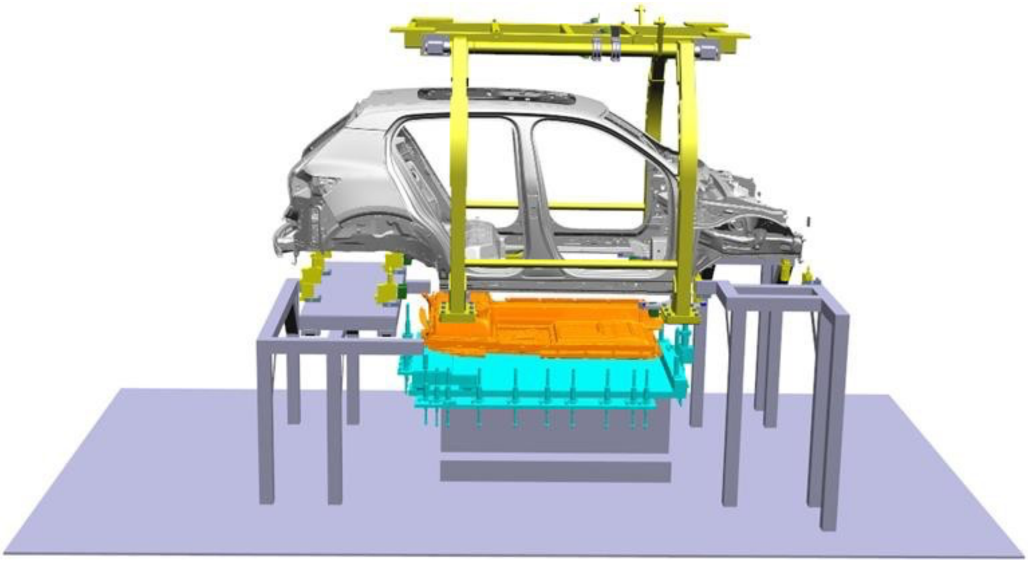
CHALMERS



Design and develop a tightening process to assemble a high voltage battery to the car

Bachelor's thesis in Science in Engineering

JULIA ÖSTENSSON MIRANDA WAHLBECK

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se
Report number E2023: 104

Report number E2023:104

Design and develop a tightening process to assemble a high voltage battery to the car

JULIA ÖSTENSSON
MIRANDA WAHLBECK

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
Division of Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023

Design and develop a tightening process to assemble a high voltage battery to the car

Julia Östensson
Miranda Wahlbeck

Report number E2023: 104
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
Illustrating Volvo decking process of carbody and battery

Gothenburg, Sweden 2023

Gothenburg, Sweden 2023

Design and develop a tightening process to assemble a high voltage battery to the car A collaboration between Chalmers University of Technology and Volvo cars

Julia Östensson
Miranda Wahlbeck

Department of Technology Management and Economics
Chalmers University of Technology

SUMMARY

The car manufacturing industry has experienced a significant transformation, with many companies transitioning towards the production of electric vehicles. Volvo Cars is among these companies, placing a strong emphasis on electric vehicles and actively exploring innovative and efficient solutions. One such solution involves the implementation of an open floor technology for assembling high voltage batteries in their cars. This thesis aims to develop a tightening process layout and technical solution for battery assembly in Volvo's electric vehicles, specifically focusing on the Slovakia factory. The study will investigate different technical solutions, including manual, automated, and semi-automated tooling. The production platform is capable of manufacturing multiple car models. The thesis will provide a general description of the production processes to maintain flexibility for producing alternative car models. The thesis includes a comparison and recommendation for automated or manual setup for the Slovakian factory and a developed new concept.

Key words: Battery, Electric vehicle, Layout planning, Tightening process, Automated setup, Manual setup, Tooling

Acknowledgement

We would like to express our greatest gratitude toward our supervisor Yasmeen Jaghbeer for supporting us throughout the thesis. We are also grateful to Chandan Manjunath at Volvo Cars for his guidance and support, which have greatly contributed to the development of our work. Finally we would like to thank the engineers within the department for participating in our discussions and valuable guidance in shaping our ideas.

Table of Content

1. Introduction

In this chapter, the thesis' problem statement and project purpose are introduced, along with the background of the issue. Additionally, the crucial aspects and limitations of the problem are presented.

1.1 Background

High voltage batteries are becoming increasingly important in the automotive industry as the demand for electric vehicles continues to grow. Assembling these batteries to the car body is a crucial step in the manufacturing process of electrical vehicles, and it requires a high level of precision and accuracy to ensure the safety and performance of the vehicle (Lowry J & Larminie J, 2012). An investigation in a manual or automated setup will be done for the factory in Slovakia. A proposal of a new concept will be done based on benchmarking and investigation on effectiveness and efficiency.

Effectiveness and efficiency are both important in manufacturing because they determine the overall productivity and profitability of a manufacturing process. According to Jacobsen & Thorsvik (2021) effectiveness refers to the ability to produce high-quality products that meet customer requirements and industry standards. This while efficiency, on the other hand, refers to the ability to produce those products in a timely and cost-effective manner. In order to analyse the effectiveness and efficiency, relevant KPIs will be evaluated.

