Montera servorör
Montera länkstång
Hänga upp reastag
montera 4:krets ventil
montera nylonrör fram
montering Hjulbasrör
montera bränslerör
klamma rör bak
klamma bälgrör
montera ventiler fram
montera i höger hjulhus

Montera i vänster hjulhus
Banda överblivna rörlängder till ram på mitten

Station 4
Flytta in axlar i steget
lyft in ram i steg
montera bälg i hjulhus
montera reastag (v-stag)
Montera länkstång
Anslut bromsslang i hjulhus
Montera överfall k-hämmare fram
montera nipplar på hjulhus samt anslut bälgrör
ställ in nivågivare fram
Montera stötdämpare i hjulhus
anslut och dra bakaxel vänster sida
Mät in bakaxel och drag övre reastag
Montera bälgar drivaxel
Flytta in axlar i steget
Montera stötdämpare i hjulhus
montera reastag i hjulhus
montera bälg i hjulhus
Montera överfall k-hämmare fram
ställ in nivågivare fram
anslut och dra bakaxel höger sida
Mät in bakaxel och drag övre reastag
Montera bälgar drivaxel
Montera battlåda till ram
Montera, anslut och klamma elskåp fram
Momentdragning på vänster sidan
Momentdragning på höger sidan

Station 5
Montera motor till ram
montera bakstam till ram
anslut och banda kablage till bakstam
Montera kardan till bakaxel
Anslut bromsslang i hjulhus
montera nipplar på hjulhus samt anslut bälgrör
Montera motor till ram
montera bakstam till ram
Montera nedre kylrör på motor
drar fast servobehållare
monterar klamma till bränslerör
Lägg i och anslut bakre chassie kablage
Anslut jordfläta vänster sida
montera ljuddämpare
Anslut kablage till vxl-låda
Klamma kablage på VXL-LÅDA
Klamning i hjulhus

Station 6
Montera bakre balk
Montera bakre balk
Montera llk-rör till motor

Montera remspännarfjäder
Montera slangar och rör mellan exptank och motor
Montera och klamma avluftningsslangar
Montera konsoler och kylare till ram
Montera och klamma nedre llk-rör
Montera plåt bakkant kyl
Montera fläktrem
anslut slangar och rör på vänster sida motor
anslut servoslangar
klamma pluskablar till crossmember balken
koppla in vattenavskiljare
koppla in säkringsdosa
Montera och anslut ureatank
Klamma kablage och slang
Montera strålningsskydd till kablar
Montera insug (slangar och rör)
Montera luftdukt
Montera ac-brygga till ram

Station 7

Montera slangar och rör mellan kylare och motor
Montera rör och slang under motor
Drag fäste för luftdukt samt övre kylarinfästning
Montera och klamma övre llk-rör
Provtryck laddluftsystem
Anslut jordfläta höger sida
inkoppling ebs bak
Bandar överblivna rörlängder
montera Tankar till ram
anslut tankar

Tasks for B9R:

Station 1

Lyft in ramsidor
Tvärbalkar; reastags fästen,
Cykelram, nedväxling, främre tvärbalk
Dragning av skruv
Lyft in ramsidor
Tvärbalkar; reastags fästen,
Cykelram, nedväxling, främre tvärbalk
Dragning av skruv
Övre reastag
Övre reastag
Montera spwcarr med kollega

Station 2

Crossmemberbalk och motorfästen
Corssmemberbalk och motorfästen
bälgplattor, konsoler
Motorfästen
Styrväxel
Monterar Jordpunkter
Motorfästen

Monterar Jordpunkter
Trycklufttank fram, Ventiler fram
servorör
Ventiler bak, lufttork
Vinkelväxel, pedaldurk, konsolprovförarstol,främre servorör
Ventiler Bak, lufttankar bak
Lägg upp och Klamma kablage över växel-låda
Montera pingtank
Montera kompressor-rör samt moppemotor
Applicera klistermärken till ram (welding instructions)
Montera förarplats till ram
Banda nylonrör vid vinkelväxel

Station 3
bälgplattor, konsoler
Klämbalkar
Klämbalkar
Pvc-rör, Nylonrör fram
Pvc-rör, nylonrör,Bränslerör
Pvc-rör bak, nylonrör, bränslerör
Urea-pump, solenoid, bärjärn, konsol
Montera elbox bak
Klamma n-rör till kompressorrör
Elanslutning av moppemotor
Montera styrkardaner
Montera provförarstol och skyddsringar
Anslut kablage och rör till elcentral och förarplats

