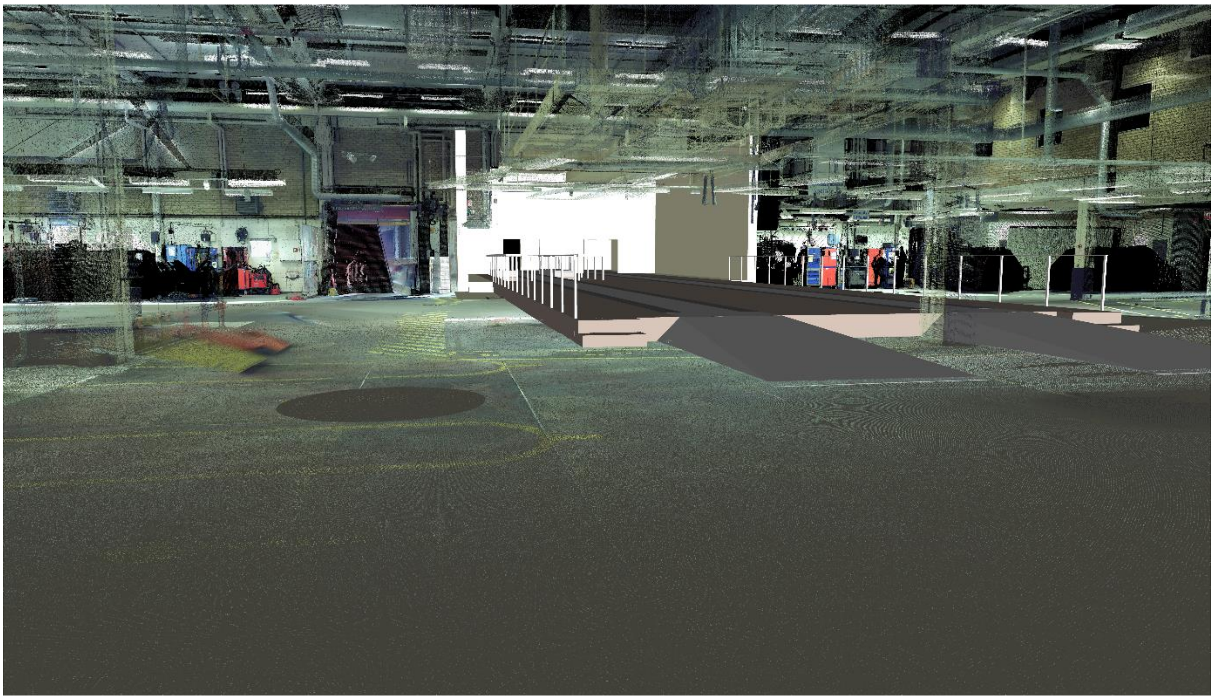

Redesigning the Layout of a Final Flow in a Production System

Layout modelling at Volvo Cars

Master's thesis in Production Engineering

John Brattberg
Ninan Theradapuzha Mathew

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

MASTER'S THESIS 2018

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Cover: A virtual model of the layout proposal for the production system at Volvo Cars

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Abstract

The production industry is facing tough challenges today. The advent of Industry 4.0 demands the need for more efficient, cost effective and sustainable production systems. Therefore, it is highly essential for manufacturing organisations to develop production systems which are flexible, high performing and at the same time more resource efficient. Volvo Cars is an organisation, which has revolutionised the automotive industry with its state of the art technology and high-end products. The main aim of the master thesis is to develop a new layout plan for the final flow in the Final Assembly at Volvo Cars' TC factory, Torslanda, Sweden. The new layout plan should have a straight production flow where all operations are visible and easy to control. The layout change should also remove all the non-value adding operations in the current final flow. A literature study was conducted to understand the methods used in general for layout planning and designing. Systematic layout planning technique was selected as a framework for layout planning and designing in the master thesis. 3D Laser scanning was applied to generate a point cloud to compare the existing TC factory 2D CAD Drawing with the current factory area. The results of the master thesis consist of three layout alternatives developed based on the Volvo Cars' current requirements, practical limitations and future considerations. The layout alternatives are presented in 2D CAD layouts. Key performance factors affecting the layout planning and design were identified. They were used to score and compare the layouts between each other. The layout alternative with the highest score is presented as a virtual model, using point cloud and 3D CAD.

Keywords

Layout Modelling, CAD, Layout Planning, 3D Laser Scanning, Production System Redesign, Systematic Layout Planning

Acknowledgement

First and foremost, we would like to express our great appreciation for all involved parties in this thesis. We have received both guidance and inspiration from your genuine interest in our work.

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We would like to thank the whole Industrial Engineering team at Volvo Cars, and mainly our supervisor Magnus Joving, who has helped us through the whole project. Thank you Magnus Joving, for taking the effort to familiarise us with the Volvo Cars production system and giving us a working space along with the team.

John Brattberg & Ninan Theradapuzha Mathew

Abbreviations

The printings of commonly used abbreviations are presented in Table i.

Table i - Abbreviations

Station name in Swedish	Station name in English
CAL	Customer acceptance line
FHC	Final Health Check
UM	Underbody coating (Swedish: “Underredsmassa”)
SIP	Standard Inspection Point
2D	Two Dimensional
3D	Three Dimensional
CC	Cross Country
KPF	Key Performance Factor

Translation of station names

Volvo Cars is mixing Swedish and English language when naming their workstations. Therefore, a translation list of all the stations with a Swedish name is presented in table ii. However, the stations name in the report will be presented in the language Volvo Cars is using.

Table ii - Translation of stations names

Station name in Swedish	Station name in English
Rullarna	Rollers
Gummibandet	Rubber line
Rangering	Arranger
Matarn	Feeder
CD-plåt	CD-sheet
Underupp	Under up
Huvcover	Hood cover
Dörrsprut	Door spray
Utkörning	Drive out
Extra hjul	Spare tyre

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1 Introduction

In this chapter, a short introduction about the hosting company Volvo Cars along with a background of the master thesis is described. The master's thesis aims and goals, research questions and delimitations are also presented here.

1.1 Volvo Cars

Volvo Cars is one of the most well-known car manufacturer in the world, headquartered in Torslanda in Gothenburg, Sweden. The company was established in 1927 and has revolutionised the vehicle industry over the years through its state of the art technology, quality and world changing innovations.

The organisation was initially started as a subsidiary of the bearing manufacturer SKF and was later acquired by Ford Motor company in 1999. In 2010, Ford Motor company sold Volvo Cars to Chinese multinational automotive company Geely Holding Group. Volvo Cars is currently owned by Zhejiang Geely Holding (Geely Holding) of China. The organisation currently has their manufacturing operations in Sweden, China and Belgium. With an average of 38,000 employees and 2300 dealers worldwide, Volvo Cars is a global organisation. The organisation's core values are safety, quality and sustainability. The company is heralding an all-electric future and has announced that all models produced from 2019 onwards will be electric or hybrid-electric.

The Volvo Cars' Torslanda production facility known as 'Torslandaverken' was started in 1964 and is currently one of Volvo Car's largest production facilities in the world. The facility mainly consists of TA factory (press/body shop), TB factory (paint shop) and TC factory (final assembly). The production facility is now delivering cars from their new platform SPA. The SPA-platform includes the models XC90, XC60, V90, V90CC and V60.

1.2 Background

Volvo Cars wants to change their final assembly layout of the TC factory at the Torslanda plant, Gothenburg. There are three main reasons for having this change. The first reason is that, at present, there is only car models of the new SPA-platform being produced at the Torslanda plant. This has caused operations that were needed for the old models to be removed. The removal of previous needed operations has created a space on the production line where no quality controls or value adding operations takes place. Now, it is just a transport area. The second reason is that, today, the final production flow is going into an isolated building where it gets separated from the main flow. This makes it harder to see what is happening at the end of the flow. A third reason is that, Volvo Cars is also having a future vision of how the factory should look like in three years. This vision requires the production flow to be redesigned into a straight flow. Therefore, Volvo Cars is interested in making a layout change where they can decrease the lead time by removing the unnecessary transport of the cars and get a more viewable flow where it gets easier to follow the cars to the end.

1.3 Aims and Goals

The goal of the master thesis is to create a new layout plan which include all of today's operations to be fitted into a shorter line, which would make the production flow straight, more visible and easy to control. From the production system perspective, the primary goal is that the new production flow should be designed to manage the takt time. Apart from that, it should be possible to take cars on and off for adjustments without stopping the production flow upstream. The layout should fulfil the precedence requirements between operations and consider factors like available space, production area utilisation, flexibility, required number of operators and productivity aspects when designing the new line.

The changed layout will create an environment where material will be added to the cars. Material addition was not performed in this area before. Therefore, to have a proper material flow, new storage areas must be considered in the new layout to effectively store and transport the materials.

1.4 Research questions

1. Can it be possible to shorten the final production flow in TC factory building to have a straight flow and still have the same takt time, flexibility and productivity?
2. Can 3D-visualisation be used to improve the understanding of the developed layout plan?

1.5 Deliverables

The master thesis should generate a plan regarding the new layout with shorter lead time and considerations regarding factory space and productivity. The proposed layout plan should include details on the new operational sequence, operators and material flow. It should also include a virtual model of the layout plan.

1.6 Delimitations

1. The new layout is planned based on a maximum capacity and a fixed station length.
2. Cost calculations for the implementation of the new layout model is not considered.
3. Implementation of the layout is not part of the thesis project.

2 Theory

This chapter will present the results from the conducted literature study. It includes information about two different areas. The first area is about understanding how to perform layout planning and design. The second area is about 3D laser scanning, how it works and the benefits and drawbacks from using it.

2.1 Layout Planning and Design

Production plant layout is a crucial factor that affect the efficiency of a production system. A efficient facility layout in the production area will not only enable the manufacturing organisation to fulfil its production target, but at the same time makes the material flow, information flow and the interaction between machines and humans smooth and efficient. Tompkins and White estimated in 1994 that a well-planned facility layout could reduce the overall manufacturing expenses by at least 10% to 30% [1] [2]. On the other hand, improper layout planning can lead to consequences that could cost the manufacturing organisations huge expenses. Therefore, to have a proper factory layout, the organisations have to effectively plan and position the machines, employees, material, storage facilities, logistics and other support facilities [1]. Hence, the manufacturing organisations spend a lot of time and investment on production system planning and design.

2.1.1 Layout Design: Key Decision Factors

Companies can have various reasons behind the purpose of designing a new production layout. Sometimes the organisations need free space in their existing factory to accommodate new business segments, new products or new manufacturing lines to provide delivery to a new customer [3]. It could also be to achieve an optimal arrangement on the production floor to reduce waste [2] [4]. Otherwise, the organisations could have specific aims such as optimise the current material flow, reduce waiting time, reduce inventory, reduce transportation, reduce lead time, increase productivity, increase product quality, reduce current operational costs, enable easier supervision, ensure safe and comfortable work environment, increase employee satisfaction [5]. Apart from all the above reasons, the fourth industrial revolution also demands the organisations to develop and implement much energy efficient and sustainable production systems in their production area. This has also motivated the manufacturing organisations to redesign their existing production systems.

Despite whatever the reasons the organisations are having, there are numerous factors that have to be taken into consideration during the production system redesign process. If these factors are not properly considered during the planning and design phase, it could affect the overall efficiency of the designed production layout. Sharma et al [6] has categorised these performance factors into seven keys. They are; space utilisation, ease of management and control, flow of material, internal household and employee satisfaction, ease of maintenance, preferred closeness and attractiveness of layout [6]. In addition to these seven keys, Amar et al [7] has proposed layout flexibility has an important factor to be considered during the design of production layouts. The authors have put forward these factors based on the standpoint that it will help to minimise the overall production time, minimise the material handling costs, improve the flexibility for arrangement and operation as well as achieve better utilisation of the available production area [7]. However, the factors considered could vary between different organisations and according to the main objectives behind each layout design process.

In the current scenario, where global warming is a major problem, Amar et al [7] suggests that it is highly significant to design, production layouts that helps to reduce the overall energy consumption and CO_2 emissions at the production facility. Hence, while designing modern factory layouts, the manufacturing organisations could also include two more performance factors like energy consumption index and greenhouse effect level [7]. Figure 2.1 represents the key performance factors for facility layout designs recommended by Amar et al [7].

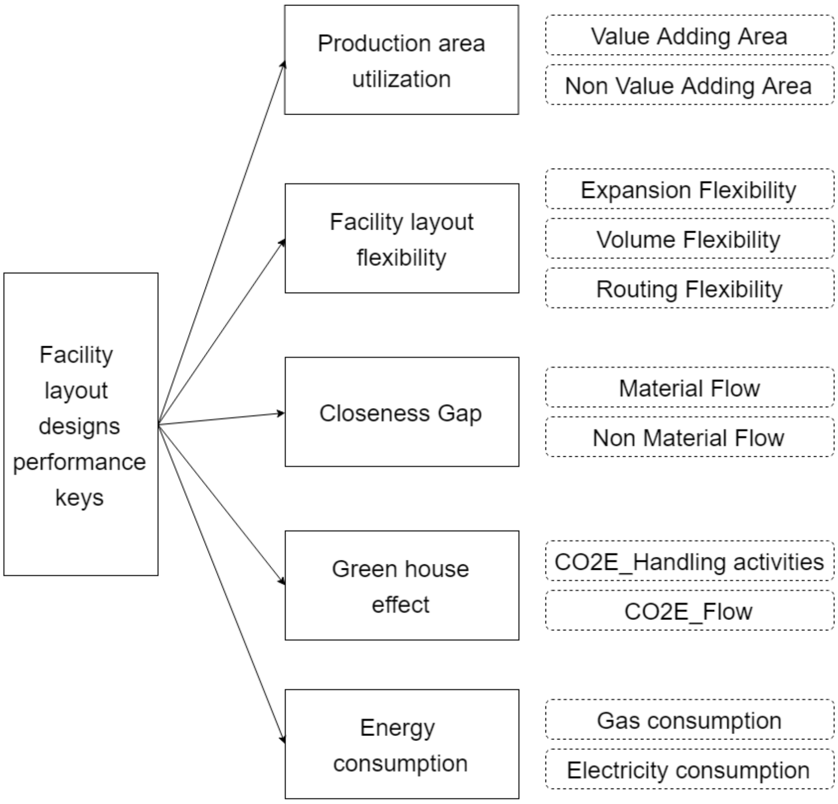


Figure 2.1 – Facility layout designs performance keys [7]

2.1.2 Systematic Layout Planning

For manufacturing organisations, finding the best production layout that satisfies all the necessary organisational needs is a complex process. There are several methods provided in various scientific articles that could help and guide the organisations in their layout planning, designing and implementation phase. One common framework mentioned in the literature is the Systematic Layout Planning method (SLP) [2], [5]. This method has been proposed by Richard Muther and improved later by Tompkins [5]. Suhardini et al [2] defines SLP as follows: “It is a step-by-step planning procedure allowing users to identify, visualise, and rate the various activities, relationships, and alternatives involved in a layout project based on input data, the flow of materials, activity of relationships and relationship diagrams”. According to Pratami et al [5], SLP is a guidance tool that help in planning and designing of a new layout or improving an existing layout.

In general, the SLP technique of layout planning and design consists of three major phases. The first phase is to identify & define the flow of materials, operations and the products in the existing layout [5]. The second phase, analyses the existing layout, defines alternative layouts, evaluate the layouts and finally selects the most appropriate alternative [5]. The third phase mainly consists of the activities associated with the implementation of the selected alternative [5].

In the article, Suhardini et al [2] has given the different steps involved in the SLP approach. The different steps up to the evaluation phase are provided in Figure 2.2.

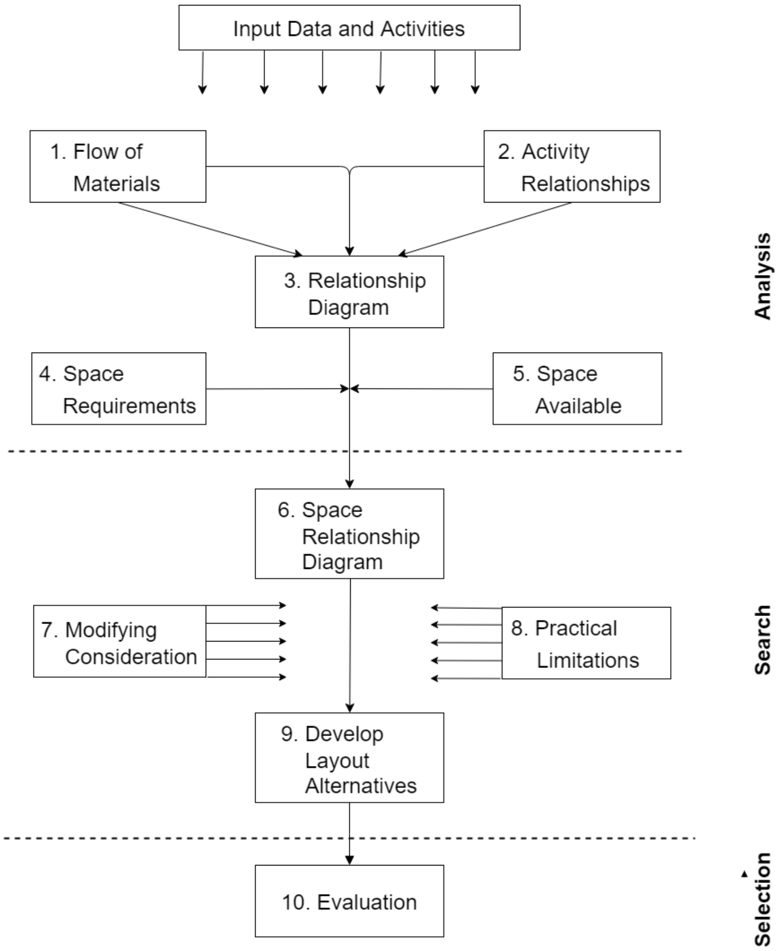


Figure 2.2 – Framework of Systematic Layout Planning [8]

Pratami et al [5] has further divided the three phases into nine steps. The first step is to define or redefine the main objectives of the layout planning. Here, apart from defining the products, the organisations will also have to take a major decision like whether they are planning to improve an existing layout or building a new one. As mentioned earlier in section 2.1, based on the main objectives regarding the layout design, the major performance keys are defined during step 1. The second step identifies and defines the primary activities (operations & material flow) and support activities that are needed to accomplish the layout objectives. The third step helps to identify the interrelationship between all the activities in the layout. Tools like Activity Relationship Chart (ARC) and Routing Sheet could be used to determine the interactions between different operations. This will also help to determine precedence between operations and thereby align the operations in such a way that helps to achieve an effective operation flow. The fourth step evaluates the current available space in the facility with the actual space requirements needed to place all the necessary equipment, machinery and personnel in the layout. Alternate layout plans are generated in the fifth step. These alternate layout plans are formulated after carefully including all the practical limitations and other major organisational considerations. In the sixth step, the alternate layout plans are thoroughly evaluated. The chosen performance factors could be used to compare between different layout plans. Several mathematical analysis techniques are also available to evaluate the layout plans. After the evaluation, in the seventh step a layout plan is selected that satisfies the organisational goals and objectives. The eighth step mainly consist of the implementation of the selected layout model. Special care should be taken at this stage to make sure that there are no deviations between the selected layout design and the actual implemented layout.