Evaluating the ergonomic design of the work environment includes assessing the work environment and the ergonomics of the tools and equipment used. By identifying any ergonomic issues, solutions could be implemented to improve worker productivity and ultimately increase the effectiveness of the manufacturing process (H.J Bullinger, 1997).

The economic aspects of the manufacturing process includes the machines, equipment and labour. By analysing these costs, it is possible to identify areas where cost-saving measures could be implemented, such as automation or lean manufacturing methods. These cost-saving measures could help to improve the efficiency of the manufacturing process and ultimately increase the profitability of the business. The economic aspects of the manufacturing process will require different cost-saving methods depending on in which country the factory analysed is placed. For instance, the labour cost is lower in Slovakia compared to Sweden. This enables more manual work, which requires a lower cost investment.

1.2 Purpose

The purpose of this thesis is to design and develop a tightening process layout and technical solution for assembling batteries in Volvo's electrical vehicles, specifically focusing on the factory in Slovakia. The study will investigate various technical solutions involving manual, automated, and semi-automated tooling.

The platform designated for the production of the new electric car has the capacity to manufacture several distinct models. Depending on the size of the car-model, a varying number of screws, ranging from 26 to 32, may be required. The Slovakian factory has been allocated the responsibility of producing a new car model, which necessitates the use of 26 screws. In order to retain flexibility and the ability to produce alternative car-models , a general description of the production processes will be provided throughout the thesis.

The project will be predicated upon the cycle time for one station established in the Slovakian factory, which currently stands at 80 seconds. The processes will be based on this metric. Once various setups have been explored, a comparison matrix for relevant Key Performance Indicators (KPIs) will be established to assess the optimal option. The KPIs will be the support for our suggested solution. The KPIs that will be considered in the comparison matrix is:

- Investment
- Geometry-control
- Space requirements
- Ergonomic aspects
- Flexibility to grow new architecture

The investment KPI measures cost for machines, equipment and labour located to the process. It is critical to evaluate the overall financial impact of the initiative. Geometry control measures the effect the decking process has on the geometry of the body. It is important to maintain operational efficiency and consistency in manufacturing processes. Space requirements measure the efficiency of the production process in terms of space utilisation. It is crucial to reduce overhead costs and increase profitability, especially in high-cost manufacturing operations. Ergonomic aspects refer to the study of how people interact with their work environment, including tools, equipment, and the overall manufacturing process. Flexibility to grow new architecture measures the company's ability to adapt and scale their manufacturing process to accommodate new product architectures . It is critical to remain competitive and respond to changing market demands in the rapidly evolving automotive industry. By optimising these KPIs, Volvo can achieve greater efficiency, profitability, and competitiveness in their car manufacturing operations. The KPI’s is described further in section 3.6.

It is important to note that the thesis work will have limitations in terms of scope. Firstly, the project will focus on presenting a digital concept, and there will be no physical prototype or similar produced. As a result of a high level of confidentiality, certain information will not be included in the report. The time restriction for the thesis imposes limitations on the scope of the work.

2. Frame of reference

The *frame of reference* section serves as a critical component in providing the reader with an in-depth understanding of the research problem and its significance within the broader field of study. Through a comprehensive analysis of relevant literature and documentation from Volvo, the *frame of reference* section aims to provide the reader with the necessary knowledge and context to appreciate the scope and complexity of the research question, as well as its potential implications for theory, practice, and policy.

Section 2.1, provides an overview of the electric vehicle industry to give the reader contextual background. Sections 2.2 and 2.3 delve into Volvo as a manufacturing company, including details on its various factories. In section 2.4 design and processes for battery assembling is presented. In section 2.5 furnish information on tightening processes is presented, which is the main focus in the project. Furthermore technical requirements, and the range of setups available for the process is presented in 2.5. Section 2.6 introduces the concept of AGV (automatic guided vehicle) as a transportation solution in Volvo's manufacturing process. Finally, Section 2.7 touches upon ergonomic considerations.

2.1 Electric vehicle industry

The electric vehicle industry has undergone rapid growth in recent years. According to Lebrouhi et al. (2021) a substantial reason for this is that governments worldwide have set ambitious targets and stricter emissions regulations, which is driving the development of more efficient and cleaner vehicles. This increases the adoption of electric vehicles as a means of reducing carbon emissions and addressing climate change. The industry is constantly evolving, with new technologies and trends emerging regularly. Some of the current trends include the shift towards electric vehicles, connected cars, and autonomous driving.

2.2 Volvo’s factories

Volvo Cars operates factories across the globe, each with its own unique considerations and challenges. Depending on the production volume of a given plant, different solutions may be more advantageous. Even though the plants have different considerations the production layout is very similar. An essential consideration in the selection of a setup and process is the assessment of various costs. The labour cost, along with the purchase cost of robots, assumes particular significance in this regard.

The project prerequisites a cycle time of 60 seconds in the Swedish factory, as stipulated by Volvo stakeholders. Meanwhile, in China, the cycle time is 120 seconds, and the plant produces 30 cars per hour. In Slovakia, the cycle time is 80 seconds, allowing the plant to produce 45 cars per hour.