Station 4
Lyft in ram
Montera framaxel inklusive bromsslangar
Montera bakaxel ihop med kollega
Montera bälgar fram och bak
Lyft in ram
Montera framaxel till ram med kollega
Montera bakaxel ihop med kollega
Montera bromsslangar till bakaxel
Anslut kabalge till bakaxel ihop med kollega
Lägg i och anslut främre kablage
Anslut kablage till bakaxel ihop med kollega
Ansluter urea slangar och kablar till pump
klammar urea detaljer

Station 5
Plus kabel
Montera f-battlåda med kollega
Dockar och åtdrar motor
Bakstam och underbalk
Knäcker motorfästen ihop med kollega
Monterar kylrör till motor
Dockar och åtdrag motor
Bakstam och underbalk
Knäcker motorfästen ihop med kollega

Montera servoslangar
Montera kapslingsplåtar
Anslut och klamma kablage till bakre elskåp och chassi
Anslut och klamma kablage till elskåp batterilåda

Station 6
Montera bälgar bak och fram
montera kardan till bakaxel
Montera rör och slang till insida ram
Montera påfyllnadsrör till ram
Anslut slang till Hydraulolje behållare
Montera mätsticka till bakstam
Klamma servorör
Anslut turbo och luftfilter
Häng upp och anslut ljuddämpare
Montera jordflätor
Anslut Bränslerör
Momentdrag nox-givare till ljuddämpare
Montera strålningsskydd till urea kablage
Montera kablage till battlåda
klamma rör och kablar runt battlåda

Station 7
Lägg på urea-tank
Lägg urea slangar på chassiet
Anslut och klamma kablar till motor
Uppstripning av överblivna rörlängder
Montera och anslut kylare
montera bränsletankar till ram
Anslut bränsletankar
Lyfta på verktygslåda

10.3.2 Line 2 – B9TL, B12B

Tasks for B9TL:

Station 1
Ta fram TB-tankar och förbered övrigt material
Hämta ram från buffert
Slipa rent jordpunkter
Demontera maskeringstejp
Montera styrventil bak
Montera skyddslister
Lägg i UREA-slangar
Montera huvudkablage (tillsammans med frambalans)
Hämta och montera kablage växellåda
Montera reläventil HB
Montera fyrkretsventil
Montera lufttork
Montera reläventil
Montera EBS-ventil
Anslut kablage till EBS-ventil

Montera föravskiljare
Montera värmesköld
Montera våttank F-8270806
Banda extra lufttankar till ram
Montera förarbetat motorfäste till ram
Montera förarbetad ljuddämpare till ram
Montera NOX-givare till ram och klamma kablage
Montera flex/slutrör
Montera pre-cat
Montera hydraulfilter/slang
Kör telfer och hämta ram från buffert
Montera nivåventil och nippel i hjulhus VF
Montera pinnbultar till krängningshämmare VF
Montera styrventil fram
Montera P-bromstank
Montera durkkonsol
Montera huvudkablage (tillsammans med bakbalans)
Montera kablage växellåda
Montera och plombera förarbetad styrväxel
Montera bultar till jordpunkter
Montera pivotarm
Montera std.konsoler till servorör
Montera nivåventil och nippel i hjulhus HF
Montera pinnbultar till krängningshämmare HF
Montera konsol och främre kretstank
Lägg i längsgående kabelmatta
Anslut och banda kablage till EBS-ventil fram
Anslut kablage till främre styrventil
Montera förarbetad pedaldurk
Montera LLK-klämma
Dra bakbalk
Montera kylrör till tvärbalk
Montera bakbalk till ram
Montera kylslang
Montera konsoler till bakre tvärbalk
Klamma och banda bränslerör och servoslangar
Dra åt durkstödskonsoler
Klistra dekal till hjulhus VF
Montera UREA-ventil

Station 2

Montera nivåventiler, nipplar, bumpgummin HB
Montera bakre kretstank
Montera regenereringstank
Montera våttank F-8270807
Montera PVC-rör och skyddsslang
Montera nivåventiler, nipplar, bumpgummin VB
Montera rör mellan föravskiljare och lufttork
Lägg i längsgående värmerör
Montera och klamma servorör bak
Montera främre länkstång
Montera nipplar och servorör fram
Hämta bränslerör och PA-rör (hjulbas)
Montera bränslerör