Finally, the ninth step consists of maintaining the implemented layout plan and adapting it according to the future needs. [5]

The manufacturing organisations can perform the process of layout planning, designing and implementation based on these nine steps. It is also feasible to adapt the SLP technique to achieve the particular goals of each layout project [5]. This is one major advantage with SLP technique [5]. Another advantage with the SLP technique is that it not only guides the organisations through the planning and design stage, but also helps in the implementation and maintenance stage. However, Pratami et al [5] observes that, SLP technique does not provide detailed guidance on how to plan the material handling aspects when designing different layout alternatives. This is one major drawback with SLP technique [5]. Hence, to obtain a layout design that includes all prominent activities in the factory floor, the SLP framework could be modified or combined with other techniques that provides detailed description on how to plan and organise material handling aspects [5]. The modern aspects of digital manufacturing and a virtual factory can be synchronised with the SLP technique to aid the layout planning and modelling process. Incorporating the virtual factory tools with the SLP framework will help all the stakeholders involved with the production system redesign process with a better visualisation of current factory layout and space availability. This will help in better planning and designing of layout alternatives. The remaining part of the literature study has focused on the impact of virtual factory tools on layout planning and modelling.

2.2 3D laser scanning

Today, manufacturing companies are competing against each other globally. This requires the companies to adjust their production to meet customer demands and become more cost efficient to keep the profitability margins high [9]. To be able to accomplish this, often with a limited budget, both the method and layout of the manufacturing system needs to be improved [9]. To achieve that, 3D laser scanning can be used. It has been used increasingly by companies during the last decade [10].

Today, the visualisation of the manufacturing system is usually done with a model in computer aided design (CAD) in either 2D or 3D [9]. However, using CAD models, in both 2D and 3D, have some drawbacks. In the 2D CAD Drawing, it can be hard for stakeholders who are not familiar with the manufacturing system to completely understand the situation. Since the perspective of the 2D CAD Drawing is limited to top view, details in the area and the height cannot be seen [11]. However, in a 3D CAD model both the height and other details can be seen, but it might be time consuming to include accurate and complete details [9]. If enough time is not spent on the details of the 3D CAD model, it can have the same problem as 2D, where it can be difficult for people from the outside to get a proper understanding of the manufacturing system. By using 3D laser scanning, multiple layouts can be modelled in the point cloud and compared to each other thoroughly in a realistic view. The evaluation process between layouts is faster with 3D laser scanning than using CAD models, mainly because of the realistic view 3D laser scanning gives [11]. 3D laser scanning is also increasing planning speed, planning quality and decreasing the planning cost [9]. In addition to this, 3D laser scanning gives the possibility to show a realistic visualisation of the layout proposal for different stakeholders e.g. production technicians and workers' union representatives [11].

2.2.1 Scanning procedure

3D laser scanning is a technology where spatial data is collected of the surrounding objects to create a point cloud [12]. The scanner is collecting spatial data by sending a laser beam, in 360 degrees horizontally and from 300 to 320 degrees vertically, which is reflected on the objects [13]. This is illustrated in figure 2.3. To measure the distance between the 3D laser scanner and the objects two different techniques are being used, phase shift and time of flight [12]. Phase shift is emitting the laser beam with three waveforms. How each of the waveforms have shifted when they are registered after being reflected is used for measuring the distance.

Time of flight is instead emitting the laser beam as a pulse. When the laser beam has been reflected and registered by the sensor, the time it took for the laser beam pulse to return is used for calculating the distance to the objects [10], [12], [14].

Figure 2.3 – A 3D laser scanner's field of view [13]

During one scan the laser beam reflections are creating a data set of millions of spatial points [13] [14] [15]. The collected data points can be coloured from merging the data set with photos taken from a built-in camera [14]. By merging several scans, they become one big point cloud. To be able to merge scans, the data sets need to overlap each other. In order to overlap with good precision a reference object is needed in the overlap [13] [14].

The reference object will help to adjust the coordinates in the spheres to build one big point cloud with correct connection between the data sets [14]. To make it easier to merge multiple scan areas, reference objects can be placed in the area. It is important that these objects are at the same position during the scans [10], as they will be used for merging the data sets in correct positions. A typical reference object is a white sphere or a checker board. These objects are having good reflective surface which helps to create a pattern of the laser beams that is recognisable when handling the point cloud data [12].

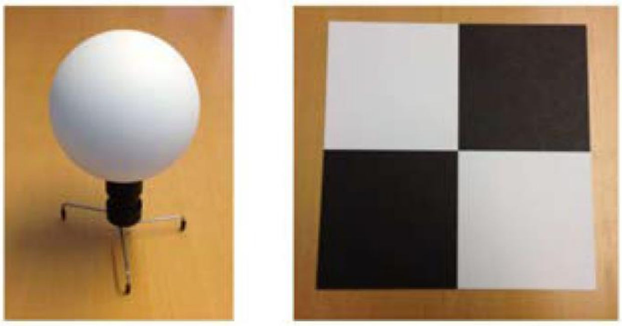


Figure 2.4 – Reference objects used in 3D laser scanning, left: Sphere, right: Checker board [12]

However, to get all the details in the scanned area and as little noise (disturbances) in the data as possible, the scan area should be free from motion. This often requires the production to be standing still during the scanning period. If the production system is active during the whole day it can require the production to be halted during the scan process. This could increase the overall manufacturing costs [12].

2.2.2 Benefits and drawbacks

By using 3D laser scanning as a visualisation and documentation tool, instead of CAD models, some advantages are gained. By having a point cloud from 3D laser scanning, the visualisation is realistic as the model includes all details. This makes it easier for stakeholders to understand and discuss around the model. Hence, it saves time in explaining the situation. This also simplifies to include different departments and managers to the discussion about future plans. Furthermore, 3D visualisation could work as a tool when analysing ergonomic aspects [13], [15]. Another good thing with 3D laser scanning is that, the point cloud is detailed enough for taking measurements in the area and use that information for move around objects. This can be done by mark the objects and drag them to a specific position. This can be used for testing different ideas and do not take as much time if similar actions were to be tested in a CAD model [13].

In general, the company will get a better understanding of the current shop floor, what limitation and possibilities there are. As an advantage, by having a realistic visualisation model from 3D laser scanning makes it unnecessary to visit the shop floor in the same degree as before. The planning and testing of new ideas can be done virtually [15]. As 3D laser scanning enables changes to be tested virtually, quicker than other virtual tools, it saves time and money in that aspect [13].

Another benefit of having the facility 3D laser scanned is the possibility of controlling the current drawings. It is not unusual for the 2D drawings to have faults, misplaced pillars and measurements, which could lead to costly mistakes if not found before doing changes to the system [13]. All the above benefits could save the company money in the long term as ideas and future plans can be tested virtually instead of being tested in real-time [11] [13].

A drawback of 3D laser scanning is that, it is hard to estimate the economic gain from using it. As it is difficult to see how much decrease in costs the use of 3D laser scanning will give in the end [13]. Another drawback is that the process of visualise the 3D laser scan can time-consuming as it requires much attention [11]. This time and resources could be spent on something more valuable. There is also a risk that the company does not use the created visualisation at all, the whole process would mean a costly investment without payback [11].

Also, to considered when using a 3D laser scanner, is that the cost could be more than just the investments in scanning equipment and the cost for someone to perform the scan and handling the data. As have been explained before, the scanning area requires to be free from motions to get good data. This may force the production to be halted during the scanning procedure which costs money, more or less, depending on the situation [12].

3 Methodology

The thesis project is divided into two steps. The main activities in each step and how they are performed is mentioned in this section. All the methods and tools used in different steps for achieving the thesis project results are also described in this section.

3.1 Literature study

The first step in the master thesis was the literature study. The main objective of the literature study was to gather knowledge regarding how to perform production system redesign. The literature was also used to find the most suitable techniques that could be utilised for the proper documentation and visualisation of the results. The literature study was conducted based on 15 scientific articles. The scientific articles were searched from sources like Web of Science, Scopus, IEEE Xplore, Science Direct and Chalmers library. The main keywords that were used for the article search are ‘Layout Planning AND Production’, ‘Production System AND Redesign’, ‘3D Laser Scanning AND Production Systems’, ‘3D Laser Scanning’ etc.

Based on the information gathered from the literature study, Systematic Layout Planning was identified as a suitable methodology for production system redesign. 3D Laser scanning was identified as a suitable technique for proper visualisation and presentation of the project results. The results from literature study are provided in Chapter 2. The next step consists of new layout planning and modelling using the Systematic Layout Planning framework.

3.2 Layout planning and designing

The layout planning, designing and modelling process was done with the help of SLP methodology. As mentioned earlier, in section 2.1.2, the main SLP framework consists of three major phases. The three major phases are further divided into nine steps to make the layout planning and designing process more efficient. The project activities are carried out based on the nine steps. Figure 3.1 shows the modified SLP framework with the nine steps.

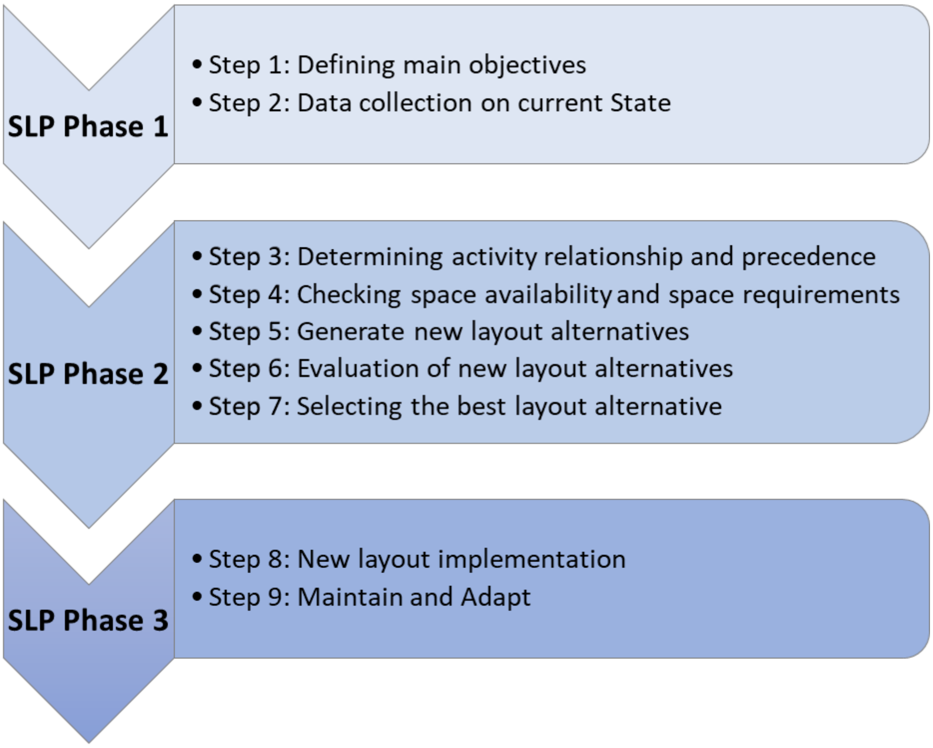


Figure 3.1 – Modified Systematic Layout Planning framework

3.2.1 SLP Phase 1

The first phase of SLP framework was performed in two steps.

Step 1 – Defining main objectives

During the first step, the main organisational objectives behind the production system redesign process were identified. The major objectives were identified based on the discussions with the project supervisor at Volvo Cars.

Step 2 – Data collection on current state; Current state mapping

In the second step, a detailed study was conducted to understand the existing layout. The current state study collected data regarding all the operations, the current production flow, number of operators, offline and online material storage locations and material flow. The information regarding the operations from the ML line and UM was collected mainly from Volvo Cars Operations Toolbox platform. The platform provided data regarding the station length, takt time, station time in TMUs and number of operators at each station. The same data regarding the CAL line and Gummibandet (GB) was collected through interviews with team leaders and factory floor visits. One team leader from Gummibandet and one from CAL line was interviewed. All the gathered data and information was consolidated in Excel sheets.

Many repair activities are conducted based on the quality checks at Rullarna, Short Track, Gummibandet and CAL line. The car models having faults are taken out of the production flow, repaired at service stations and added back to the production line at different stages. The information regarding the repair flow patterns, service station locations and the re-entry points to the production line was collected through factory visits and were consolidated on excel sheets. Apart from that, the information regarding the material flow, material storage and logistics were obtained mainly through factory floor visits. While gathering information regarding material storage, importance was given to details like the different type of part items stored, storage material type (pallets or boxes), pallet type, number of pallets, online storage location (kept close to the production line for easy access during assembly), offline storage location (kept at a particular location in the factory floor for easy reimbursement to online storage locations). Apart from that, the interviews with team leaders and the factory floor visits also helped to gather information regarding safety and ergonomic concerns. The first and the second step together completes the first main phase of the SLP framework.

3.2.2 SLP Phase 2

The second phase of SLP framework was performed in five steps. The evaluation of the current state and the existing factory layout was done in step 3 and step 4. The design and development of layout alternatives was done in step 6. The evaluation of the designed alternatives was done in step 7. Finally, the selection and presentation of the best alternative was done in step 8.

Step 3 – Determining activity relationship and precedence

In the third step, the current layout is evaluated based on the information collected during the first two steps. The interrelationship between different operations at the factory floor was analysed. A precedence diagram was formulated. The precedence diagram is provided in Appendix A. The total length and space required to fit all the required operations was calculated based on the data obtained from the current state study. Each operation's corresponding station length was obtained through team leader interviews, factory visits and also from Volvo Cars Operations Toolbox platform, was used for the calculation of total length and space required for all operations.

Step 4 – Checking space availability and space requirements

To move the operations from the current ML and UM line upstream, the space availability in the upstream production area had to be analysed. In the fourth step, to analyse the space availability in the factory floor, the 2D CAD Drawing of the TC factory was used. The 2D CAD drawing was obtained from Volvo Cars Operations Toolbox platform. Before using the 2D CAD drawing to identify and measure the space requirements needed for production system redesign, the 2D CAD drawing has to be verified with the actual conditions in the production floor. This type of verification and validation are necessary to understand whether there is any difference between the details mentioned in the 2D CAD Drawing and the actual production floor. If there is mismatch, then it will affect the production system redesign process. For example: if the position of a pillar in the actual production floor is different from the position mentioned in the 2D CAD Drawing, it will cause problems while implementing the new layout design in the factory floor. Therefore, early verification will help to eliminate such undesired expenses during the implementation phase of the new layout design. Hence, 3D Laser Scanning was used for the verification and validation of the 2D CAD Drawing.

3D Laser Scanning

The 3D laser scanning was performed with a laser called FARO Laser Scanner Focus^{3D} which was borrowed from Chalmers. Before starting with the scanning, the interesting area was scouted to see, where the possible scanning points could be and where to place reference markers. Since the scanning was performed during an active shift, it was important to see how the movements of cars and workers was in the scan area. The areas with most movements was scanned during lunch break to get as little disturbances as possible in the scan data.

The reference markers that were used was reflecting spheres, see Figure 2.4. They were placed in positions where they could be seen by the scanner in at least two different scanning positions. The aim was to have three reference markers in the overlap between two scans to get a high precision during the merging of the scans later. After the reference markers were fixed, the scanning of the area was performed.

The scanner was set to proper settings to catch enough details in the environment. The scanning positions were chosen to get all the production area captured from different angles. Each scan took about five to seven minutes and collected 30-40 million of points of data. The number of scans needed to cover the whole area was 24. If the overlap between two scans had duplicate of data points, they were eliminated by Faro's data management software, called SCENE.

The 24 scans were imported to SCENE, were the scanned data was collected and managed. In this software, the scans were merged, from 24 individual scans into a single point cloud. To merge the scans into a single point cloud, each scan's coordinate system was adjusted to become one global coordinate system. To make the fitting of the scans precise the reference markers was controlled in the software as well. When this was completed the single file was exported to another software called Autodesk Recap.