The tightening process that will be implemented in the Swedish and Chinese factories is nearly completed and will be taken into consideration when evaluating the process design for the Slovakian plant. The factory in Slovakia is currently under construction and is not yet operational. Regarding the process setup for the Volvo Cars plant in Slovakia, there are several possible approaches. One alternative entails manual operation by human operators, whereas another involves automation through the use of robots. A third option involves a hybrid solution, combining both robotic automation and human operators.

2.3 Inside the factories

Section 2.3.1 provides a description of Volvo's factory layout. In section 2.3.2, the focus is the utilisation of platforms.

2.3.1 Layout

The layout of a car manufacturing plant plays a crucial role in determining the efficiency, quality, and overall cost of production (Hassan, 1994). As such, it is essential to periodically reevaluate and optimise the layout to meet changing demands, market trends, and emerging technologies.

Volvo Cars follows a standardised line layout for the production of all its vehicles, with the A-shop, B-shop, and C-shop forming the primary stages of the assembly process. The C-shop, which represents the final assembly stage, involves the placement of various components such as the panoramic roof, windshield, and bumpers. In the context of the project at hand, the focus will be on the C-shop, where the tightening process for the battery will be performed as the first step.

2.3.2 Platform

Volvo has a few different platforms for their vehicles. A platform refers to a shared set of design and engineering components that form the basic structure of a vehicle (Simson, Jiao, Sidique, 2010). The underlying platform of the car is the same but each model has the unique body style and features. This approach enables car manufacturers to streamline their manufacturing processes, reducing the time and resources required. Volvo has adopted a platform strategy to facilitate the development and production of several of its car models. For this thesis the investigation will be based on t platform.

2.4 Design and processes for battery assembling

Volvo Cars currently assembles its electric vehicles with battery packs attached to the floor of the car. However, in order to reduce costs and weight, the company is exploring the use of "open floor technology," in which a high-voltage battery serves as the floor (as shown in yellow in figure 1). This technology is a new solution that has been adopted by other companies in the car industry, including Tesla, which also uses an open floor design with the battery serving as a structural component of the body. When the car body arrives at the C-shop, which is responsible for final assembly, it will not have a floor, making the structure inherently weak and susceptible to deformation. Once the battery is assembled, however, the body becomes more rigid, and the overall strength is improved.

Figure 1. Battery orientation in Car-body (Volvo cars, 2023)

The new solution will involve tightening 26-32 screws beneath the car using two different variations, depending on the car model being produced. The number of screws needed will vary based on the specific car model. The tightening process will be performed with the same strict standards to guarantee that consistent quality and safety levels are upheld.

2.5 Station for tightening process

The tightening process that will be implemented in the Swedish and Chinese factories is decided and will be taken into consideration when evaluating the process design for the Slovakian plant. The factory in Slovakia is currently under construction and is not yet operational. The estimated time for operation start is the year 2026. Regarding the process setup for the Volvo Cars plant in Slovakia, there are several possible approaches. One alternative entails manual operation by human operators, whereas another involves automation through the use of robots. In section 2.5.1 the palette and its importance is described and in section 2.5.2 screw feeding is described. Further in section 2.5.3 will present the automated setup and section 2.5.4 will present the manual setup.

2.5.1 Pallet

Volvo uses pallets during the production of their cars. To assemble the battery to the car body those pallets are of important use and are necessary to create a safe, secure and ergonomic work environment. The palette is illustrated in figure 2. The pallet serves as a platform for the transportation and storage of all the car components for the undercarriage and provides a stable surface for the movement. In the production of the new car model, the battery will be assembled on a pallet. On the palette there are pins that guide the battery toward the car body. The pins are a support for the battery in xy direction guiding support. It also has z direction guiding support where the undercarriage, in our case the battery, lays on.

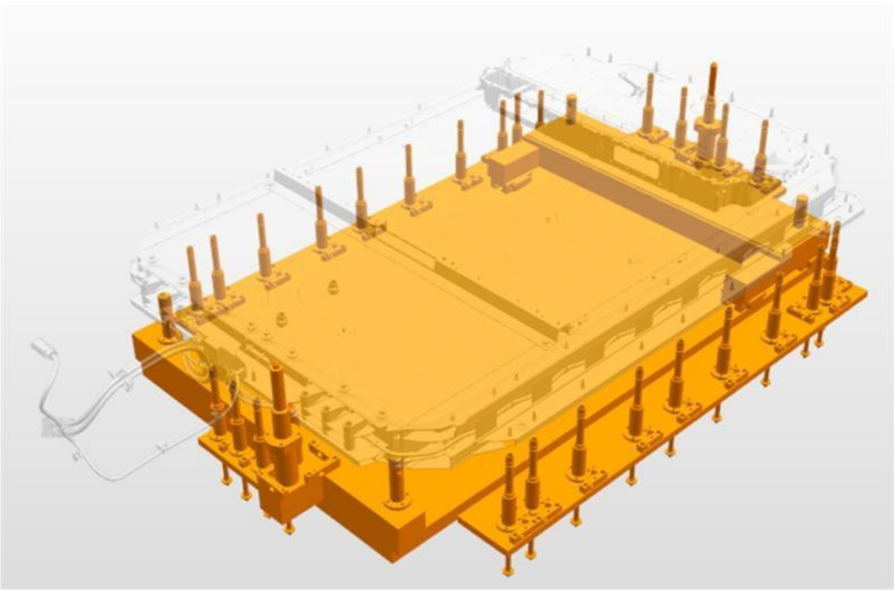


Figure 2 . Illustration of pallet (Volvo cars, 2023)

2.5.2 Screw feeding

Prior to the tightening process, the screws need to be loaded. This is called screw feeding. For a manual screw feeding the screws are loaded to the spindles by operators. In an automated screw feeding the screws are fed directly to the robot via automated machines or directly to the pallet.