Anslut och klamma kabel till nivågivare och styrventil HB
Anslut och klamma i hjulhus HF
Klamma längsgående värmerör
Förmontera gummi och stripes till konsoler över hjulshus
Hämta och lägg i PA-rör över hjulhus
Hämta länkstång till högerbalansen
Montera LLK-rör/slang på lösen
Montera servoslangar
Klamma och banda PA-rör
Montera förarplats
Anslut PA-rör till blockeringsventil och handbromsventil
Montera konsol till provförarstol och häng på skyddringar
Montera provförarstol och banda skyddsringar
Montera styrkardan till vinkelväxel
Anslut och banda kablage under ram (EBS, ventilbrygga)
Lägg ut kabelmattor över hjulhus HF
Hämta och anslut kablage till elcentral
Banda kablage till elcentral
Banda kablage bakom förarplats
Banda kablar över hjulhus HF

Station 3

Montera strålningsskydd över bränslerör och servorör
Anslut och klamma PA-rör
Montera skyddsslangar i genomförningar framför bakaxel
Lägg i kablage (nivåreglering)
Anslut och klamma PA-rör
Anslut och banda kablage
Anslut PA-rör till tankar
Ta emot PA-rör från bakdel (hjulbasrör)
Klipp, vipsa och anslut PA-rör bakom hjulhus
Banda PA-rör över och framför hjulhus
Klipp, vipsa och anslut PA-rör framför hjulhus
Klamma servoslangar och bränslerör
Banda kablar bakom hjulhus HF

Station 4

Montera oljepåfyllningsrör
Anslut och banda PA-rör bakom hjulhus
Ta fram och placera axlar för dockning
Sänk ram till framaxel HF
Koppla lyftband och travers till bakre tvärbalk
Montera krängningshämmarfäste, bakaxel
Montera reastag, bakaxel
Ställ in nivågivare, bakaxel
Montera stötdämpare, bakaxel
Ta bort tornen och montera bälgar, bakaxel
Lossa och flytta lyftband och travers till framdel
Montera övre reastag och stötdämpare, framaxel
Montera bromsslang, framaxel
Montera krängningshämmare båda sidor, framaxel
Montera bälg, framaxel
Montera nipplar, PA-rör och låssprint till hjulhus, framaxel
Ställ in nivågivare, framaxel

Justera, montera bakre länkstång, framaxel
Ta fram och placera axlar för dockning
Beställ flak och axlar till nästa chassie
Sänk ram till axlar och lossa lyftkättingar
Dra kronmuttrar nedre reastag båda sidor, framaxel
Montera krängningshämmarfäste, bakaxel
Montera reastag, bakaxel
Ställ in nivågivare, bakaxel
Montera stötdämpare, bakaxel
Ta bort tornen och montera bälgar, bakaxel
Montera bromsslangar och dra gummiklämmor, bakaxel
Montera övre reastag och stötdämpare, framaxel
Montera bromsslang, framaxel
Montera krängningshämmare båda sidor, framaxel
Montera bälg, framaxel
Montera nipplar, PA-rör och låssprint till hjulhus, framaxel
Ställ in nivågivare, framaxel
Kör telfer och hämta ram från steg 1
Sänk ram till axlar
Montera konsoler för batterilåda
Montera batterilåda
Montera och banda kablage i och bakom hjulhus VF
Montera och banda kablage i och bakom hjulhus HF
Momentdra och markera krängningshämmarfäste VB
Anslut och banda sensorkablar längs bromsslang HB
Momentdra och markera krängningshämmarfäste HB
Hämta och förarbeta UREA-tank
Montera UREA-tank till ram
Hämta och anslut powerbox
Anslut vattenslangar UREA

Station 5

Anslut kopplingsstycken till start o stoppknappar
Anslut och klamma kabel till generator
Montera avgasrör (flexrör)
Dra motorkuddar VB
Montera klambalk
Klamma kylrör till klambalk
Återmontera bakre del kardan (i rätt splines!)
Montera motor till chassie
Återmontera termostathus till motor
Montera servoslang till motor
Klamma pluskabel
Anslut och klamma kablage till motor och växellåda
Montera PA-rör
Montera LLK-rör till motor
Montera bulkhead
Klamma kablage
Montera jordfläta VB
Montera förarbetad konsol med servobehållare
Montera slangar till servobehållare
Montera oljepåfyllningsrör
Anslut kopplingshandske och kopplingsstycke till motor
Klamma oljepåfyllningsrör och oljesticka till motor