In Autodesk Recap, the point cloud's noise, from workers and cars who moved in front of the scanner during the scanning could be removed. Also, unnecessary data in the point cloud, like areas which was not a part of the thesis scope, unwanted objects and unnecessary details were removed. By removing both noise and redundant data, the point cloud became cleaner and easier to work with. In addition, the file size got smaller which made it easier to handle. Before exporting the file to Autodesk Navisworks, the point cloud was split into two parts, one with the ceiling and one with the walls and the floor. This could be used for giving a better view from above as the ceiling part could be kept hidden when reviewing options. To be able to use the point cloud with 2D and 3D CAD models simultaneously, the point cloud was exported to

Autodesk Navisworks manage 2018 with rsc-format, as this software can append multiple data-files.

Control of 2D CAD drawing

To check the accuracy of the 2D CAD Drawing over the production area, Volvo Cars is having today, both the point cloud and 2D CAD Drawing of the current state was opened together in Autodesk Navisworks manage 2018. This showed the differences between the 2D CAD Drawing and the point cloud. The different areas that was compared was picked randomly over fixed objects, walls and pillars, in the whole area to minimise random differences.

The verification between the point cloud and the 2D CAD Drawing proved that differences between the 2D CAD Drawing and the actual production area were very low. Therefore, the 2D CAD Drawing was used to analyse and determine the space availability in the current factory floor. The software, Autodesk AutoCAD 2018, was used for the analysis of the current state. The reason for picking this software was because Volvo Cars is using it today.

Step 5 – Generate new layout alternatives

In step 5, different layout alternatives were developed. In the early state, brainstorming was the main activity. The inputs from current state analysis was utilised to frame different layout ideas. The weekly meetings at Volvo Cars provided information regarding the major organisational considerations and about current practical limitations in the factory. This resulted in limiting the different ideas down to three different layout alternatives. These three layouts were created in Autodesk AutoCAD 2018.

Step 6 – Evaluation of new layout alternatives

The sixth step corresponds to the evaluation of the three layout alternatives developed. The layout alternatives were compared based on key performance factors (KPF's). Initially twelve KPF's were formulated based on the reflections from the information gathered during the weekly meetings and the literature study. Out of the twelve, six performance factors were finalised with the help of Volvo Cars for layout comparison. The details about the KPF's are provided in Appendix B.

The 'Evaluation matrix', see section 5.3, was used for the layout comparison process. Each KPF was weighted on a scale from 1 to 5 based on their significance in the production system redesign process. Here, the score of 1 indicates the lowest value and the score of 5 indicates the highest value. The individual weightage was assigned by the supervisor from Volvo Cars. Then each layout alternative was rated against each other based on these six performance factors with a score of 1, 2 or 3. For a particular performance factor, the best layout alternative is given a score of 3. The second best is given a score of 2 and the least suitable one is given a score of 1. The scores were allocated for all layout alternatives in the evaluation matrix based on the above criteria.

Another matrix was used to calculate the total score for each layout alternative. Initially, for each layout alternative, the individual score obtained for a particular performance factor was multiplied with the respective performance factor weightage value assigned by Volvo representative. For each layout alternative, the obtained score was defined as the weighted score for that particular performance factor. The same was repeated for all performance factors. After that, to calculate the overall score obtained by each layout alternative, all the weighted scores were summed up. It is provided in section 5.3.

Step 7 – Selecting the best layout alternative

Based on the scores obtained from step 6, the highest scored alternative was selected. The 2D layout drawing that was scored to be the most suitable layout, was to be shown as a 3D model, see section 5.4.

3D CAD model

To build the 3D CAD model, the point cloud was adjusted in Autodesk Recap. Data points that was blocking the new lines and building extension were removed. After the file were adjusted for that, it was transferred to Autodesk Navisworks manage 2018, as this software could handle 3D CAD objects to be inserted to the point cloud. The 3D CAD objects represent extension of the building, two new lines and car lifts.

The 3D CAD objects was created in CATIA. The size, width and length, of the objects was collected from Volvo Cars 2D CAD drawing of the production area. However, the height is not shown there. Therefore, the height of the objects was decided from measuring the objects in the factory or from discussions with Volvo Cars. To complete the 3D CAD model, the finished CAD objects was imported to the point cloud as CAT files. The objects were placed in correct position in the 3D CAD model by measuring the distance between the objects and points in the 2D CAD drawing.

3.2.3 SLP Phase 3

The third and the last phase of the adopted SLP framework consists of two steps. The eighth step corresponds to the implementation of the selected layout design at Volvo TC factory. The ninth step consists of the maintenance of the new production layout and adaptation of the new layout according to future needs. The activities related to the implementation of the best alternative selected is not included in the scope of this thesis project. The implementation will be done by Volvo Cars later in the future. Therefore, SLP framework phase 3 is not part of the thesis project.

4 Current state mapping

In this chapter, the current state of the final production flow is described. How the production flow in the final area is, what stations the cars go through, what operations each station is performing on the cars, what material is added to the cars and how the material is stored in the production area are mentioned in this section. It also includes information of the adjustment areas and where they are placed.

4.1 The final production flow description

The final flow of TC-factory in Torslanda is shown in Figure 4.1, where the station areas are marked with boxes. The final flow starts where the cars are moved onto 1-8 line where several controls are performed, mostly about finding and adjusting unwanted gaps on the body of the car. After 1-8 line the cars moves to Toe-in station for adjusting the wheels to correct angles. However, if a car has the feature to change ground clearance, the car should go through a height control before it goes to Toe-in station. After Toe-in station the car's radar and cameras are checked in a station called Fas. Then it is moved to the Roller station and then being driven through the Shorttrack and up to Gummibandet. From Gummibandet, it goes to CAL-line and if it passes the control checks it moves to a transport line where the Tejp-dekorlist is performed. From here, the car is moved to another transport line which takes the car to a lift. When the car is raised, the car goes over the area called Dance-floor, where the car can be operated from underneath. The lift puts the car down on the ML-line which is the final line of the final flow and from here it is driven out to the yard to get distributed to its buyer.

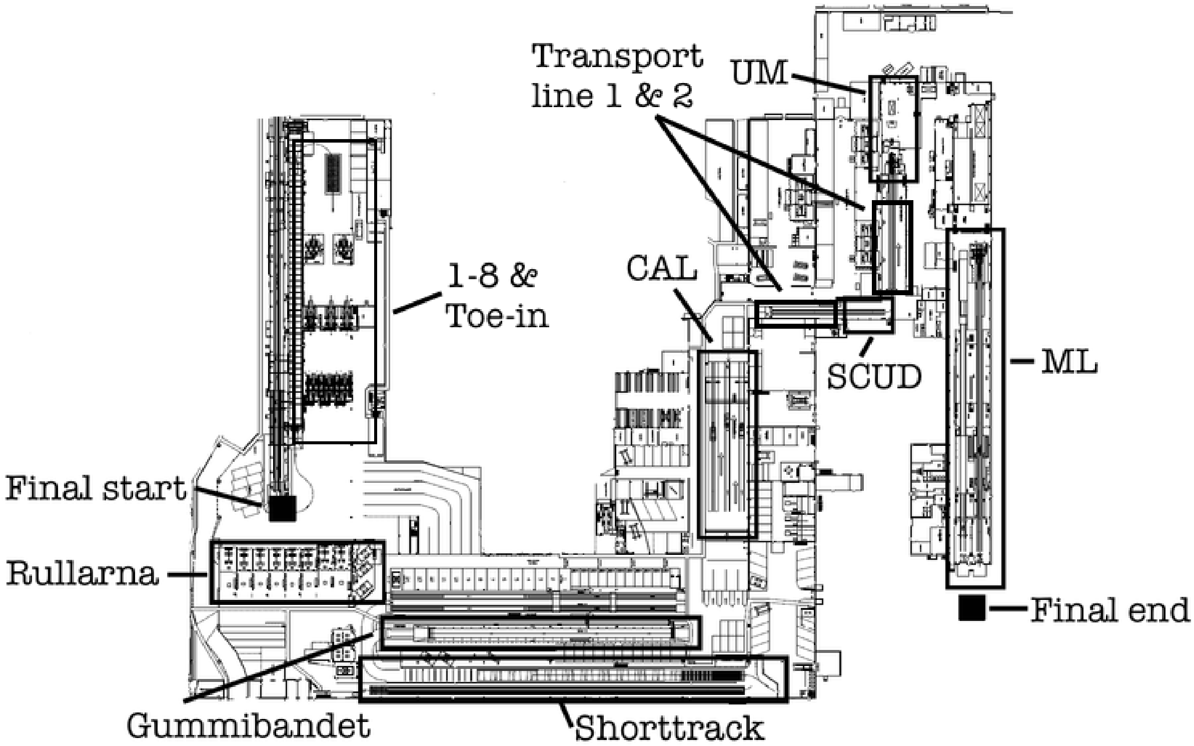


Figure 4.1 – Final production flow

4.2 Station description

In this section is the stations which are relevant in this master's thesis described. The mentioned details of each station are of importance when creating the new layouts, as all of operations in the current state should be fitted in the future layouts.

4.2.1 Rullarna

In this station the car is tested in an isolated area (booth), where it is driven on rollers, see Figure 4.2. The eight booths where the cars are tested is shown in the top of the picture.

The car is tested through a program with acceleration and brake tests. Here, for the first time the car gets enough time to get warm to create pressure inside the engine. Therefore, the engine room is checked for leakages afterwards. If there are no problems found the car moves to Shorttrack. However, if there is a fault the car can be taken out of the flow to be adjusted. Since this test exceeds the takt time, there is eighth parallel booths in order to manage this. The total number of operators is ten. The extra two operators are added to manage the time taken for driving the car on the short track and also the walk back from leaving the car at Gummibandet.

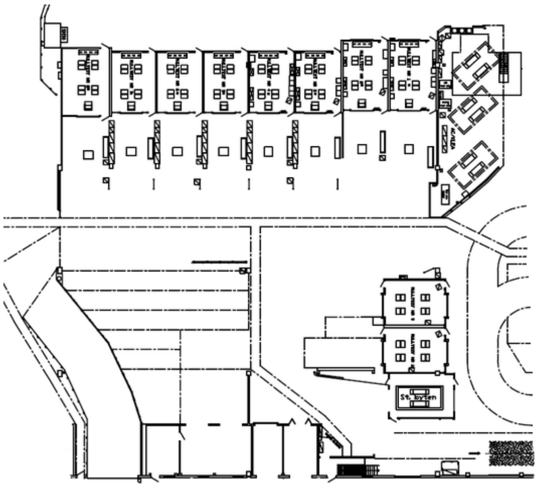


Figure 4.2 – Rullarna station

4.2.2 Shorttrack

The Shorttrack, see Figure 4.3, is managed by the same set of operators who work at the Rullarna. Shorttrack is a test-track where the car is driven over obstacles with changing pattern to create different vibrations. By doing this the operator will detect if something sounds wrong. After the Shorttrack station, the car can either be taken to the next line, Gummibandet, or be taken out of the flow for adjustments. For safety reasons, the Shorttrack have a time-restriction of adding cars to close to each other.

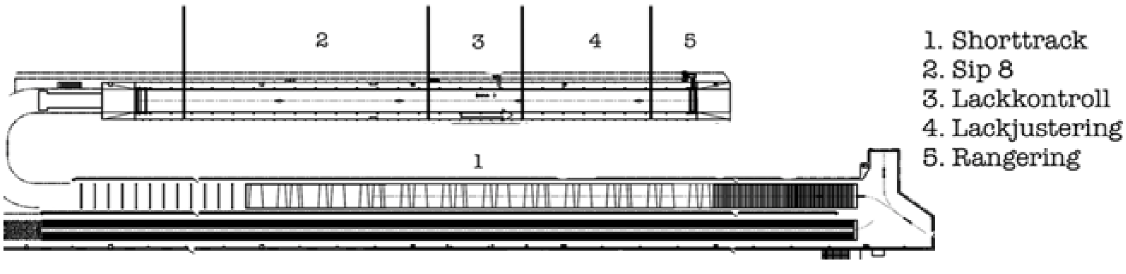


Figure 4.3 – Shorttrack and Gummibandet

4.2.3 Gummibandet

On Gummibandet there are three teams working: SIP 8, TB-paint and UM. The stations which they control are separated with lines in Figure 4.3.

The SIP 8 team is doing a factory control of both the exterior and interior. The station requires a length of five car length and five operators. After this station, the TB-paint team takes over and performs exterior control and adjustments of the varnish. To do this the team have two stations. The first station is called Lackkontroll, which requires two car lengths and four operators. Here, the operators search the cars' varnish for faults. The second station is called Lackjustering, at this station the identified faults are adjusted. This station requires one operator over three car lengths. If the faults are too complex or time consuming the fault is marked to be fixed, off the line in an adjustment area. After this, the UM team takes over at a station called Rangering. Here, the car gets a cover for the interior of the driver's door and also the plastic protections of the rear bumper are removed. After that, the operator drives the car to the CAL-line or if the car has a fault it can be taken to adjustment area.

4.2.4 CAL-line

The CAL-line is the second visual control of the car. Here, the operators check the cars from a customer perspective. The CAL-line is having two parallel lines with the same stations on each line, see Figure 4.4. The third line on CAL-line is a buffer of cars with varnish fault. The first station is called Fokus. It is performed over one car length on each line and it is two operators needed, one on each line. The next station is CAL-station which requires five operators, two operators on each line and one going between the lines. The station needs two and a half car length. After that the car comes to a station called Repair confirmation where the found faults could be fixed. The complexity of the faults decides whether the fault can be fixed on the line or if it needs to be taken to adjustment area. CAL-line also have an extra check for cars that should be delivered to Japan, this is performed by the operator at Repair conformation. There is one operator on this station and the operator has one car length on each line.

The last station is called Matarn and is performed by one operator over one car length on each line. The operators are driving the cars from CAL-line to the transport line into ML building. However, before they drive off CAL-line they place a transport decal and remove plastic protections on the front bumper.

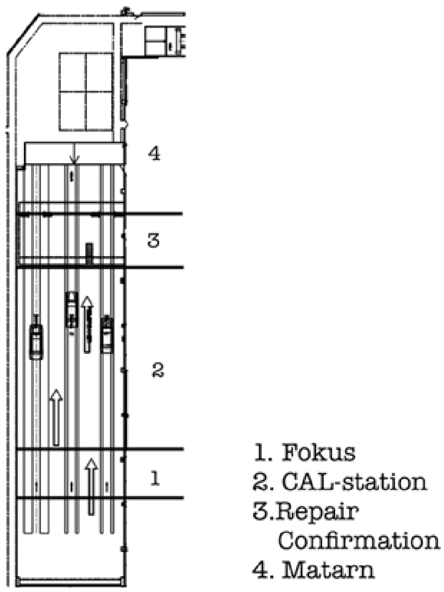


Figure 4.4 – Customer Acceptance Line (CAL)

4.2.5 Transport line 1

This transport line 1, see Figure 4.5, is seven car lengths long. However, there is only one car length being used from a station called Tejp-dekorlist. This station is placed here temporary, it requires one operator, where the work task is to remove the protective tape from the decor panels in the car. The removal of the tape is only performed on decor panels made of metal. All XC60 cars are excluded from this operation. This causes the station to have some waiting periods, as all cars do not have tape to remove. At the end of this line the car is moved to another transport line, the station which moves the car is called SCUD and is performed by one operator.

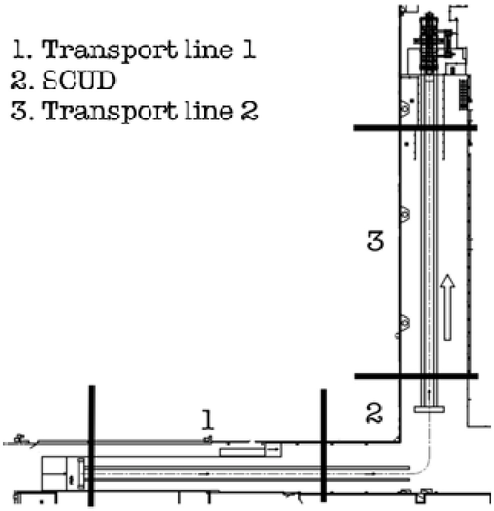


Figure 4.5 – Transport line 1 and Transport line 2

4.2.6 Transport line 2

This line is a transport line to the lift, see Figure 4.5, it is seven car lengths long. It has a higher takt time than other lines and works as a small buffer. However, suppliers to Volvo Cars is using this line to do quality controls of their products in the car. Their presence is not mandatory to consider in future layouts as they are not part of Volvo' production system.

4.2.7 UM

Here, the lift raises the car above the operators' head, to be able to do some operations from underneath the car. There are three stations which requires the car to be lifted. The three stations where the operator works from underneath is shown in Figure 4.6. The lift can be seen in the middle of the figure.

The first one is called CD-plåt, here the car gets a protective sheet assembled under the engine. To do this, the operator load a robot with ten screws and one protection sheet. The next station is called Expander, this station has two tasks. The first task is supervising whether all screws are fastened correctly. If the screws are missing or loose the operator fix this with a screwdriver. The second task is to put two expanders in each front wheel of the car, this will increase the height of the body. This is required when driving the car up on the transport lorry. The number of cars with requiring expanders is fluctuate between 2% up to 5% depending on the season. The last station is Underupp where the car is checked underneath by viewing. After this, the lifted cars are transported to ML-line, through twelve car lengths with no value-added operations.