2.5.3 Automated setup

Automated production refers to the use of technology to perform tasks that were previously done by humans. Automated production and robotics has had a big part in the manufacturing industry in the past years (Tessaleno et.al. 2017). The reason for this is especially because of the high flexibility, high quality, low costs and efficiency that the machines prevent. Another benefit with using robots instead of human workers is that they can work around the clock and do not have a need for a break. One potential approach is to employ a mixed setup, where an automated configuration can be utilised in conjunction with manual setup. This allows for the integration of both automated and manual processes. It is crucial to note that, due to safety regulations imposed by Volvo, it is not feasible to combine manual labour with robots. However, incorporating automated tools, lifts and equipment alongside a manual setup is permissible. Employing automated aids for operators in a manual setup is time-efficient and greatly contributes to the efficiency of the assembly process.

2.5.3.1 Robot tightening

An automated setup can include a robot. Robots are commonly used in car manufacturing to tighten screws as part of the assembly process. This is because robotic screwdrivers can provide consistent, precise torque and speed, which can be challenging to achieve manually. Robotic screwdrivers (shown in *figure 3*) can be programmed to tighten screws to specific torque values, ensuring that each screw is tightened to the same level of tightness. This helps to improve the overall quality and reliability of the car.

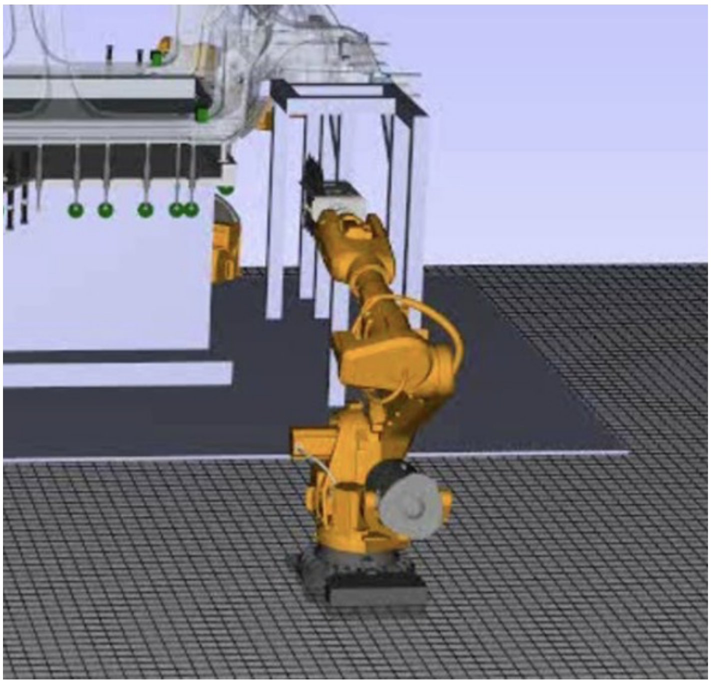


Figure 3. Illustration of a robot for tightening process(Volvo cars, 2023)

2.5.3.2 Automated nutrunners

An automated nutrunner with a built-in screwdriver is a powerful tool commonly used in assembly line production. This tool consists of a motor and a spindle, which are connected to the screwdriver bit that can be programmed to fasten bolts and screws to a specific torque value. This design enables you to tighten all the screws at one go. The nutrunners are shown in *figure 4* on the pallet, whereas one of them is marked with a pointer.