Ansluter kylslang till motor V-sida
Dra kylrörsklämma under motor
Montera bulkhead
Banda bakom hjulhus
Justerklipp, vipsa och anslut bränslerör
Banda och klamma kablage över bakaxel HB
Banda och klamma längsgående slangar och kablage
Montera powerbox
Klamma kablar till batterilåda
Banda upp bränslerör på lösen

Station 6

Hämta längsgående vattenslangar och kabelmatta
Montera kardan till växellåda
Montera bromsslangar och dra gummiklämmor, bakaxel
Montera förarbetad UREA-pump till chassie
Montera slang HB
Montera slang till pingtank
Dra pingtank
Anslut slangar till hydrauloljetank
Montera LLK-slangar till kyl, kylslangar och dra kylrör
Läckagetesta LLK-system
Montera insugningsslang
Banda och klamma kablage till motor
Klamma oljepåfyllningsrör och oljesticka till bulkhead
Transportbanda kablage i plastpåse
Anslut kablage till bakre powerbox, exp.tank och kylfläkt
Banda och klamma kablage under soffa
Montera insugsslang till kompressor
Montera kylslang och kylrör
Anslut och banda sensorkablar längs bromsslang VB
Klamma vattenslangar över bakaxel HB
Anslut och klamma kablage till UREA-pump
Klamma kablar till powerbox
Klamma och stripa överskott på pluskabel mellan hjulhus

Tasks for B12B:

Station 1

Passa in ram
Montera styrväxel
Montera nipplar och servorör
Montera Kablage
Montera skyddslister
Montera krängningshämmare
Montera konsoler på hjulhus vä sida, placera konsoler på hö hjulhus
Montera konsoler på hjulhus hö sida
Anslut och klamma bränslerör
Montera pedalplåt
Montera ventilbrygga och PVC-rör
Passa in ram
Montera övre länkarmar
Montera ventiler

Brotcha jordpunkter bak och fram
Montera lufttork
Montera lufttankar i hjulbas
Passa in ram
Anslut och klamma bälgrör hö sida fram. Montera nivågivare och bromsslang hö sida fram
Montera vinkelväxel
Montera nivågivare vä bak
Montera hö nivågivare
Konsol förarstol (Uppskattad tid)
Förarstol
Förberedelser för montage av tank mellan hjulhus
Montering av varningsdekaler
Bipackning av tank vid hjulhus
Monterar förarbetade fästen för kyl på chassie
Montera och dra fast övre fäste

Station 2

Anslut och klamma kablar i ventilbrygga
Drag n-rör från pedal och bakåt
Anslut och klamma n-rör
Placera, anslut och klamma nylonrör
Placera och klamma pluskabel från tv-balk framför bakaxel och bakåt, Placera "huvudkablage" från tv-balk framför bakaxel. Klamma kablage fram till tv-balk framför motor.
Montera styrkardan
Anslut och klamma bälgrör vä sida fram. Montera nivågivare och bromsslang vä sida fram
Konsol batterilåda
Montering förarplats och styrkardan
Inkoppling PA-rör vid förarplats

Station 3

Montera undre länkarmar samt stötdämpare fram
Placera servorör vid tv-balk framför bakaxel och montera klammor på lösen.
Montera bakre servorör.
Montera och klamma bälgrör. Montera bumpstopp. Anslut och klamma nivågivarkablar
Montera och klamma bälgrör. Montera bumpgummi. Anslut och klamma nivågivarkablar
Montera elcentral
Montera konsoler och batterilåda
Fastsättning av kablage
Inkoppling i el-central
Inkoppling kablage vid förarplats
Strömkablar vid el-central
Klamning överlängder vid förarplats

Station 4

Montera PVC-rör och AdBlueslangar, klamma slangar och kablar (EU4)
Ta fram axlar /flak och ta emot ram
Montera vulstplatta, täta, gummiring. Montera vipsnippel till rör,banda fast. Hö sida
Montera konsol nivåventil, anslut nivåventil, montera och säkra stag till krängningshämmare. Hö sida
Förbered för montering av IFS och hämta vagn med förarbetad IFS. Hö sida
Montera IFS till länkarmar. Montera styrarm. Montera krängarstag till länkarm. Montera styrstag, Anslut bromsslang. Montera stoppskruv hjulutslag. Hö sida
Montera bälg och ställ in bälghöjd med domkraft, Justera nivåventil. Hö sida