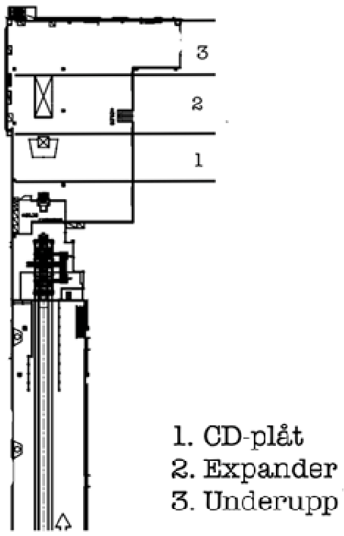


Figure 4.6 – Underredsmassa (UM line)

4.2.8 ML

The car is put down on ML-line from the lift. The ML-line have eight different stations spread out on the line. There is one car length of transport on this line, see Figure 4.7. The first station is Huvcover, the car gets a plastic protective sheet on the hood. This is performed by two operators over one car length. The second station is called Factory Health Check (FHC) and here the car's electrical system gets a control check. Another operator is putting on a wrap guard on the door next to the driver's door to protect it from getting scratches. In the same station, the operators are also mounting transport hooks on the car if needed, in the front and one in the rear. In the same area of FHC there is robot which will help the operator to lift a spare wheel into the car. This is only done on a very small part of the cars, no statistics on how many percentage, but requires the line to stop for two minutes. Since it is so seldom a car need this spare wheel there is no separate operator on this balance. The third station is Dörrsprut, here the operator applies wax inside the door to protect it. The operator is also putting on a protective part under the chassis called "damping patch" or "lifting bracket" depending on which model it is. At this station it is one operator at each side of the car and they work over one car length.

For ergonomic reasons the working platform is lowered to 110 centimetres below ground level. This helps the operator to get a better access to the work task. After Dörrsprut, the car arrives at SA-station and here the car gets confirmed for being acceptable for delivery. The operator is also checking whether any previous tasks that have to be done is pending or not, like adding the transport hooks. This is performed by one operator over one car length. The next three stations are to put on a plastic cover to the whole car. This is done by six operators and the operators are divided equally into three stations. In the first station, the operators place the cover over the car body and fasten it in the front and the rear. In the second station, the operators fasten the cover from underneath on both sides of the car. In the third station, the operators fix the cover on to the windshield and also fasten the cover on the driver's door. To completely cover the car, it requires six car lengths. Over these three stations the height of the working platform is adjusted for ergonomic reasons.

The first station is on ground level, but to be able to reach under the car on the second station the working platform is lowered to 110 centimetres below ground level. In the third station it is raised to 55 centimetres above ground level for the operator to reach the top of the front window and the working platform is lowered to ground level over this station. The last station, number eight, is Utkörning. Here, the operator drives the car off ML-line out to the yard for getting transported to its destination. It is done by three operators over two car lengths.

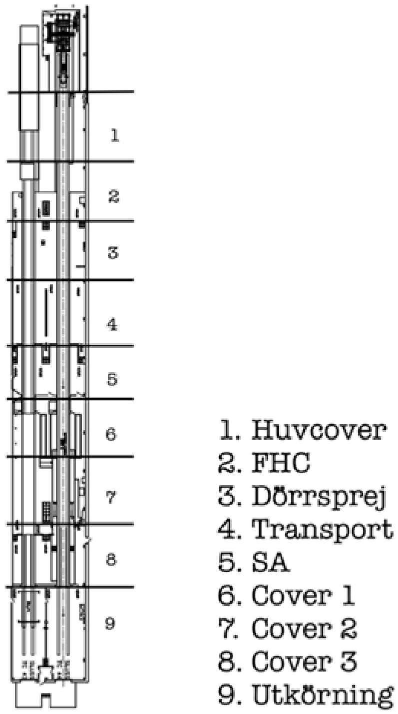


Figure 4.7 – ML line

4.3 Balancing of current state

The balancing of all operations in current production flow is given below in Table 4.1.

Table 4.1 – Balancing of current state

Line	Station	Car length	No. of operators
-	Rullarna	-	10
	Shorttrack	-	
Gummibandet	SIP 8	5	5
	Lackkontroll	2	4
	Lackjustering	3	1
	Rangering	1.5	3
CAL – both lines included	Fokus	2	2
	CAL station	5	5
	Repair Confirmation	2	1
	Matarn	2	2
Transport	Tejp-dekorlist	1	1
	Scud	1	1
UM	CD-plåt	1	1
	Expander	1	1
	Underupp	1	1
ML	Huvcover	1	2
	FHC	2	2
	Dörrsprut	1	2
	SA	1	1
	Cover 1	2	2
	Cover 2	2	2
	Cover 3	2	2
	Utkörning	2	3

4.4 Material storage & material flow

The material needed in the final flow is today stored at a stock point outside of UM. From this stock point, the material is brought into different stations which adds material to the car. Each of these stations have a local storage area close to the working area. The amount of material stored at the stations is dependent on the need and available space. It is the logistics operators who feed the material to the stock point and from that area the material is brought to the UM and ML stations with a local material handler. The space allocated for material storage in the current layout is shown in Figure 4.8.

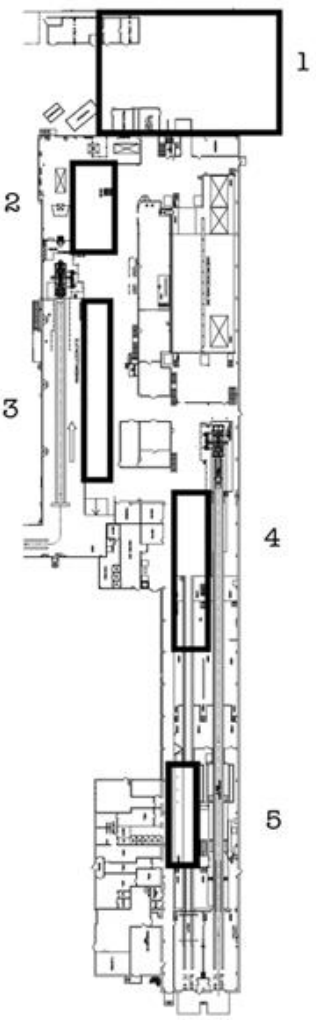


Figure 4.8 - Material storage areas

4.4.1 Material Storage at UM and ML

At UM, the material addition is taking place at the operations CD-plåt and Expander. UM storage area is indicated as number 2 in Figure 4.8. At CD-plåt station, plates and screws are needed to do the operation. Full size pallets are used for the storage of plates. Two full size pallets are kept at the storage place near the station. This is to provide easy access of material to the operators at the station. Apart from that, seven full size pallets containing material are kept slightly away from the station for easy replenishment whenever necessary. Half size pallets are used for the storage of screws. One half size pallet is kept at the storage place near the station. One more half size pallet is kept slightly away from the station for easy replenishment whenever necessary. At the Expander station, expander material is presented to the operators in small boxes with the help of storage racks. Two boxes are kept on either side of the station for easy access to the material. One full size pallet containing expander material is kept a few metres away from the station for easy replenishment whenever necessary.

At ML, material addition takes place at almost all operations. ML area is indicated as number 4 and 5 in Figure 4.8. All the required materials are stored in different areas like number 3, 4 and 5 as indicated in Figure 4.8. The first operation is Huvcover and the material needed for this operation is stored in three full size pallets at the storage place near the station. Apart from that, another six full size pallets containing the material is stored in the area, indicated as number 3 in Figure 4.8 for easy replenishment. After the Huvcover operation, the next station includes operations like FHC, wrapguard and transport hooks. For some car models there are also rails and a spare tyre added. The FHC operation does not contain any material addition. For the next operation, wrapguard material is presented to the operators on wrapguard holders for easy access. There are two wrapguard holders at the station, one on each side. One full size pallet is kept near the station itself for easy replenishment in the area, indicated as number 4 in Figure 4.8. In the case of transport hooks, one full size pallet is kept at the storage place in the station for easy access to the material. One full size pallet is kept in the area, indicated as number 3 in Figure 4.8 for easy replenishment. Similarly, one full size pallet of rails is kept at the storage place in the station for easy access to the material. One full size pallet is kept in the area, indicated as number 3 in Figure 4.8, for easy replenishment. For the spare tire operation, one pallet containing two tyres is kept at the storage place near the station. Apart from that, one full size pallet containing spare tire covers and one full size pallet containing wheel string is kept at the storage place near the station. Then the car moves to the station Dörrsprut. Two types of materials are added in this station - damping bracket and lifting bracket. Both these materials are presented to the operators in boxes. Two boxes of damping bracket and one box of lifting bracket is kept on storage racks on either side of the station for easy access to the material. One full size pallet of Damping bracket and one full size pallet of lifting bracket is kept in the area indicated as 5 in Figure 4.8 for easy replenishment. After the Dörrsprut station, the car moves to the SA station. There is no material addition taking place at this station.

After the SA station, the cars move to the Cover stations 1, 2 and 3. All the material required is stored in the area indicated as 5 in Figure 4.8 for easy replenishment. The mounting cover material comes in different part numbers for different car models. Currently ten full size pallets containing different variants of mounting cover material is stored in the area, indicated as 5 in Figure 4.8, very close to Cover station 1 (more specifically the area in front of SA station). The operators access the material from here. In addition to that, there are another six full size pallets of cover material stored in the area indicated as 5 in Figure 4.8 for easy replenishment of stock. There are fourteen more storage spots for stocking mounting cover material in the area indicated as 5 in Figure 4.8, in addition to the six spots where the material is kept for easy replenishment today. At the last station, Utkörning there is no material addition.

Apart from this, there is also material addition taking place during operations like ‘Rangering’ and ‘Matarn’. At Rangering, the material added is door panel protection. Usually, the car itself is used as a material carrier for the door panel protections. The operator takes the material from the car for performing the operation. But as a backup, one box of door panel protection material is also kept at the storage rack near the station. Two boxes of door panel protection material are kept in the area indicated as 3 in Figure 4.8 for replenishment whenever required. At Matarn, the material added is one of two decals, Trdek or Lågch. The two items are presented as rolls (one roll each) in storage racks at the station. The operator takes the material from the rolls for performing the operation. Two boxes each of decal Trdek and decal

Lågch material are kept in the area indicated as 3 in Figure 4.8 for replenishment whenever required. At the transport line, where Tejp-dekorlist station is, one roll each of decal Trdek and Lågch material is kept in a storage rack. This is kept as back up to make sure that the material addition is carried out at the end of Tejp-dekorlist station, in case the adding of decal Trdek or Lågch material does not happen at Matarn.

4.5 Adjustments areas

In the current production layout, the car has the possibility to be taken off the production flow to be adjusted and then brought on the production line again. These areas are located in the flow as before and after Shorttrack, after Gummibandet and after CAL line. Depending on what type of adjustment the car requires, it is brought to different areas. The adjustments areas are presented in Figure 4.9.

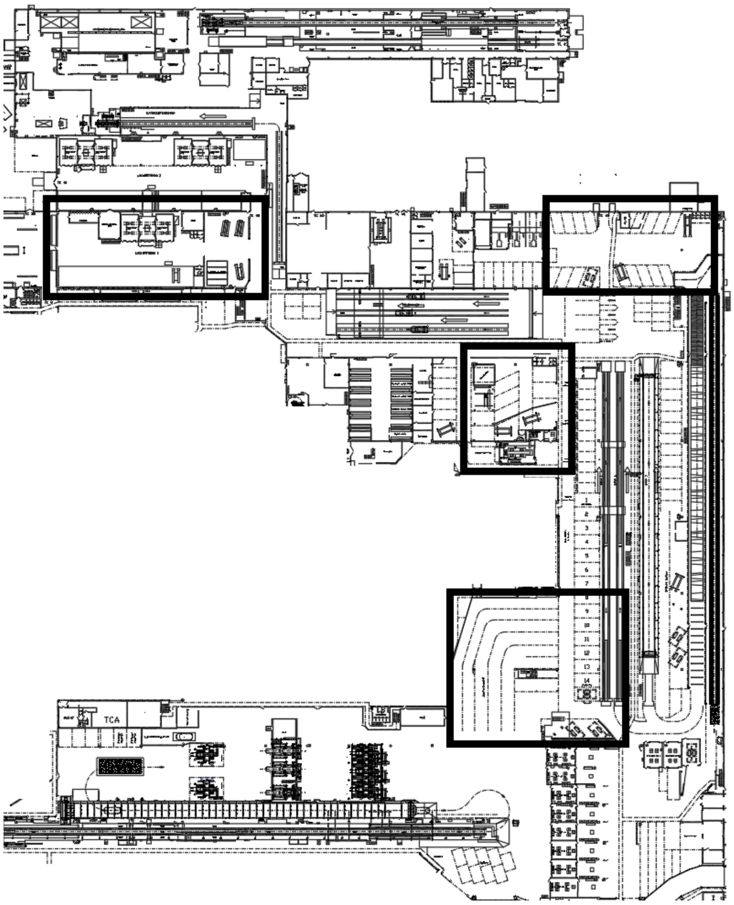


Figure 4.9 – Adjustment areas

5 Results

In this chapter, the results from the thesis project are provided. In the first section is the 2D CAD drawing checked. In the second section is three different layouts presented with details about production flow, balancing, material flow and storage, material handling and the dimensions of the lines and extension to the building. Each layout is graded with different KPFs which is used to compare the layouts in the third section. In section four, is the layout with best score presented as a 3D CAD model.

5.1 Comparison between 2D CAD drawing and point cloud

To ensure that the 2D CAD drawing could be used for designing the new layout, its details needed to be controlled. It is essential to check whether the fixated pillars, walls and production lines are in same location both in the 2D drawing and in the factory or in other words how much the 2D drawing reflects the reality. This was important to answer before moving on with the layout designing.

The result from merging the 2D CAD drawing and the point cloud from 3D laser scanning showed that the 2D CAD drawing reflects the reality well and the details in the drawing are in the right place. The control measurements were taken in five places over the production area. The five measurements showed differences of 52 mm, 49 mm, 36 mm, 108 mm and 25 mm. The exact positions were the measurements are taken can be seen in Figure 5.1.

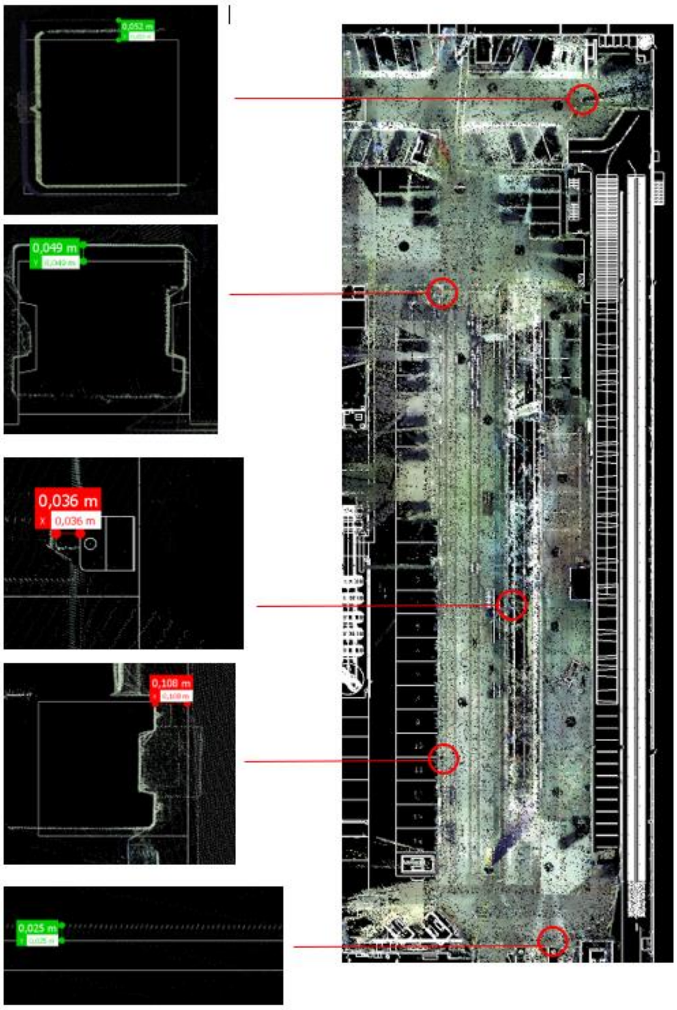


Figure 5.1 – Comparison between 2D CAD drawing and point cloud

5.2 Layout proposals

From the current state analysis and received feedback from Volvo Cars, three different layouts are presented below. All of them are having a straight flow which was one of the goals of this thesis. However, they all requires an extension to the factory building.

To be able to compare the layout proposals with each other, each layout is graded with the help of six KPFs. The six KPFs are:

- Required operators
- Flexibility
- Number of operations moved to other lines
- Production area utilisation
- Buffer
- Future expansion

Each KPF is explained in detail in Appendix B.

The three layouts are all going through today's electrical adjustment area. The electrical adjustment area is shown in Figure 5.2 marked with a dashed square. This area is moved to Hockeyrinken instead, black square. To have enough space for this will Hockeyrinken add more parking spaces in the recycling area, dotted square, which is placed inside of Hockeyrinken today. The recycling area is moved elsewhere in the factory. It is also required to remove Rullarna booth 9 and 10 to get the space to have the new UM line in layout 1. In the current production layout, booth 9 and 10 of Rullarna are backup booths for cars that needs to be tested again. So, in layout 1 when a car needs to be tested again in Rullarna, the car needs to use one of the Rullarna booths (1-8) in the production flow.