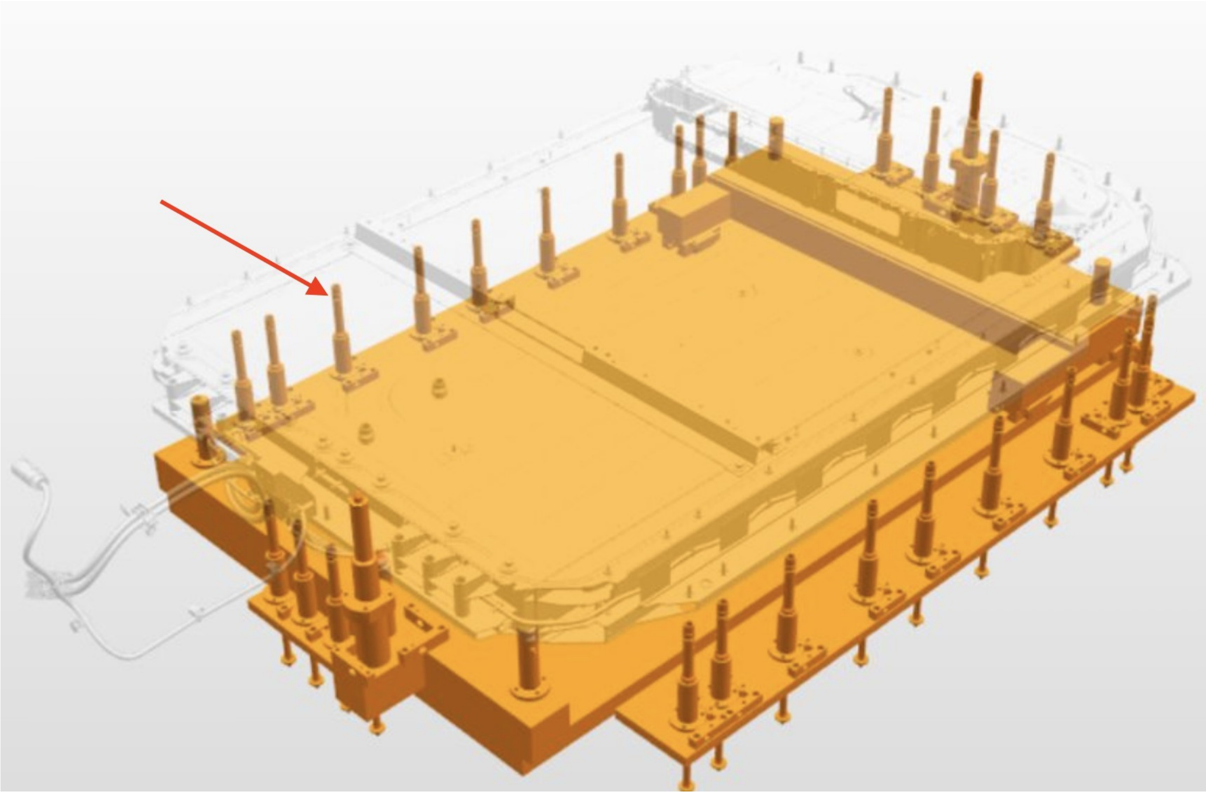


Figure 4. Nutrunners on pallet(Volvo cars, 2023)

2.5.4 Manual setup

A manual setup that involves operators is very common in the manufacturing industry. It is often used in production where the variety of products is high, hence there is a high flexibility to change the setup and the process. In comparison with an automated setup it can be difficult to reprogram machines to perform new tasks or to adjust to changes in the production requirements. Another advantage with using operators is that they can provide valuable feedback to changes and improvements. In addition to this, the manual setup doesn't require a repair station due to the flexibility of the operators. If something needs to be adjusted the operators are able to do this while the process is running.

2.6 The Key Performance index

In this section, the Key Performance Indicators (KPIs) that will be employed in this thesis are presented. These KPIs will gauge various aspects of different solutions, enabling a comparison to identify the most optimal solution. The chosen solution will be proposed as the new concept.

2.6.1 Investments

Investment requirements can differ depending on the setup chosen. For instance, implementing an automated setup involves acquiring robots, which can be quite costly. However, the effectiveness of robots may justify the high upfront investment. On the other hand, using human operators is a cheaper option initially, but in the long term, it can be costly for the company due to the need to pay their salaries every month. In contrast, robots only require one-time purchase and maintenance costs for the company. Investment costs for transportation between the stations, solution for screw feeding and other crucial parts of the process is also taken into consideration.

2.6.2 Geometry control

According to Volvo documentation the geometry control includes measurements with 6 sensors before and after the bolting to the body. The concept of a structural battery decking to the body has an effect on the geometry of the body. The geometry control isn't something investigated in this thesis but is a crucial step in the process and is therefore taken in consideration. Notably, the body is weaker compared to the battery, which functions as a structural component and is the strongest part. Therefore, if the battery is tightened to the weaker part, it will conform to the stronger part, and a body outside the specification indicates a flawed design.

2.6.3 Space requirements

To design a process at a particular station, it is crucial to determine the required amount of space. This is because the space needed can vary depending on the solution employed. Opting for a solution that requires less space can be advantageous, as it allows for more space allocation to other stations in the factory. For this process the robots require more space to be able to operate than what operators do.

2.6.4 Ergonomic aspects

When designing the process for operators it is important to think of the ergonomics aspects. Ergonomics is the study of how to design equipment and environments to minimise physical strain on the user (Dennis et.al. 2004). The ergonomic aspects are important to consider in order to ensure a good environment for employees in an organisation. This prevents them from injuries and other health consequences, which in turn also prevent the organisation from unnecessary cost. In our thesis, we emphasise that a conducive ergonomic environment for assembly work comprises elements such as an appropriate working height, the utilisation of suitable tools, and the provision of good accessibility.

According to Volvo Car's documentation regarding ergonomic requirements the optimal height positions for hands for male is 1000-1400 mm and for women 800-1100 mm. This is illustrated in *figure 5*. The green area is the most optimal ergonomic height, the red area is the worst scenario.