Montera vulstplatta, täta, gummiring. Montera vipsnippel till rör och banda fast. Vä fram.
Montera konsol nivåventil, anslut nivåventil, montera och säkra stag till krängningshämmare. Vä fram
Hämta materiallåda, anslut nivågivare, k-hämmare, stötdämpare och nedre reastag vä bak
Drag nivågivare. K-hämmare och stötdämpare vä bak
Anslut övre reastag, ta bort fixtur samt sänk ram
Drag reastag, hjälp hö sida med mothåll
Höj ram montera bälg, sänk ram, travers till mitten
Montera IFS till länkarmar. Montera styrarm. Montera krängarstag till länkarm. Montera styrstag, Anslut bromsslang. Montera stoppskruv hjulutslag. Vä fram
Montera bälg och ställ in bälghöjd med domkraft, Justera nivåventil. Vä fram
Anslut drivaxel till ram reastag,stötdämpare, nivågivare
Dragning k-hämmare och stötdämpare
Reastag drivaxel
Montera gummikudde och ljudisplåtar
Drag och klamma kablar och N-rör från motorbalk och bakåt
Klammning i vagn för EBS
Inkoppling EBS-kablage fram h-sida
EBS-fram vänster
Montering och inkoppling av tank mellan hjulhus

Station 5

Docka motor, anslut vä motorfäste
Anslut bromsslangar inkoppling EBS
Bromsslang, klamning och lossa reglerstång
Docka och drag motor och staket
Bromsslang och bälgar
Montera kardanaxel till axel
Bakstam montering
Turbo luftburk, anslutningar ovanför vxl
Anslutningar uppifrån vid bakstam
Anslutningar baksida bakstam
Anslutningar v-sida bakstam
Anslutningar kablage och luft på plåt på bakstam
Inkoppling v-sida vxl kabel och bränslerör
Täckplåtar v-sida
Täckplåt h-sida bak
Kablar till startmotor
Slang till avgasbroms
Montera g-klammor kring slang och rör
Montera rör till kylare på chassie
Montera förarbetat rör på chassie
Montera ljudisplåt
Stänkskyddsplåtar drivaxel v-sida
Dra åt jordflätor (2 st)
Montera noxgivare insida plåt
Montera ljuddämpare på chassie
Montera värmeskydd
Inkoppling och klammning vid vxl.
Inkoppling och klammning av n-rör vxl-låda
Slang på servorör
Stänkskyddsplåtar drivaxel h-sida

Station 6

Monterar slangar v-sida

Montering stålrör och ventil vid lufttork
Slang på servorör
Extra tid för ESTAID
Montering av främre tank
Klammning vid tankar
Montera stålrör och klammor
Montera klammor vid exp.tank
Montera slangar och klammor
Monterar g-klamma till slang
Montera förarbetad kyl
Montera klammor mellan kyl och rör
Dra fast konsoler och klammor
Montera grön hydraulslang på fläktmotor
Montera n-rör på hydraulmotor
Klamma
Montera hydraulslang med slangklamma och g-klammor
Montera insektsnät
Montera täckplåtar
Hjälp frammontör med bränsletank
Montera rörböj till flexslang
Montera och dra undre fäste
Montera klamma för ingående rör
Justera och dra fast rör mot metallslang
Anslut till givare och injektor,klamma
Klamma överskott på sladd underifrån
Klamma klart vid rörböj

10.4 Simulation details

The simulation model has been evaluated over 100 days of 8.6 hours of work with different settings for variant operators and the presented deviations in this chapter. For the evaluation of the resource utilization, 20 replicates where used.

The deviations used in the simulation are triangular distributions for manual work that stretches from 5% shorter than average time to 15% more. Details are presented in table 7.

Since the model worksheets are based on the most common model, a triangular distribution is also used to handle the different small variants on the buses.