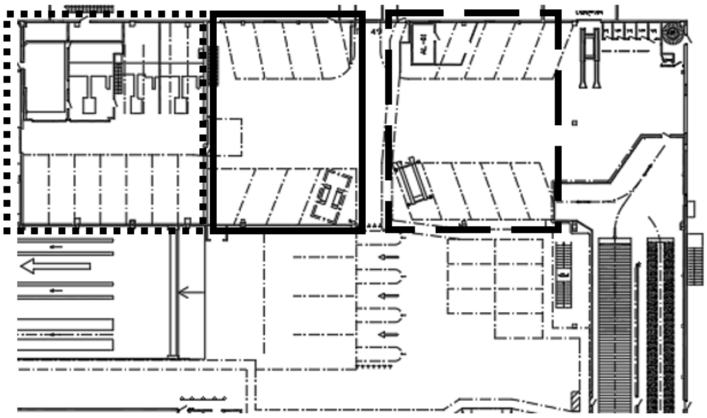


Figure 5.2 – Hockeyrinken changes

5.2.1 Layout 1

In layout 1, the production flow is made into a straight flow, from Shorttrack to the delivery yard, as requested from Volvo Cars. To have all the required operations in a straight flow, four new lines are designed in layout 1. To accommodate the new lines, the current factory building needs to be extended. Layout 1 is represented in Figure 5.3.

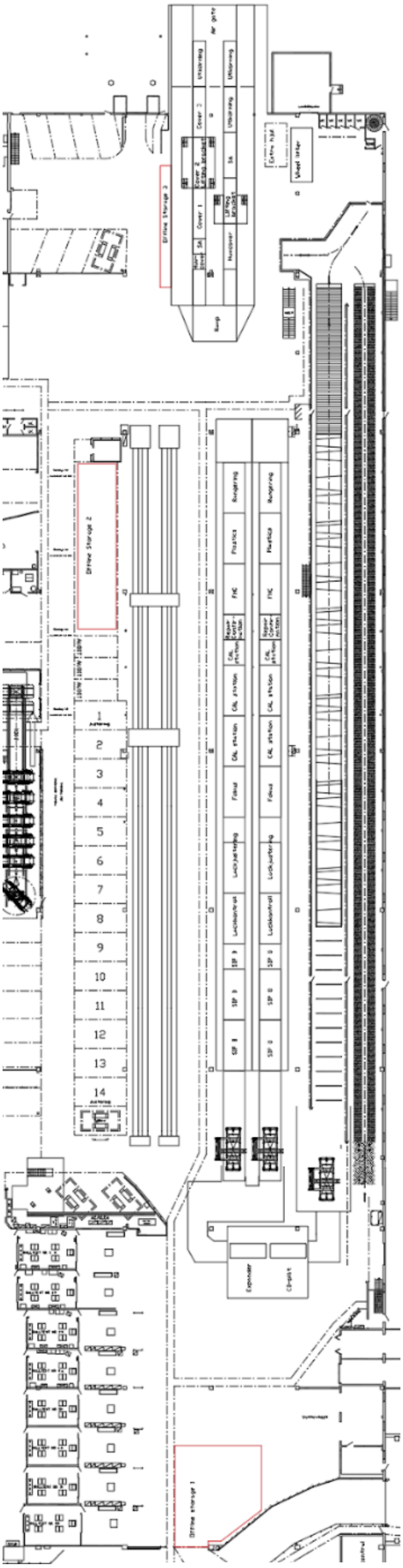


Figure 5.3 – Layout 1

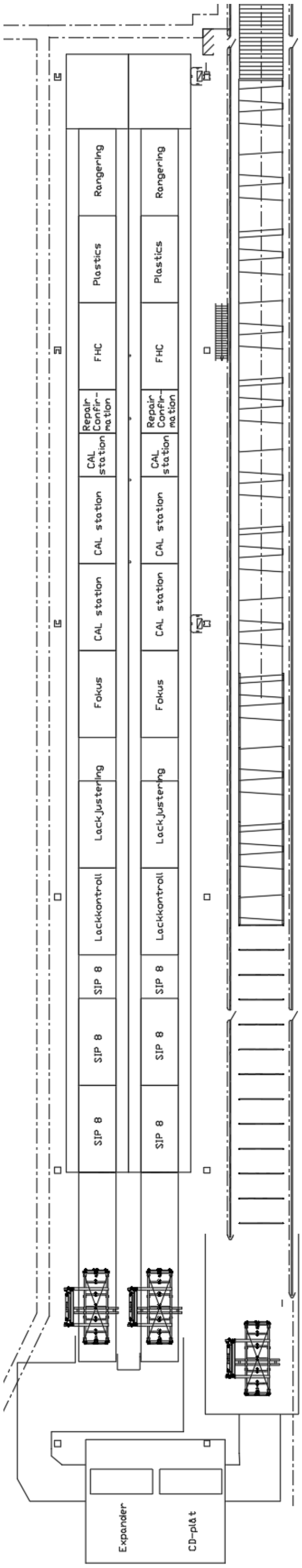


Figure 5.3.1 – Zoomed in at Gummibandet

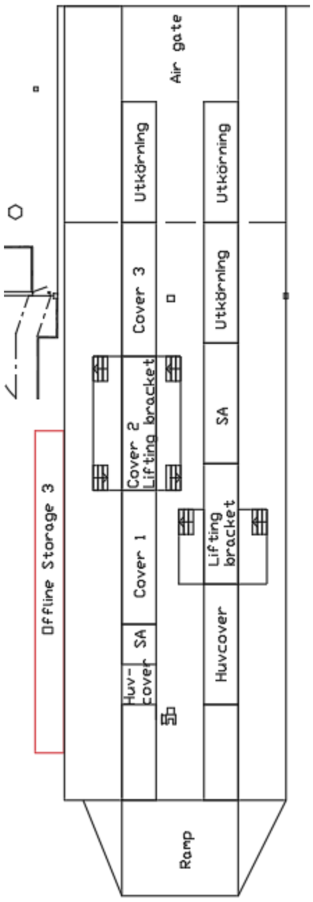


Figure 5.3.2 – Zoomed in at Cover line and ML line

Production flow description

In layout 1, the production flow is the same as the current state until Shorttrack. The cars will move from the Rullarna booths to either Shorttrack or to the adjustment areas depending on whether the cars have faults or not. After the Shorttrack, the production flow is different from today as the new UM line will be placed directly after Shorttrack. From Shorttrack the cars will be driven to the lift area, the lifts will deliver the cars to the new UM line. The car will go through CD-plåt and Expander-Underupp station in the new UM line. The lift will put down the cars on the two new Gummibandet.

At the two new Gummibandet all the control operations, both from TB-paint and CAL teams, are done. In layout 1, the FHC station is also included in the two new Gummibandet. After the CAL line operations, the next station is FHC station. From the FHC station, the cars move to the Plastics station. Then the last station in the Gummibandet, performs Rangering operation. After the Gummibandet, the cars can move to the adjustment areas depending on whether the cars have faults or not. If a car needs a spare tyre, then it will move to the Extra hjul station which is offline. The cars that does not have any faults and does not need a spare tyre will directly move to either the new ML line or the Cover line.

The Cover line will only accommodate cars that should have covers. Hence, the production flow is separated into two lines, the new ML line and the Cover line. In the new ML line, the cars move through the stations Huvcover, Brackets, SA and Utkörning. In the Cover line, the precedence requirements are different. Hence, in the Cover line, the cars first go through the Huvcover station and then the SA station. After the SA station, the cars go through Cover station 1, Cover station 2 and Cover station 3. The operation where the lifting and the damping brackets are added to the cars is done at Cover station 2. The last station in the Cover line is Utkörning.

Relocated operations

Layout 1 have all the operations in the current production layout except the Dörrsprut operation. The Dörrsprut operation is moved into TB-factory. Apart from that, the Extra hjul operation is moved to an offline location next to the new ML line, see dotted box in Figure 5.4.

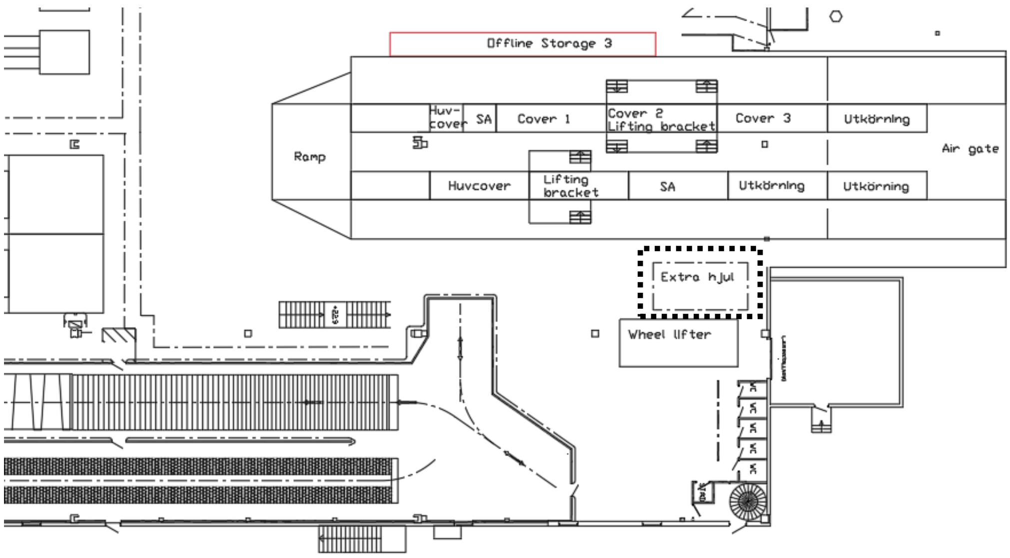


Figure 5.4 – Offline operation in layout 1

The relocated operations are provided in Table 5.1.

Table 5.1 – Relocated operations in layout 1

Operation	Suggested area for relocation
Dörrsprut	TB-factory
Extra hjul	Offline location provided in Figure 5.4

Balancing

As mentioned earlier, the first two stations in layout 1 is Rullarna and Shorttrack. The balancing of the operations in Rullarna booths and Shorttrack is the same as in the current production layout. However, after Shorttrack is the cars moved to the new UM line. The balancing of operations in the new UM line is given below.

New UM line

The first station in the new UM line is CD-plåt. The CD-plåt station is having one car length with one operator as of today. The next station is the Expander station. From the current state analysis, it was found that the percentage of cars that need expanders are low, 2% to 5%. Hence, the operator at the Expander station would have the time and space to perform both the Expander operations and the Underupp operation. As a result, in layout 1, the Expander-Underupp station is having one car length with one operator. After this station, the cars will move to the two new Gummibandet.

New Gummibandet

As mentioned earlier, in layout 1, the main aim is to have a straight line flow from the Gummibandet to the delivery yard which include all the operations in the current production layout. To achieve this, it is needed to extend the current factory building. At the same time, in order to keep the layout 1 implementation cost as minimum as possible, the overall factory extension required has to be controlled. From the current state analysis, it was found that, having two parallel Gummibandet will provide space to include all the required operations with minimum factory building extension as possible. Thus, in layout 1, there are two new parallel Gummibandet. As there are two new lines, the takt time in each Gummibandet is reduced to 35 cars/hour compared to 70 cars/hour in the current production layout. The balancing of operations in the Gummibandet are given below.

The first station in the new Gummibandet is the SIP 8 station. As of today, the SIP 8 station is five car lengths long in total, with 2.5 car lengths in each Gummibandet. Since, the takt time is 35 cars/hour in the new Gummibandet, the five current operators are divided between the two lines. The operators will have the same time for performing their operation as they have today. The five operators will be divided to one car length each. This means that the last 0.5 car length in each line will be performed by the same operator. The same principle is followed for the next two stations, Lackkontroll and Lackjustering. In each line, the Lackkontroll station is one car length long with two operators. Similarly, the Lackjustering station is 1.5 car length long with one operator in each Gummibandet.

The CAL operations are currently performed in two parallel lines in the current production layout. Therefore, the balancing of CAL operations in the new Gummibandet are performed in the same way as of today. The Fokus station in each line is one car length long with one operator. After that, the following station is CAL station. The CAL station in each Gummibandet is 2.5 car lengths long with 2.5 operators. After the CAL station, the next station is Repair Confirmation. The Repair Confirmation station in each line is 0.5 car length long. A single operator is shared within the two Gummibandet. The FHC station in each Gummibandet is one car length long with one operator. The next station is Plastics. Here, the operators remove the Tape Bumpers, Q-glass and the Tejp-dekorlist. The Plastics station in each line is one car length long with one operator. The last station in the new Gummibandet is Rangering. The Rangering operation in each Gummibandet is one car length long with one operator. So, totally two operators are there to drive the cars from the two Gummibandet to the next stations in layout 1. The driving distance from the two new Gummibandet to the Cover line or the new ML line is shorter when compared to driving distance in the current production layout. Hence, the total number of operators needed to perform Rangering operation is reduced from three in the current production layout to two in layout 1.

The new ML line and the Cover line in layout 1 is designed to be flexible to accommodate cars not only from the Gummibandet, but also from the adjustment areas and the Extra Hjul station. Therefore, the maximum percentage of cars in the new ML line is set to be 90%. As mentioned earlier, the Cover line will only have cars with covers. The maximum percentage of cars in the Cover line is expected to be 30%. This value is decided based on the current state analysis. The balancing of operations in the new ML line and the Cover line is given below.

New ML line

The maximum takt time in the new ML line is 90. The first station in the new ML line is Huvcover station. The Huvcover station is 0.9 car lengths long with two operators. After the Huvcover station, the next station is Brackets station. Here the operators add lifting or damping brackets to the car. The Bracket station is 0.9 car lengths long with two operators, one on each side of the car. The following station is SA station. The SA station is 0.9 car lengths long with one operator. The last station in the new ML line is Utkörning. The Utkörning operation is 1.8 car lengths long with three operators. The driving distance between the new ML line and the delivery yard is higher in layout 1 when compared to driving distance between the current ML line and delivery yard in the current production layout. Hence, the number of operators required to perform Utkörning for New ML line operation is three in layout 1.

New Cover Line

The maximum takt time in the new Cover line is 30. Since the takt time is low, the operators will have more time to perform the operations when compared to the current production layout. As a result, the operator intensity is reduced in some stations. The first station in the new Cover line is Huvcover station. The Huvcover station is 0.3 car lengths long with two operators. Since the takt time is low, as mentioned earlier, the two operators are not fully utilised. Thus, the same operators are performing the operations in the next station as well. The next station is SA station. Here the operators from the Huvcover station not only perform the SA station operations, but also add Decal and Door cover to the cars. The SA station in the cover line is 0.3 car length long.

After the SA station, the cover operations are performed. The cover operations are done in three stations. Each Cover station is one car length long. Since the takt time is low, the total number of operators required to perform the cover operations is reduced from six in the current production layout to four in layout 1. The operations in Cover 1 and Cover 2 is performed by the same two operators. These two operators are adding the lifting or damping brackets to the car in Cover 2 since this area is lowered. Cover 3 and Utkörning is performed by four operators. This is due to the higher driving distance in layout 1 between Utkörning and the delivery yard. The last station in the Cover line is Utkörning and it is one car length long.

The balancing of all operations in layout 1 is given in table 5.2.

Table 5.2 – Balancing of layout 1

Line	Station	Car length	No. of operators
-	Rullarna	-	10
	Shorttrack	-	
New UM	CD-plåt	1	1
	Expander/Underupp	1	2
New Gummibandet – both lines included	SIP 8	5	5
	Lackkontroll	2	4
	Lackjustering	3	2
	Fokus	2	2
	CAL station	5	5
	Repair Confirmation	1	1
	FHC	2	2
	Plastics	2	2
	Rangering	2	2
New ML	Huvcover	0.9	2
	Lifting/Damping bracket	0.9	2
	SA	0.9	1
	Utkörning	1.8	3
Cover line	Huvcover	0.3	2
	SA	0.3	
	Cover 1	1	2
	Cover 2	1	
	Cover 3	1	4
	Utkörning	1	

Material flow and material storage

The primary objective in layout 1 is to use the car as a material carrier. In that case, the car must be filled with the all the required material at a point before Rullarna, much upstream in the production flow. Volvo Cars has suggested 1-7 line as a possible location. The materials could be kitted in a box in the trunk of the car, in such a way that the box makes no noise while the car is driven through Shorttrack. Otherwise, the noise from the material box will disturb the actual noise checks conducted during Shorttrack operation. If this idea is feasible, then there are no additional material storage locations needed in layout1.

However, as this is not approved yet, as an alternative option, the material storage locations are marked as black solid shapes in Figure 5.5.

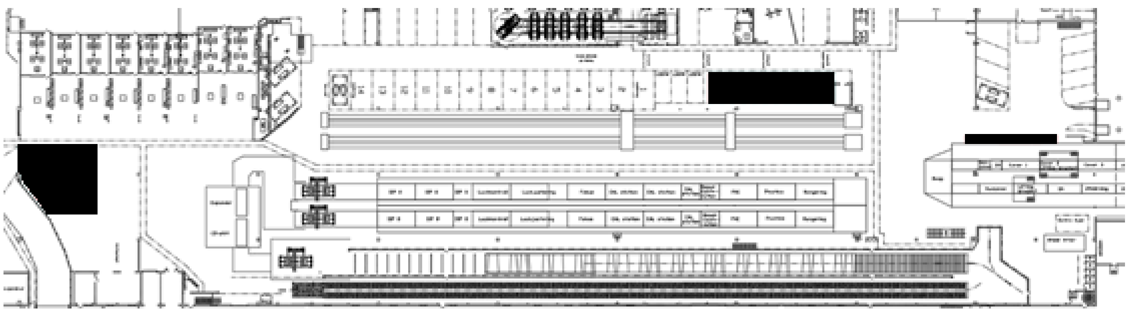


Figure 5.5 – Material storage locations in layout 1

Layout dimensions

To implement layout 1, two new Gummibandet, new UM line, new ML line, Cover line and an extension to the current factory building must be built. The dimensions of all the entities mentioned above are provided below in table 5.3. Apart from that, lifts are needed in the new UM line to raise the cars above the operators. The type of lifts that will be implemented in layout 1 will be decided later by Volvo Cars. Hence, the dimensions of the lifts are not provided.