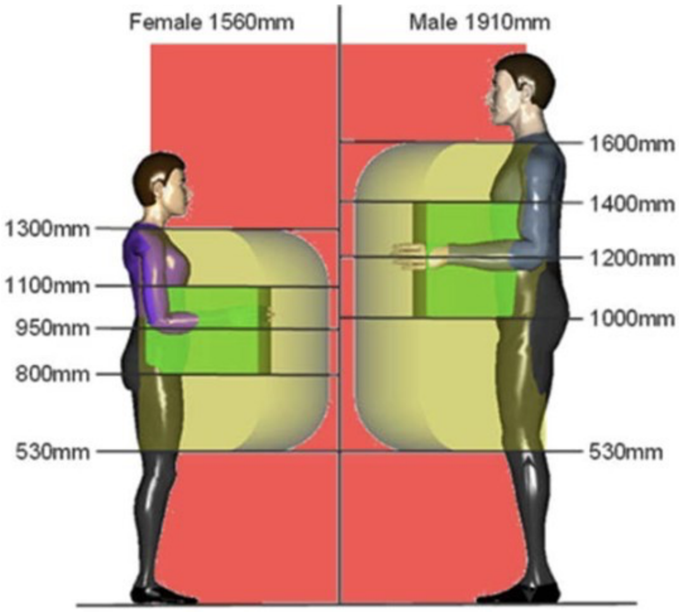


Figure 5. Ergonomic zones for male and women(Volvo cars, 2023)

Assembling a battery manual requires tightening screws from underneath which is not ergonomic suitable. Using a spindle when assembling has several ergonomic benefits. It makes the task easier and minimises the risk of ergonomic injuries. The spindle is a tool that holds the screw in place and allows the user to turn it with minimal effort, which reduces the risk of hand and wrist strain (see *figure 6*). The screw will already be loaded so the operator will not be required to look up and load it manually. Additionally, a spindle helps to keep the screw in place, preventing it from slipping and reducing the need for the user to hold it in place. This can help to reduce the risk of repetitive motion injuries and muscle strain. Using spindles is better for the operator and a quick process, though a more expensive solution. Using spindles when tightening is also known as having a rich pallet.

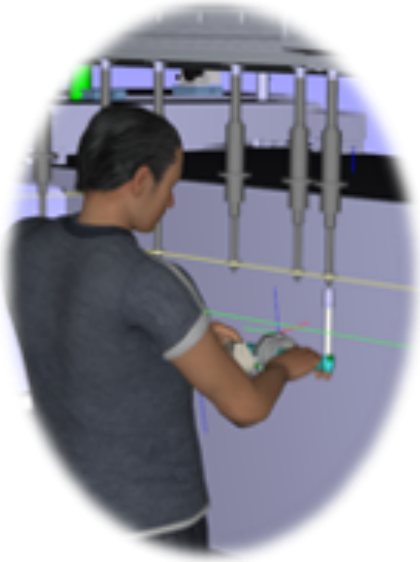


Figure 6. Operator using spindel to tighten screws (Volvo cars, 2023)

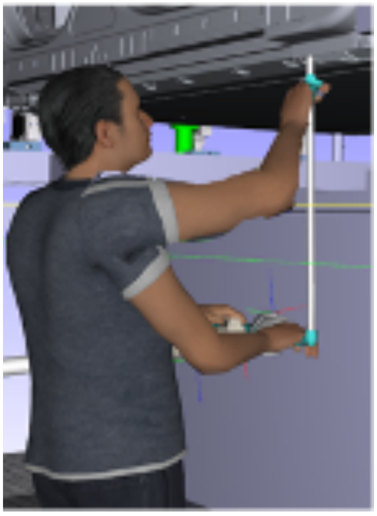


Figure 7. Operator not using spindel to tighten screws (Volvo cars, 2023)

Poor pallet means that the screws are tightened without spindles. In this case the neck and hands/arms are in yellow and red zones. Neck is tilted backwards due to the need to see fasteners (see *figure 7*). Tightening tool held with a lifting arm will reduce weight but not vibration and all torque forces. Using a rich pallet with spindles is more ergonomic. The neck and hands/arms will be in a good working zone. Tightening tool held with a lifting arm that takes up weight and torque forces. Therefore, using spindles is mandatory to use with the manual setup.

2.6.5 Flexibility to grow new architecture

The layout's space protection feature offers flexibility for developing new architectures, which is essential for producing various types of cars with different platforms on the same assembly line. For instance, Volvo can produce a car model beyond what is planned for the factory in Slovakia which for instance has a larger platform.

2.7 Technical requirements

Technical requirements are crucial because they ensure that the station is capable of performing its intended function. By defining the specific requirements that must be met, technical requirements provide a clear set of guidelines that help to ensure that the station is properly equipped and configured to meet its objectives. Additionally, technical requirements help to ensure that safety and quality standards are met and maintained, reducing the risk of defects, safety hazards, and other issues that could negatively impact the final product.

2.7.1 Clearance

To ensure that the decking process proceeds smoothly and without incident, it is necessary to maintain a sufficient clearance between all parts and the body on the pallet during the assembly process. In accordance with manufacturing requirements, a minimum clearance of 15 mm is necessary for all parts to prevent conflict. If the clearance is not sufficient, additional geometry tolerance calculations must be performed to ensure that all parts are properly positioned and aligned during the assembly process. By strictly adhering to these clearance requirements and performing the necessary calculations as needed, it is possible to maintain a safe and efficient assembly process that meets the necessary quality and safety standards.