Times and distributions					
	Min [%]	**Min**	**Medel**	**Max**	**Max [%]**
B12M	0.97	15.84	16.255	19.46	1.20
B12B	0.77	14.15	18.456	19.37	1.05
B9S	0.95	12.87	13.556	14.2338	1.05
B7R	0.96	15.91	16.585	17.32	1.04
B9R	0.94	13.22	14.047	14.99	1.07
B9L	0.89	10.71	12.075	12.07	1.00
B7RLE	0.95	14.9	15.687	15.88	1.01
B9TL	0.92	16.04	17.499	17.89	1.02

Table 7 – Distributions for assembly time

10.5 Analysis of compatibility with 2008 prognosis

The presented production system has also been compared with the production results from 2007 as well as the prognosis for the ten first months of 2008. The distributions between the models are presented below. Month 7 is not statistically in control, this due to holiday for the employees.

The result of the comparison is presented in table 8. The column 'Total' is the prognosticated result for the ten first months and the comparison for 2007 is for a whole year of production.

The result shown is that for the first two and the last month the deviation (offset) of result compared to the production system design is above 1.2 chassis/day. If the deviation between prognosis and production system design is around 1 chassie per day it is possible to catch up to production by working overtime. It is also possible as described in Simulation Results to change the takt time to avoid working overtime.

This shows that the production system presented in this master thesis is able to handle the deviations between models.

2008	1	2	3	4	5	6	7	8	9	10	Total	Total 20
B9TL	38	39	37	45	44	50	7	36	36	49	381	543
B9R	20	23	21	29	16	26	9	34	16	27	221	240
B9S	9	11	8	12	9	7	5	3	6	8	78	60
B9L	4	4	8	9	2	8	1	5	18	31	90	30
B9LA	2	2	5	5	2	8	1	2	4	7	38	6
B12M	24	19	21	27	19	10	2	13	19	38	192	241
B12MA	4	2	2	2	0	0	0	0	2	4	16	24
B12B	101	104	63	80	62	71	15	90	74	71	731	957
B12BLE	32	44	43	34	29	17	3	13	12	17	244	354
B12BLEA	0	2	5	11	0	0	0	0	2	0	20	23
B7R	24	48	39	14	16	16	0	20	27	28	232	471
B7RLE	57	56	52	66	68	70	30	88	86	70	643	883
	315	354	304	334	267	283	73	304	302	350	2886	3832
Line 1	144	165	156	164	132	145	48	165	178	213	1510	1955
Line 2	171	189	148	170	135	138	25	139	124	137	1376	1877
% Line 1	45.7%	46.6%	51.3%	49.1%	49.4%	51.2%	65.8%	54.3%	58.9%	60.9%	52.3%	51.0%
% Line 2	54.3%	53.4%	48.7%	50.9%	50.6%	48.8%	34.2%	45.7%	41.1%	39.1%	47.7%	49.0%
Output 1	11.0	11.2	12.3	11.8	11.9	12.3	15.8	13.0	14.1	14.6	12.6	12.2
Output 2	13.0	12.8	11.7	12.2	12.1	11.7	8.2	11.0	9.9	9.4	11.4	11.8
Offset 1	-2.0	-1.8	-0.7	-1.2	-1.1	-0.7	2.8	0.0	1.1	1.6	-0.4	-0.8
Offset 2	2.0	1.8	0.7	1.2	1.1	0.7	-2.8	0.0	-1.1	-1.6	0.4	0.8

Table 8 – Comparison of 2008 prognosis

10.6 Is a single line scenario possible

A way of designing a production system that is relatively stable against the fluctuations in demand between models is to use a single line scenario that handles all the existing models and variants. This is feasible if it is possible to balance all models and variants to be produced on a single line without large balancing/variant losses.

It is possible to produce Volvo Buses in Borås on a single line?
The probable biggest problem is that the takt time will decrease and be approximately 20 minutes in which the cycle time will be around 15 minutes. So if wanted to build buses on one line a larger investment must be made to secure a faster handling of chassis inside the factory to keep the time ratio between assembly and handling low.

To re-balance all work to a maximum of 15 minutes per station is not possible. Since the maximum number of operators will be constant (4 with variant operators), the largest work capacity a station would be able to handle would be approximately 60 minutes. This time is too small to be able to put a B7R/RLE chassis together so it is moveable. A solution to this problem might be to have a semi-parallel line at some assembly steps.

An effect a single line scenario will have is that the organization standing behind the production must be stable and able to cope with the higher complexity a single line contributes with. An unplanned stop of the line will have a larger affect on the output than in a multiple line scenario; this makes it more crucial to have a line with a high reliability.

With the variation of today in total assembly time between the models and the effects mentioned above is it not appropriate to implement a single line scenario at Volvo Buses in Borås.