Table 5.3 – Dimensions in layout 1

		Layout 1
Length/Width [m]	**Building extension**	15,1 / 13
Length [m]	**UM line**	12
	Gummibandet	90
	ML line	41,5
	Cover line	41,5

Layout Evaluation based on KPFs

Here, layout 1 is evaluated using six performance factors selected for layout comparison. The evaluation is based on comparison with the current layout.

Table 5.4 – KPF evaluation of layout 1

KPFs	**Current layout**	**Layout 1**	**Evaluation**
Required operators	54	54	Same number of operators as current layout.
Flexibility	4	2	Fewer breakage points in the production flow for adjustments.
Number of operations relocated	0	2	Two operations are relocated.
Production area utilisation (value added car lengths / total number of car lengths)	58%	76%	Higher utilisation of the production lines. However, seven car lengths are just transportation.
Buffer	13	5	Buffer capacity is lower.
Future expansion	13	2	Fewer car lengths for adding future operations.

5.2.2 Layout 2

Layout 2 is presented in Figure 5.6. It is having a straight production flow from Shorttrack to the delivery yard as requested from Volvo Cars. In difference to layout 1 it only has one Gummibandet which results in a different design in both required space and balancing.

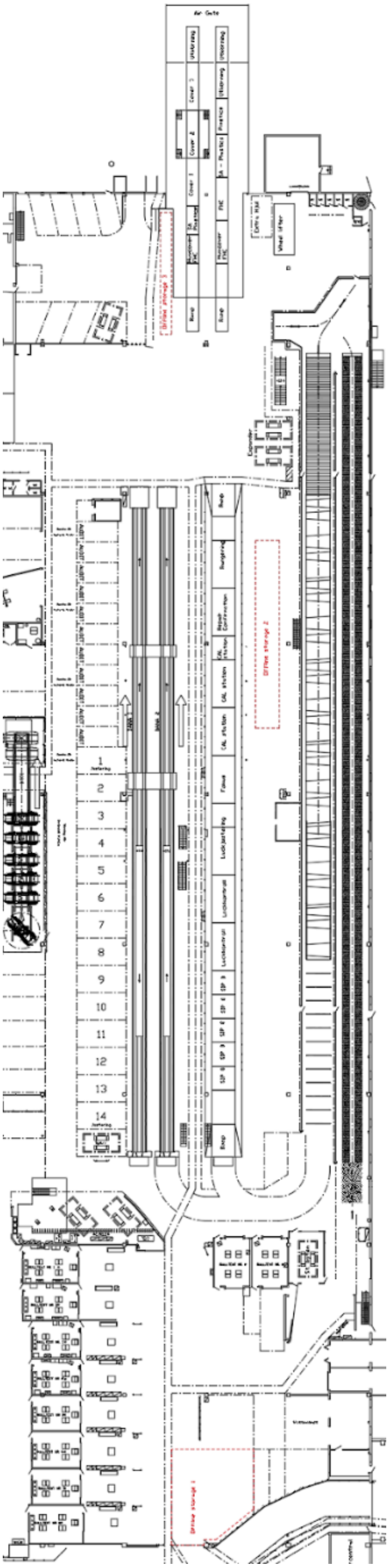


Figure 5.6 – Layout 2

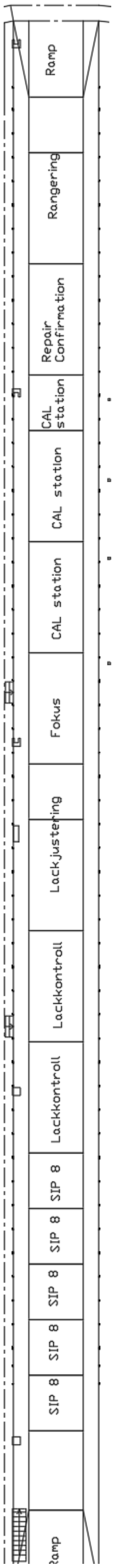


Figure 5.6.1 – Zoomed in at new Gummibandet

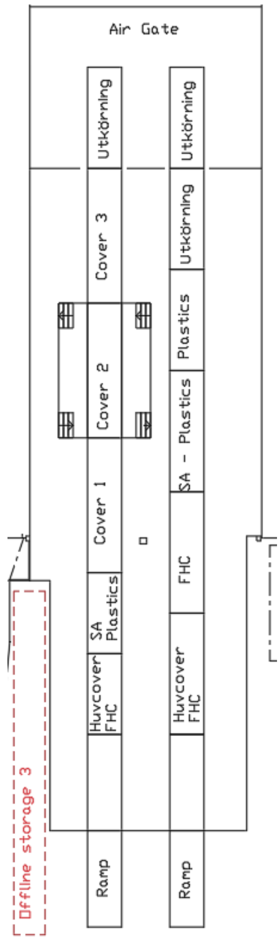


Figure 5.6.1 – Zoomed in at Cover line and new ML line

Production Flow

In layout 2, the production flow is the same as the current production layout, until the cars reach the new Gummibandet. The cars will move from Rullarna stations either to Shorttrack or to adjustment areas. From Shorttrack, will the cars move directly to the new Gummibandet or to the adjustment areas depending on whether the cars have faults or not. All the control operations, both from TB-paint and CAL teams are performed in the Gummibandet. After the Gummibandet, the cars will be moved to repair centres if needed. The cars after the necessary repair operations will be added either to the new ML line or the Cover line. The cars that need expanders will be driven to an offline location where the expander operation will be performed. The same procedure is followed for cars with Extra hjul operation. After the Expander operation or after the Extra hjul operation the cars will be added either to new ML line or the Cover line. All the cars without any faults and does not need expanders or extra hjul will move directly to the new ML line or Cover line.

In the new layout 2, the ML operations will be carried out in two lines, the new ML line and the Cover line. The new ML line will have all the cars without covers and its stations are performed in the following order: Huvcover station, FHC station, SA station, Plastics and then Utkörning. In the new cover line, the operations are performed in the following order: Huvcover station, FHC station, SA station, Plastics, Cover 1, Cover 2, Cover 3 and then Utkörning.

Relocated Operations

The operations CD plåt and Underupp are not included in layout 2. These operations are moved upstream and could be coupled with operations in the 'Merging Point' area in the factory. The expander operation and the extra hjul operation is planned to be performed offline at a suitable location close to an area between the new ML lines and Gummibandet, see dotted boxes in Figure 5.7.

Apart from that, the Dörrsprut operation will be moved to TB factory building and the operation where the lifting brackets and damping brackets are added to the car will be moved to Toe-in station. The relocations are listed in table 5.5.

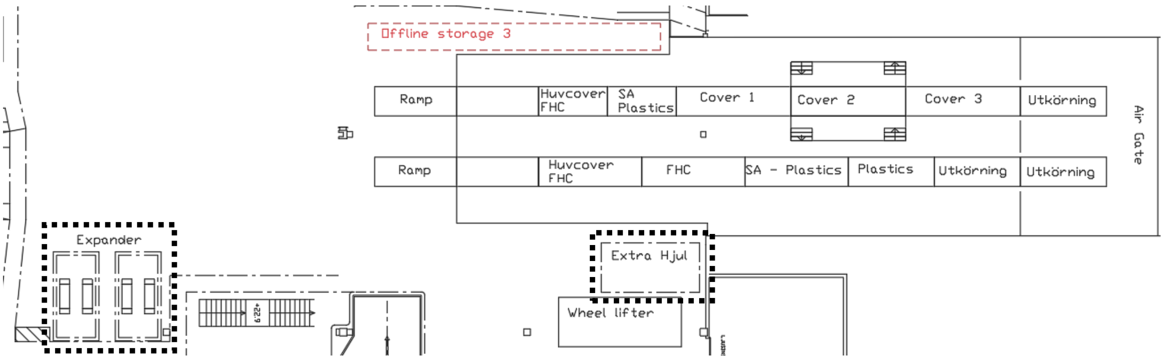


Figure 5.7 – Offline operations in layout 2

Table 5.5 – Relocated operations in layout 2

Operation	Suggested area for relocation
CD-plåt	Merging point area
Underupp	Merging point area
Dörrsprut	TB-factory
Lifting/damping brackets	Toe-in
Extra hjul	Offline location provided in Figure 5.7
Expander	Offline location provided in Figure 5.6

Balancing

As in the current production layout, the first two stations in layout 2 are Rullarna and Shorttrack. The balancing of the operations in Rullarna booths and Shorttrack is same as of today. After these stations, the cars move into the new Gummibandet.

In this alternative, the new Gummibandet is built to fit all the control and check operations performed in the current Gummibandet and the CAL line. In order to fit all these operations in a single line, the number of car lengths required for different operations have to be reduced. In order to reduce the car lengths, the number of operators required for performing these operations have to be increased. The balancing of operations in the new Gummibandet is explained below.

New Gummibandet

In the new Gummibandet, the takt time is 70. The first station, SIP 8 will take only 2.5 car lengths when compared to five car lengths in the current production layout. As the number of car lengths are halved, the total number of operators in SIP 8 station is doubled. In the new Gummibandet, SIP 8 station will have a total of ten operators. The next station is Lackkontroll station. From the current state analysis, it was found that the Lackkontroll station cannot be halved as already there are two workers at each Lackkontroll station. Thus, further increasing the number of operators will crowd the stations and will not provide enough space for each operator to work. Hence, the Lackkontroll operation will be performed in two car lengths with a total of four operators, same as of today. But, like the SIP station, the Lackjustering station is halved and will be performed in 1.5 car lengths will a total of two operators rather than just one operator in the current production layout. After this station, the CAL line operations are performed.

In the current production layout, the CAL line operations are performed in two parallel lines with a takt time of 35 each. In layout 2, the CAL line operations are done at a takt time of 70 in a single line. Hence, it is not required to increase the operator intensity to perform CAL line operations as the operators will get enough time to perform their tasks. The next station is Fokus. The Fokus station operations will be performed in a single car length with two operators. After that, the CAL station operations are done. The CAL station in 2.5 car lengths long with five operators. The following station is Repair Confirmation. The operations at this station is carried out in a single car length with one operator. After the repair confirmation station, the Rangering operation is performed in 1.5 car lengths with three operators. The operators will also add Door Cover and Decal to the car at Rangering.

In layout 2, after the new Gummibandet, it is two new lines, the new ML line and the Cover line, when compared to only one ML line in the current layout. The Cover line and the new ML line is designed to be more flexible, as they have to accommodate cars not only from the new Gummibandet but also from the adjustment areas, expander stations and extra hjul stations. The takt time in these new lines will always vary according to the percentage of cars without covers. At present, the maximum quantity of cars in the Cover line is expected to be 30%. The new ML Line does not have cover cars and a maximum of 90% of cars are expected in the new ML line. Hence, the car lengths for each station in these new ML line and the Cover line are also calculated based on the same ratio. Therefore, total car lengths required for each station in the new cover line is 30% of the current value and total car lengths for each station in the new main ML line is 90% of the current value. The balancing of operations in the new ML line and the Cover line is provided below.

New ML line

The first station in the new ML line is Huvcover-FHC station. This station includes all operations from the current Huvcover station and FHC station, except the extra tyre operation. In the current production layout, these are two different stations. From the current state analysis, it was clear that the operations from the Huvcover station and the FHC station could be performed simultaneously without hindering each other. Apart from that, combining the Huvcover station and the FHC station will save space and thereby have multiple benefits like include more stations, reduce the overall length of the line and also the total extension of the factory building required. So, in layout 2, the Huvcover-FHC station operations are performed within 1.8 car lengths with four operators (same as of today).

The next station in the new ML line is called SA-Plastics. From the current state analysis, it was understood that, at the current SA station, the operator is only performing checks and he is not actually working on the car. So, there is space and the possibility to add one more operator to perform some other operators at the SA station without hindering the actual SA station operations. Hence in layout 2, the SA-Plastics station will have two operators. One operator will perform the SA station operations. The other operator does the Plastics operations. So, the SA-Plastics station is 1.8 car lengths long with two operators. The last two car lengths are Utkörning. The Utkörning operation is 1.8 car lengths long. In layout 2, the driving distance from the new ML line to the yard is higher than the driving distance from the ML line to the yard in the current production layout. Hence, there are three operators to perform Utkörning in layout 2.

Cover Line

The first station in the Cover line is Huvcover-FHC station. As mentioned earlier, this station includes all operations from the current Huvcover station and FHC station, except the extra tyre operation. However, in the Cover line, the maximum takt time is 30. So, the operators will have more time to perform the tasks. Hence, in layout 2, in the Cover line, Huvcover-FHC station is 0.6 car lengths long with only two operators compared to 4 operators in the current production layout. The two operators will first perform the Huvcover operation and then perform the operations from the current FHC station. The second station in the cover line is SA-Plastics. As the takt time is low, one operator performs both SA station operations and also remove Tape bumpers and Q-glass. So, the SA-Plastics station in the Cover line is 0.6 car length long with one operator.

The cover operations are done in the next three stations. As mentioned earlier, the takt time in the Cover line is only 30. Therefore, the operators have more time to perform the operations. Hence, in layout 2, the cover operations are carried out within three car lengths, when compared to six car lengths in the current ML line. For the same reason, the total number of operators needed to do the cover operations are also reduced to four in layout 2, when compared to six in the current production layout. The first two operators do the operations in cover station 1 and cover station 2. The last station in the Cover line is Utkörning and it is one car length long. As mentioned earlier, in layout 2, the driving distance from the Cover line to the yard is higher than the driving distance from the current ML line to the delivery yard. As a result, in layout 2, four operators equally share the operations in cover station 3 and Utkörning.

The balancing of operations in layout 2 is given below in table 5.6.

Table 5.6 – Balancing of layout 2

Line	Station	Car length	No. of operators
-	Rullarna	-	10
	Shorttrack	-	
New Gummibandet	SIP 8	2.5	10
	Lackkontroll	2	4
	Lackjustering	1.5	2
	Fokus	1	2
	CAL station	2.5	5
	Repair Confirmation	1	1
	Rangering	1.5	3
New ML	Huvcover + FHC	1.8	4
	SA + Plastics	1.8	2
	Utkörning	1.8	3
Cover line	Huvcover + FHC	0.6	2
	SA + Plastics	0.6	1
	Cover 1	1	2
	Cover 2	1	
	Cover 3	1	4
	Utkörning	1	

Material storage & Material Flow

The primary objective in layout 2 is to use the car itself as a material carrier. If it is feasible, then there is no requirement of additional material storage areas in layout 2. But, in case the car cannot be used, then as an alternative, material storage locations and logistics for layout 2 are suggested below. The material storage locations are marked as black solid shapes in Figure 5.8.

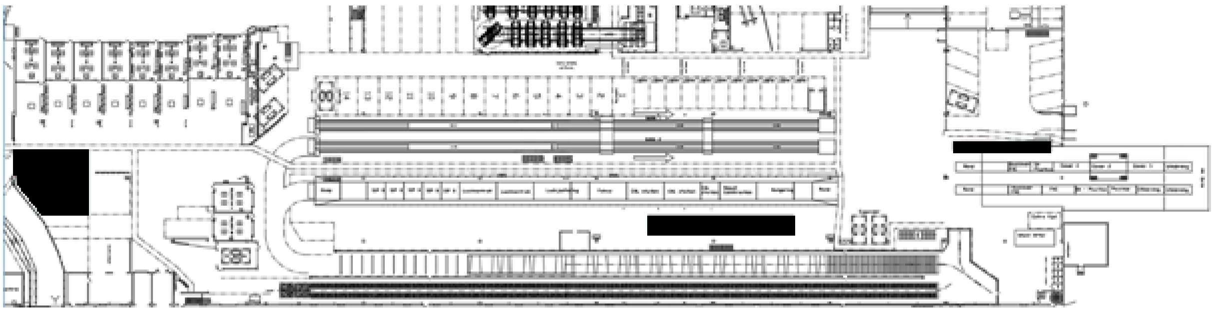


Figure 5.8 – Material storage locations in layout 2

Layout 2 has two online material storage areas. One on the left side of the new cover line (online storage location 1) and one on the right side of the new main ML Line (online storage location 2). The operators will access the materials required for performing operations from these locations. Apart from that, layout 2 also has two offline storage locations for easy replenishment of materials to the online storage locations. The logistics division at Volvo Cars has confirmed that, they will provide the materials to offline storage location 1. A material handler will be used to transport material from offline storage location 1 to offline storage location 2. The same material handler will provide the materials to online storage locations whenever necessary.

Layout Dimensions

To implement layout 2, a new Gummibandet, new ML line, Cover line and an extension to the current factory building must be built. The dimensions of all the entities mentioned above are provided below in table 5.7.

Table 5.7 – Dimensions in layout 2

		Layout 2
Length / Width [m]	**Building extension**	27,5 / 12
Length [m]	**Gummibandet**	98,6
	ML line	44,7
	Cover line	44,7

Layout Evaluation based on KPF's;

Here, layout 2 is evaluated using six performance factors selected for layout comparison.