2.7.2 Body handling points

The new electric vehicle will feature a high-voltage battery that replaces the undercarriage. The fornt design of the battery is fixed and only the rear part of the battery is designed to fit different car sizes. The battery is defined in x direction in rear. For example, smaller cars produced in China require smaller batteries. To ensure standardisation across all models, the battery features "body handling parts," that maintain a consistent appearance, length, and screw placement. Any necessary modifications must be made outside of these designated areas (highlighted in the box in *figure 8)* to maintain consistency and avoid potential issues during assembly. By following these standards, the assembly process can proceed efficiently and effectively, resulting in high-quality, standardised products. This is a part of Volvo's strategy with the R&D department to be able to handle different battery sizes in the same process.

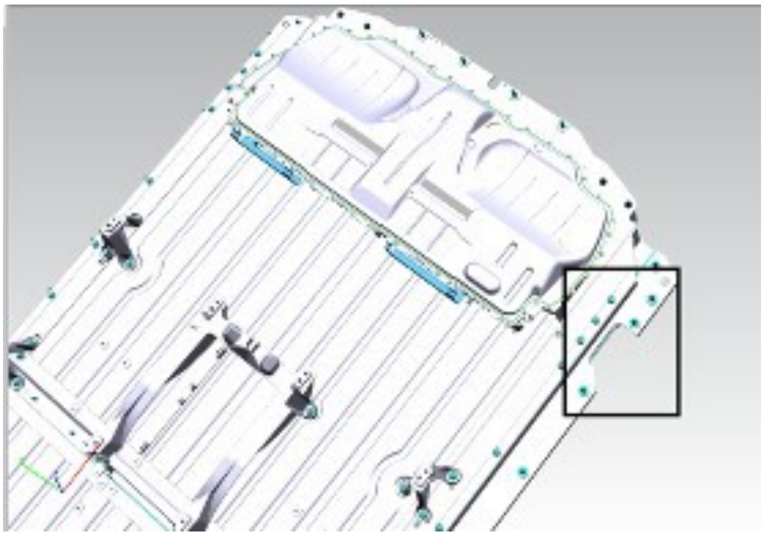


Figure 8. Body handling points on battery (Volvo cars, 2023)

2.7.3 Divorced guidelines

Since the structure of the car body is relatively weak compared to the battery, the body will deform to the battery. However it is crucial that the body does not deform too much or cause any problems. According to simulations and testing Volvo has decided that there are 10 screws that need to be placed in the first station. *Figure 9* illustrates the battery and the 10 required screws are shown as the green parts. This concept of assembling batteries is the same on all plants.

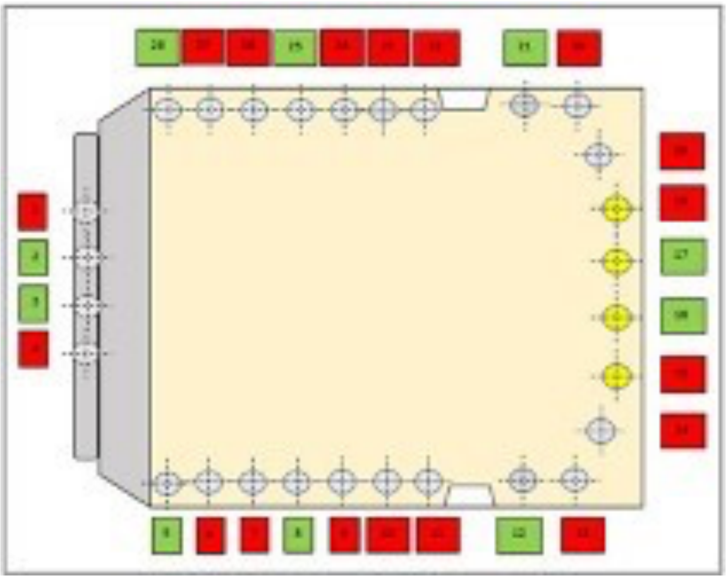


Figure 9. Divorced guidelines

(Volvo cars, 2023)To tighten more than the 10 screws in the first station are preferred to mitigate the risk of a failed tightening process. In the event of a failure, an operator would need to manually tighten the screw, which is a time-consuming process. By increasing the number of screws tightened in the first station, the likelihood of all the required screws being tightened correctly is higher. If an additional screw is not tightened correctly, the process can continue, and the issue can be resolved during the next station. Historic data from Volvo's bolting table in Torslanda shows an availability of 99%. Therefore, out of 10,000 cars, 100 cars are expected to have faults. Though, in a manual setup, 10 screws tightened in the first station are sufficient since the operator can address any issues without stopping the process. The 10 screws in question are depicted in *figure 9*, specifically identified as the green screws.

2.8 Transportation methods

To transport the battery and the car body there are different methods. In section 2.8.1 Automated guided vehicle (AGV) is presented followed by conveyor belt in section 2.8.2, hangers in section 2.8.3 and skillet line in section 2.8.4. These transportation methods will be taken into consideration when designing the new concept.