Table 5.8 – KPF evaluation of layout 2

KPFs	Current layout	Layout 2	Evaluation
Required operators	54	55	More number of operators than current layout.
Flexibility	4	3	Fewer breakage points in the production flow for adjustments.
Number of operations relocated	0	6	Six operations are relocated.
Production area utilisation (value added car lengths / total number of car lengths)	58%	88%	Higher utilisation of the production lines. However, three car lengths are just transportation.
Buffer	13	0	No buffer capacity.
Future expansion	13	3	Fewer car lengths for adding future operations.

5.2.3 Layout 3

Layout 3 is having as the other two layouts a straight flow to the delivery yard from Shorttrack. However, in this layout more stations are being moved upstream to other parts of the factory. This have allowed the stations to be design in another way which have resulted in only needing two new lines. Nevertheless, a building extension to the factory is still required. Layout 3 is presented in Figure 5.9.

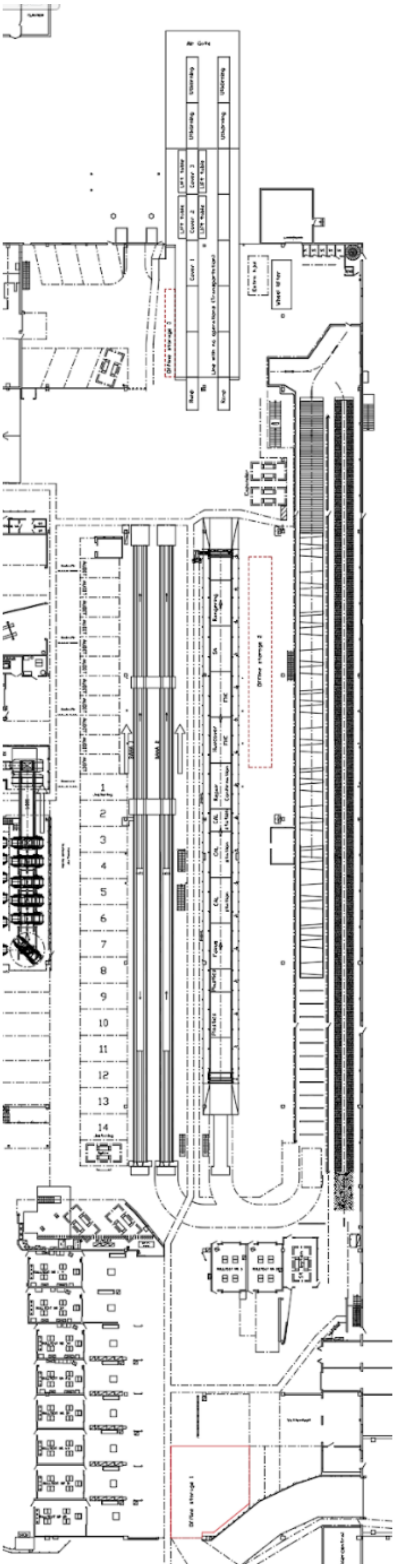


Figure 5.9 – Layout 3

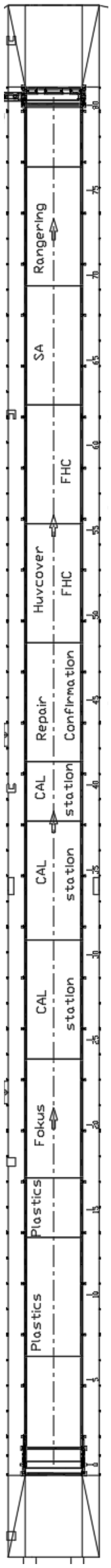


Figure 5.9.1 – Zoomed in at Gummibandet

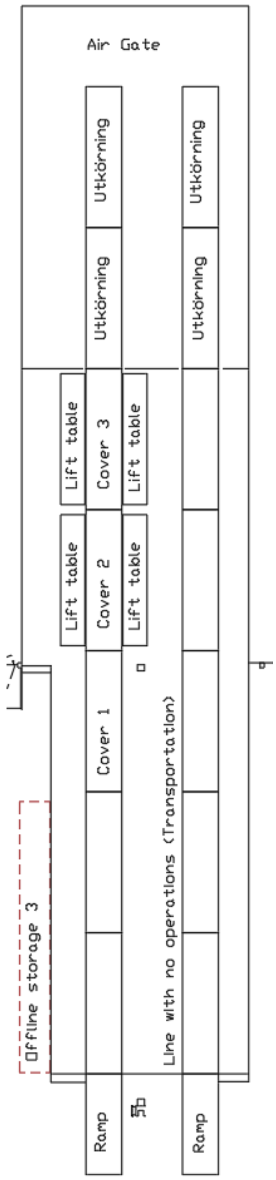


Figure 5.9.1 – Zoomed in at Cover line and Delivery line

Production flow

In layout 3, the production flow will be as it is today until the cars reach Gummibandet, see Figure 5.9. The cars will move from Rullarna to either Shorttrack or to adjustment areas in the factory. After Shorttrack, the cars will move to Gummibandet or to an adjustment area if a fault was found in Shorttrack. When compared with other two layout alternatives, layout 3 does not have a new Gummibandet. It utilises the Gummibandet in the current production layout. Gummibandet in layout 3 includes the stations: Plastics, Fokus, CAL station, Repair confirmation, Huvcover-FHC, SA and Rangering.

After Gummibandet, cars will move to the adjustment areas if any repairs are needed. Otherwise, the cars that need expanders will move to the Expander stations. In the same way, the cars that need a spare tyre will move to the Extra hjul station. After that, the flow will separate into two lines, Cover line and the Delivery line. The Cover line will only handle cars that needs covers and the Delivery line will handle the rest of the cars. As mentioned earlier in layout 1 and layout 2, the cars that does not have any repairs or either need expanders or spare tyre will directly move into the Cover line or the Delivery line. The operational precedence in both the Cover line and the Delivery line is provided in Figure 5.9.

Relocated operations

In layout 3, the CD-plåt and Underupp stations are moved upstream in the factory. These operations are planned to be coupled with operations in the 'Merging Point' area of the factory. Apart from that, in layout 3, the cars should be factory complete at the end of Gummibandet. So, in order to increase the flexibility in the Gummibandet, both SIP 8, Lackjustering and Lackkontroll are moved upstream. These operations will be moved to 1-7 line. By doing this, the operations from ML line can be performed at Gummibandet.

The Expander and the Extra hjul operation is planned to be performed offline at a suitable location between the Gummibandet and the Cover line and Delivery line. The suggested locations for the Expander and the Extra Hjul station is provided in Figure 5.10 as dotted boxes.

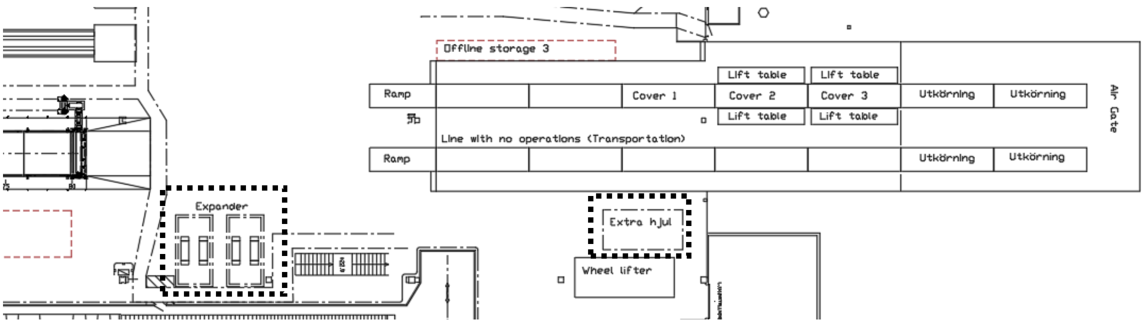


Figure 5.10 – Offline operations in layout 3

In layout 2, the Dörrsprut operation is relocated to TB factory building and the lifting brackets and damping brackets operation will be moved to Toe-in station. All the suggested relocations are listed in table 5.9 below.

Table 5.9 – Relocated operations in layout 3

Operation	Suggested area for relocation
SIP 8	1-7
Lackjustering	1-8
Lackkontroll	1-8
CD-plåt	Merging point area
Underupp	Merging point area
Dörrsprut	TB-factory
Lifting/damping brackets	Toe-in
Extra hjul	Offline location provided in Figure 5.10
Expander	Offline location provided in Figure 5.10

Balancing

In layout 3, the first two stations are Rullarna and Shorttrack. The balancing of the operations in these stations are same as of today. After these stations, the cars move into the Gummibandet.

Gummibandet

The length of the Gummibandet in layout 3 is same as of today. However, the operations performed here are different, when compared to the current production layout. As mentioned earlier, SIP 8, Lackjustering and Lackkontroll are moved upstream. Thus, free space was obtained in the Gummibandet. This free space was utilised to add all operations from the CAL line, some operations from the ML line and other operations where plastics are added or removed from cars. The balancing of operations in the Gummibandet is given below.

The takt time at Gummibandet is 70 cars/hour, same as of today. The first station is the Plastics station which is 1.5 car lengths long and requires one operator. Here, the operator does Tejp-dekorlist operation and remove other plastics. After this, the CAL line operations are performed. In the current production layout, the CAL line operations are done in two parallel lines each with a takt time of 35. Hence, as mentioned earlier, in layout 3, it is not required to increase the operator intensity to perform CAL line operations as the operators will get enough time to perform their tasks. The next station is Focus. This station is one car length long with two operators. After that, the CAL station which is 2.5 car lengths long with five operators. After that, the following station is Repair confirmation where the operations are done within a car length with one operator.

After this station the operations from the current ML line are performed. The next station is Huvcover-FHC station. In the current production layout, these are two different stations. From the current state analysis, it was clear that the operations from the Huvcover station and the FHC station could be performed simultaneously without hindering each other. Apart from that, combining the Huvcover station and the FHC station will save space and thereby makes it possible to include more stations in the Gummibandet. So, these two stations are combined in layout 3. Four operators are required to perform the operations. After the Huvcover- FHC station, the next station is SA station. The SA station is one car length long. From the current state analysis, it was understood that, at SA station the operator is only performing checks and he is not actually working on the car. Therefore, it is free space which gives possibility to add one more operator to perform some other operators at the SA station without hindering the actual SA station operations. Hence, the SA station has an additional operator who adds door cover and decal to the car. Therefore, in layout 3, the SA station has two operators. The last station in Gummibandet is Rangering. As in layout 2, the Rangering station is 1.5 car lengths long with two operators. So here the driving distance to the next station from the Gummibandet is less when compared to the current production layout. Subsequently, the number of operators required to perform Rangering is reduced to two in layout 3 as in layout 2.

After the Gummibandet, the cars move to the Cover line or the Delivery line. The Cover line and the Delivery line should be more flexible, as they have to accommodate cars not only from the Gummibandet but also from the adjustment areas, expander stations and the extra hjul station. Hence, the cover line is expected to have a maximum takt time of 30% and the Delivery line is expected to have a maximum of 90% of the 70 cars/hour takt time. This will allow adjustments cars to be added to the lines without stopping the production flow upstream. The balancing of operations in the Delivery line and the Cover line is given below.

Delivery Line

The first part of the Delivery line is a transport line of four car lengths. After that, the Utkörning is performed within two car lengths. In layout 3, the driving distance between the Delivery line and the yard is higher than the driving distance between the current ML line and the yard. As a result, the Utkörning is performed with three operators.

Cover Line

The first part of the Cover line is a transport line of one car length. After that, there are three cover stations each one car length long. As mentioned earlier, the maximum takt time in the Cover line is 30% of the takt time, 70 cars/hour. So, in layout 3, the operators have more time to perform the operations in the Cover line. Hence, the cover operations and the Utkörning is performed in the same way as it is in layout 2. The cover operations are carried out within three car lengths, when compared to six car lengths in the current ML line. Subsequently, the total number of operators needed to do the cover operations are also reduced to four in layout 3, when compared to six in the current production layout. The first two operators do the operations in cover station 1 and cover station 2. The last station in the Cover line is Utkörning and it is two car lengths long. The driving distance from the Cover line to the yard is higher than the driving distance from the ML line to the yard in the current production layout. As a result, in layout 2, four operators equally share the operations in cover station 3 and Utkörning.

The balancing of operations in the layout 3 is given in table 5.10.

Table 5.10 – Balancing of layout 3

<table>
<tr><th>Line</th><th>Station</th><th>Car length</th><th>No. of operators</th></tr>
<tr><td rowspan="2">-</td><td>Rullarna</td><td>-</td><td rowspan="2">10</td></tr>
<tr><td>Shorttrack</td><td>-</td></tr>
<tr><td rowspan="7">Gummibandet</td><td>Plastics</td><td>1.5</td><td>1</td></tr>
<tr><td>Fokus</td><td>1</td><td>2</td></tr>
<tr><td>CAL station</td><td>2.5</td><td>5</td></tr>
<tr><td>Repair Confirmation</td><td>1</td><td>1</td></tr>
<tr><td>Huvcover + FHC</td><td>2</td><td>4</td></tr>
<tr><td>SA</td><td>1</td><td>2</td></tr>
<tr><td>Rangering</td><td>1.5</td><td>2</td></tr>
<tr><td rowspan="2">Delivery line</td><td>Transport</td><td>4</td><td>0</td></tr>
<tr><td>Utkörning</td><td>2</td><td>3</td></tr>
<tr><td rowspan="5">Cover line</td><td>Transport</td><td>1</td><td>0</td></tr>
<tr><td>Cover 1</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>Cover 2</td><td>1</td></tr>
<tr><td>Cover 3</td><td>1</td><td rowspan="2">4</td></tr>
<tr><td>Utkörning</td><td>2</td></tr>
</table>

Material flow and material storage

As mentioned above in layout 1 and layout 2, the primary objective is to use the car itself as a material carrier. However, if the car cannot be used, then as an alternative, material storage locations and logistics for layout 3 are provided below. The material storage locations are marked as black solid shapes in Figure 5.11.

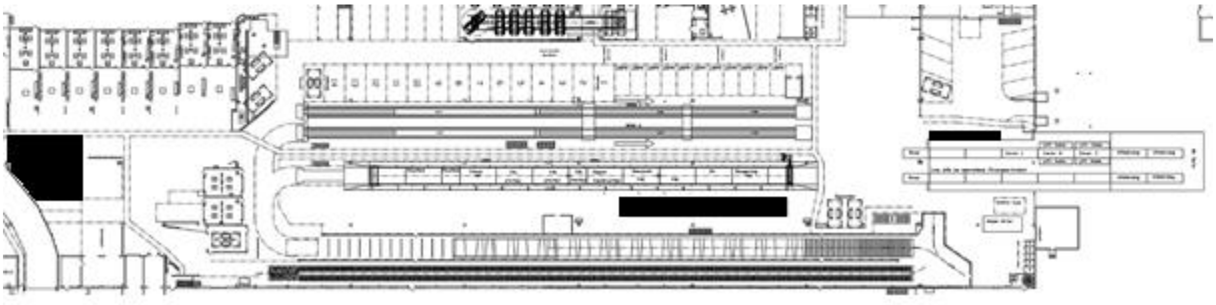


Figure 5.11 – Material storage locations in layout 3

The material storage locations in layout 3 is same as in layout 2. Layout 3 has only one online material storage area, located on the left side of the cover line. This is because, no material is added to the car in the Delivery line. The operators will access the materials required for performing operations from this location. Layout 3 also has two offline storage locations for easy replenishment of materials to the online storage location. As in layout 2, the logistics division at Volvo Cars has confirmed that, they will provide the materials to offline storage location 1. Therefore, a material handler will be used to transport material from offline storage location 1 to offline storage location 2. The same material handler will provide the materials to the online storage location whenever necessary.

Layout Dimensions

To implement layout 3, two new lines, Cover line and Delivery Line are required. In order to accommodate these two lines, a building extension is required to the current factory area. The dimensions of all the entities mentioned above are provided below in table 5.11.

Table 5.11 – Dimensions in layout 3

		Layout 3
Length/Width [m]	**Building extension**	32 / 11
Length [m]	**Gummibandet**	91
	ML line	54
	Cover line	54

Layout Evaluation based on KPF's

In table 5.12, layout 3 is evaluated using six performance factors selected for layout comparison.

Table 5.12 – KPF evaluation of layout 3

KPFs	Current layout	Layout 3	Evaluation
Required operators	54	36	Less number of operators than current layout.
Flexibility	4	3	Fewer breakage points in the production flow for adjustments.
Number of operations relocated	0	9	Nine operations are relocated.
Production area utilisation (value added car lengths / total number of car lengths)	58%	74%	Higher utilisation of the production lines. However, five car lengths are just transportation.
Buffer	13	0	No buffer capacity. However, the delivery line can be used as buffer if it has empty car lengths.
Future expansion	13	8	Fewer car lengths for adding future operations.

5.3 Comparison of layout alternatives

The evaluation matrix used to compare the three proposed layouts with the KPFs, is provided in table 5.13.

Table 5.13 – The different KPFs with their weightings and layout scores compared to each other

Criteria	Weight	Layout 1	Layout 2	Layout 3
Required operators	5	2	1	3
Flexibility	3	1	2	3
No. of operations moved	2	3	2	1
Production area utilisation	3	2	3	1
Buffer	4	3	1	2
Future expansion	2	1	2	3

To get the final score of each layout the weight factor is multiplied with the grade score for each KPF and then summed to a total score, see table 5.14. The total scoring for layout 1, layout 2 and layout 3 is respectively 39, 32 and 43. This shows that layout 3 is the most suitable layout from a perspective where each KPF is valued alone.

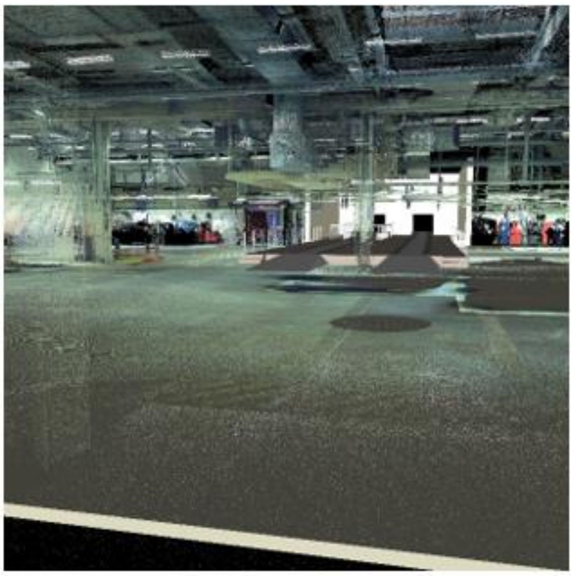
Table 5.14 – The total score of each layout

Criteria	Layout 1	Layout 2	Layout 3
Required operators	10	5	15
Flexibility	3	6	9
No. of operations moved	6	4	2
Production area utilisation	6	9	3
Buffer	12	4	8
Future expansion	2	4	6
Total Score	39	32	43

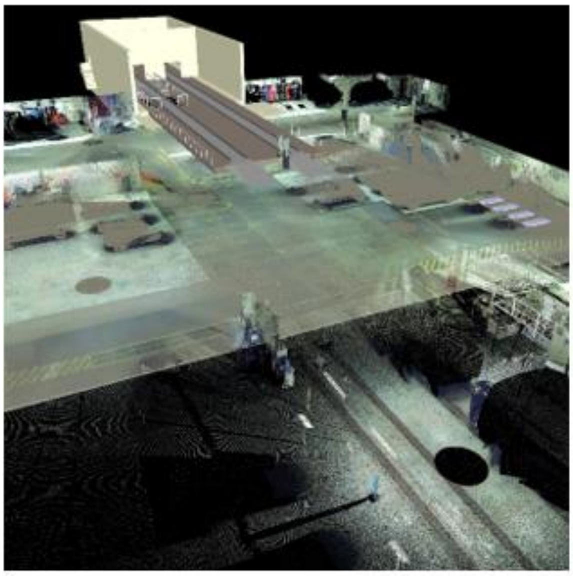
5.4 Virtual model of layout 3

Layout 3 is developed from its 2D CAD drawing into a virtual model. The virtual model is a combination of the point cloud from the 3D laser scans and the 3D objects built in CATIA. The result from the evaluation matrix in section 5.3 and the inputs from Volvo Cars were the main deciding factors that suggested which layout alternative to be presented further as a virtual model. This can be used to get all involving stakeholders to have a similar picture of how the future layout will look like. Layout 3 in a 3D perspective can be seen in Figure 5.12, a-d.

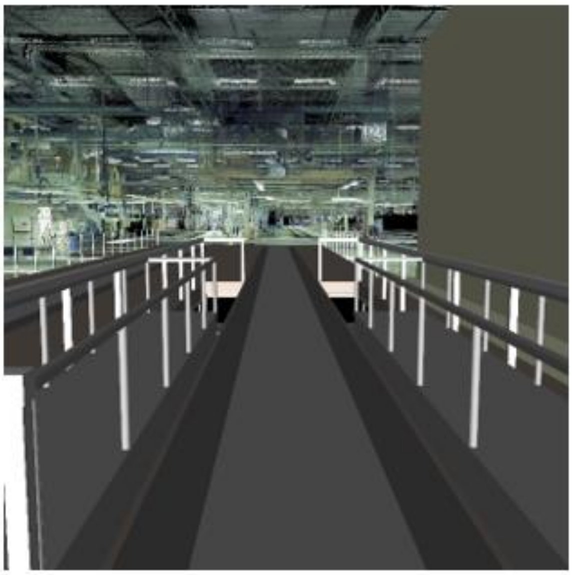
a



b



c



d

Figure 5.12 – The virtual model in four different angles, a-d

6 Discussion

This chapter in the report mainly includes discussions regarding the project results and the techniques used in the project to achieve the results.

6.1 3D laser scanning

The created point cloud from the 3D laser scanning is has various quality in different areas. This is something that occurred due to the motions from operators and cars during the scan sessions, some areas were crowded and some completely free of motions. However, this was not the only reason for getting lower quality in the point cloud. In some areas there were parked cars or other objects placed on the ground. These cars and objects were captured by the laser and later removed in the creation of the point cloud. The removal of the cars and objects created small zones with less data points. This made the point cloud look incomplete in these zones. In this thesis, the defects in the point cloud did not have a major effect as it was the outer walls and pillars (fixed objects) that were compared to the 2D CAD drawing. The fixed objects were having good number of points in the point cloud. However, in the creation of the 3D CAD model of layout 3, the zones with less data points gave a negative visual impact as they appeared as dark spots. Nevertheless, these zones where filled with CAD parts to make the point cloud more appealing for the viewer.

In the literature study, it was found that a 3D CAD model could be beneficial as it gives the stakeholders a mutual understanding of the model which make the discussions more effective and relevant to the point. This was something that could have been used in the weekly meetings at Volvo Cars instead of simple 2D CAD drawings. At Volvo Cars, there were several times when there were uncertainties regarding the measurements between different entities in the layout. This could have been easily solved with the help of a point cloud.

Furthermore, 3D visualisation makes it possible to include operators and other floor staff during the layout planning and designing procedure. The operators could provide suggestions on the actual working conditions as they have more practical insights on the ergonomic aspects in the production area. This will help to plan and design layouts with workstations that are more socially sustainable. At Volvo Cars, there was very less inclusion of workers during the layout planning meetings. Apart from that, if Volvo Cars would use 3D laser scanning for creating models of the area in the future, it is favourable to clear the area of objects and movements before scanning as it would give an even better visualisation of the area.

6.2 Misses in communication

Meetings were conducted every week at Volvo Cars for planning the new layout which included representatives from different departments. At many instances, the decisions made during the previous meetings regarding the layout design were changed in the next meeting due to new suggestions or requirements from the top management. There were many back and forth discussions regarding which operations could be relocated, suitable location for relocation and the possibility of having a separate Cover line. This affected the decision-making process regarding the design and prolonged the finalisation of the new layout alternatives

Apart from that, the meetings were attended by different representatives every week. Even though, it helped to generate fresh ideas and suggestions, more often, it hindered the progress of the decisions made in the last meeting. The new participants had a different opinion about the decisions taken. The layout planning process would have been more efficient and fast if all the stakeholders were available during all the meetings.

6.3 New production layouts compared to current layout

The three layout alternatives that is presented in the results section have been designed based on current state analysis, practical limitations in the factory and the future organisational considerations. All the three layout alternatives have certain common benefits when compared to the current production layout.

The current production layout has more transport lines when compared to the new layout alternatives. The transport line 1 and transport line 2 in the current production layout are not needed in the new layout alternatives. This provides Volvo Cars more space in the factory as well as reduced operational expenses due to the decreased number of operators. In addition, eliminating the transport lines also helps Volvo Cars to decrease the lead time.

Another common advantage is that the new layout alternatives have a straight flow when compared to the current production layout. In the current production layout, the Gummibandet, CAL line and the ML line are at different locations. The cars were driven from one line to the other. In the new layouts, all these operations are in a straight line. This will reduce the driving distance between these operations. In addition to that, a straight-line flow will make it easy to control the production flow until the car gets delivered to the yard.

However, the new layout alternatives have some disadvantages when compared to the current production layout. The driving distance from Utkörning to the delivery yard is higher in the new layout alternatives when compared to the current production layout. Therefore, more operators are needed to perform Utkörning in the new layout alternatives. This could over time increase the overall operational expenditure for Volvo Cars. Another disadvantage is that, in layout 1 and layout 2, TB-paint and CAL perform their controls on the same line. This is a drawback as they are checking for the same faults. Without the possibility for repairs between them, the CAL control will lose some of its purpose. However, in the current layout and layout 3 TB-paint and CAL are separated.

6.4 Differences between new layout alternatives

The new layout alternatives have several differences between each other. Therefore, each of the new layout alternative has its own benefits and drawbacks. However, to identify the best alternative among them, the three alternatives must be compared against the same parameters. This is the reason why the layout alternatives are compared using the KPF's.

From the KPF comparison, layout 3 has the highest score. The main reason is that, layout 3 scored the highest in 'Required Operators' criteria which has the maximum weightage, according to Volvo Cars. Layout 3 has the lowest number of operators when compared to layout 1 and layout 2. Another advantage is that, in layout 3, the TB-paint control and CAL control are not performed on the same line. The TB-paint control is relocated upstream and the CAL control is carried out on the Gummibandet. In layout 1 and layout 2, all these control operations are performed on the new Gummibandet. This is a drawback as both stations are checking for the same faults without the possibility for repairs between them. This would make CAL control to lose some of its purpose.

Layout 3 has the highest score for the KPF- Flexibility when compared to other layouts. This is because, in layout 3, the cars could be taken on and off the production flow for repair operations, exactly as in current production layout. In layout 1, the cars cannot be taken to the adjustment area for repairs after the Shorttrack. From the Shorttrack, the cars directly move to the new UM line and then to the new Gummibandet. So, the faults that were identified at Shorttrack can be repaired only after the new Gummibandet. Layout 2 also allows cars to be taken for repairs from Shorttrack and Gummibandet as in layout 3. However, in layout 2, the

TB paint control and CAL control are performed in the same line. Hence, this makes layout 2 less flexible when compared to layout 3.

Furthermore, layout 3 have some disadvantages when compared to other layouts. In layout 3 and layout 2, CD sheets are assembled in Merging point area in the factory before Rullarna and therefore it is difficult to detect any leakages. Even though, the leakage problems happen very rarely, if it occurs then it can cause customer issues. However, in layout 1, the CD-plåt station comes downstream of Rullarna. Hence, the cars could be checked for leakage before the CD-sheets are assembled. Further, layout 3 has the minimum score for the KPF-Production area utilisation. This is because, the new ML line and the Cover line in layout 3 have transport paths where no operations are performed. Thus, there transport paths are non-value adding. Layout 2 has the maximum score in this criterion.

In addition, the Expander station is offline in layout 2 and layout 3 when compared to online in layout 1. At present, the percentage of cars with expanders are only 2-5%. However, if the percentage of cars that need expanders increase in the future, it will be difficult to have the Expander station offline. More lifts and operators would be needed to drive the cars back and forth from the offline location to the lines. Apart from that, layout 1 have buffer capacity of 5 cars in the lift at the new UM line which is absent in the other layouts. Therefore, layout 1 can handle unexpected production disturbances without immediately stopping the production flow.

Based on all the statements above, it is arguable that, each layout has the possibility of becoming the most suitable one. It depends on what parameters has been taken into consideration or being prioritised. Therefore, in the future, details from the different layout alternatives could be mixed to develop a new layout that could fulfil all the requirements.

6.5 Cost aspect

The cost aspect is something that was excluded in this project. The reason was not to limit the possibilities for a layout solution. It would also have been difficult to gather specific cost information from suppliers and construction companies as the layouts would require custom fitted orders. However, to exclude the cost aspect totally from being a part of the decision making was difficult.

During the weekly meetings at Volvo Cars, the main agenda was the questions and information about constraints regarding layout planning. However, along with that the cost factor was also brought up. The costs for including different details in the layouts was estimated from experienced stakeholders. To include solutions in the layouts that was too expensive, in relation to Volvo Cars budget, was considered as irrelevant. Therefore, the planning and designing of the layouts were affected by costs.

7 Conclusion

This project has been investigated the possibility of having a new layout in the final production flow. The new layout should make the production flow more visual, easy to control and also reduce the non-value adding operations of today's line. The project results have been presented with the help of virtual tools.

In this project, SLP method was used as a guidance for layout planning and designing. The project suggests that, SLP method can be used for creating a layout design, even though the layout is not built from scratch. The activities that has to be performed in each main phase in the SLP framework was modified to suit the project requirements. 3D laser scanning was also performed in the final production area. The point cloud created from the 3D laser scans was compared with the current 2D drawing of Volvo Cars' TC factory. The comparison showed that Volvo Cars have a detailed 2D CAD drawing. Hence, 2D CAD drawing was used for designing the new layouts.

The project resulted in three layout proposals. They all fulfil Volvo Cars' requirement of having a straight production flow to the delivery yard. However, each layout has a certain number of operations moved to other parts of the factory. This gave each layout proposal an unique design. The proposed layouts are precise as the new lines are placed in favour for not interfering with load bearing pillars or other lines' flow. This was ensured by investigating the final production area with the point cloud. The highest scored layout based on the KPIs was presented as a 3D model using the point cloud. This gave a greater understanding and helped to give a more complete picture of the layout.

Each layout has its benefits and drawbacks. Hence, each layout can become the best possible solution, depending on the KPFs taken into consideration. Therefore, it is important to point out that, during the implementation phase, there is also the possibility for combining certain solutions from each layout to create an entirely new layout alternative. However, the balancing of stations needs to be assessed before implementing the same.

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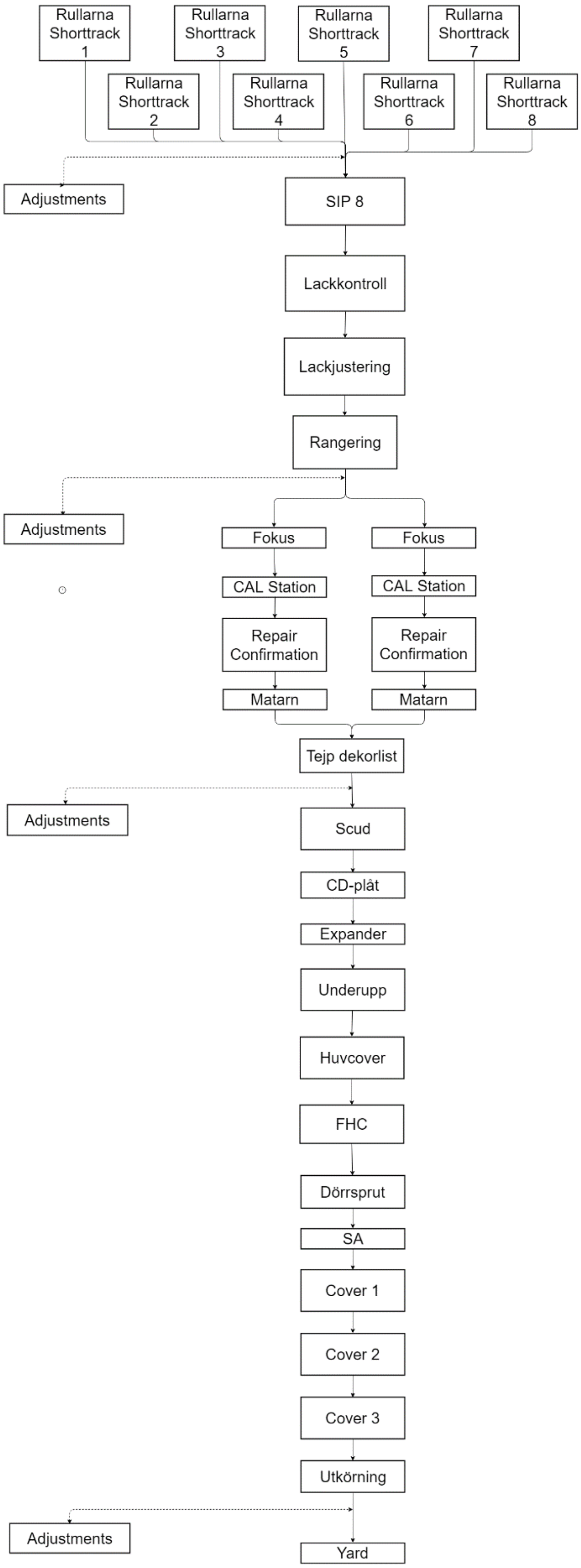
Appendix A - Precedence diagram (Current production flow)



Appendix B - Six Key Performance Factors

Required operators

This KPF is measuring how many operators that is requested in a certain layout. It is good to have as low number of operators as possible. The yearly cost for one operator is 600 thousand SEK.

Flexibility

This KPF is valuing how the layout will handle the possibility of taking cars on and off the production line for adjustments in an effective way. The distance between line and adjustments area should be considered. It also considers how the cars can be taken on and off without hindering the upstream flow.

Number of operations moved to other lines

This KPF is valuing how many of today's operations that will be moved to another part of the factory. It is good to keep the number of moved operations as low as possible as it is difficult to find open spots in the rest of the factory. It usually cost money to move operations to other areas, not only in physical labour but also in education and learning the operation.

Production area utilisation

This KPF is about how well the production line is being used. It measures how much of the production line that contains value adding operations or non-value adding operations. In general, will the non-value adding part consist of the cars being transported with no operations or if it is driven between lines.

Buffer

This KPF is about the amount of buffer that are available in the production line. By having buffers, the production line becomes more protected from disturbances upstream or downstream.

Future expansion

In this KPF, the layouts are graded by how well they could be adapted to additional operations. In the future, the cars will probably have an increased amount of technology and needs to be tested and controlled somewhere. Today, this is performed in the final flow. Therefore, it is beneficial if there is availability of space for such operation additions in the layouts. A high value in this KPF could mean that the new layout will have a longer lifetime.