2.8.1 AGV

In line with the digitalisation and the spirit of the 4.0 industry AGV has been more common to use in the automobile industry (Liu, 2020). AGVs are self-guided vehicles (see figure 10) that are used in a variety of industries to transport materials and goods. AGV usage in Volvo factories globally has increased due to flexibility and wide range of usability. Though there are many advantages, it is expensive to implement. *Figure 10* illustrates a factory with cars on AGVs.

Figure 10. Automatic guided vehicle (Agefotostock, accessed 2023)

2.8.2 Conveyor belt

A conveyor system is a mechanical equipment used for transporting materials from one location to another, which is especially useful for heavy or bulky items (Shinde & Patil, 2012). They are commonly used in material handling and packaging industries, and can safely transport loads of all shapes, sizes, and weights. Conveyor systems can be hydraulic, mechanical, or fully automated, and there are various types available, including gravity, powered belt, pneumatic, vibrating, flexible, vertical, and live roller conveyors. They are widely used in many industries, including automotive, agricultural, food processing, pharmaceutical, and packaging. Factors to consider when selecting a conveyor system include its intended use, the material sizes and shapes, and loading and pickup points.

2.8.3 Hangers

In car manufacturing, a hanger is a device used to hold and transport car bodies or parts throughout the various stages of the assembly process. The hanger is typically attached to an overhead conveyor system and moves the car body or part from one workstation to another. This is illustrated in *figure 11.*

Figure 11. Car body in hanger(Mobility Engineer technology, accessed 2023)

2.8.4. Skillet line

In car manufacturing, a skillet refers to a type of assembly line that uses a moving platform to transport vehicles through the various stages of production. The skillet is a large metal structure that supports the vehicle as it moves down the assembly line, and it can be adjusted to accommodate different types of vehicles. This is shown as the floor that the operator stands on in *figure 12.*

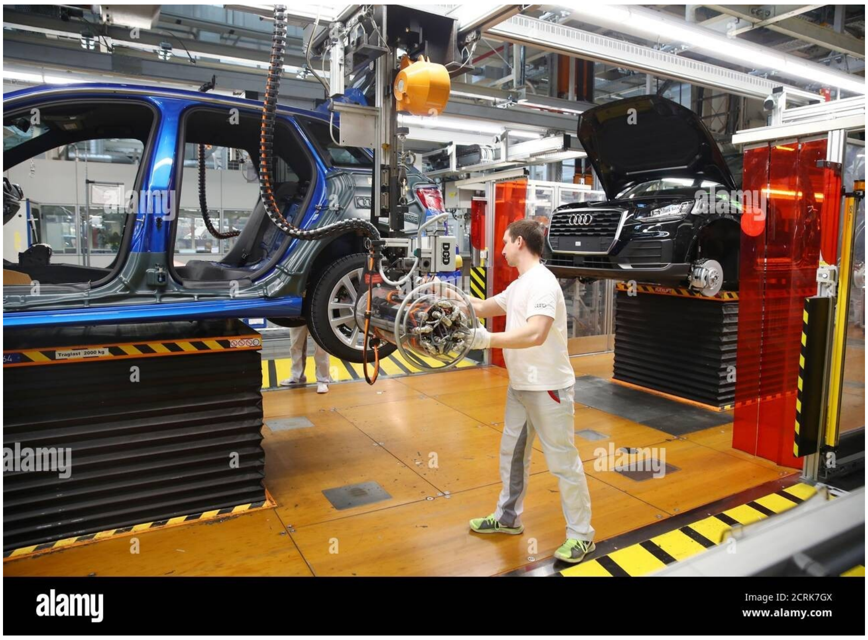


Figure 12. Skillet line (Alamy, accessed 2023)

3. Method

The use of research methods and methodologies is crucial when conducting research or degree projects to ensure proper, correct and well-founded results. According to A. Håkansson (2013) it is important to use them at the beginning of the process to support the research and affect the outcome. The methodology of this project has involved a combination of research, observation, benchmarking, focus groups, simulation testing, and comparison analysis. The strategy for conducting a research or degree project is crucial for obtaining correct and valid results, achieved through the implementation of different methods (Håkansson, 2013).

Initially, an analysis was conducted to examine the present techniques and technologies utilised in the assembly procedure within Volvo's factories. Information was gathered on the Key Performance Indicators (KPIs) acquired from the process solutions employed in Sweden and China, Volvo's documentation, and observations. This included a visit to the research and testing facility in Torslanda, where a prototype of the high voltage battery was accessible, and multiple trials of the decking and tightening process were carried out to observe the sequence of events and duration.

The thesis utilised benchmarking as another research method to gain insights into industry practices and standards. Comparable companies that employed similar techniques were analysed through benchmarking, providing a comprehension of industry norms. Benchmarking is a research technique that identifies best practices and areas for enhancement, making it an indispensable tool for businesses striving to improve performance, remain competitive, and enhance credibility (Raymond, 2008). The benchmarking process consisted of watching videos of various companies' car manufacturing processes on YouTube. This approach yielded valuable information and inspiration for enhancing performance and gaining a competitive edge to the new concept.

To gain a more comprehensive understanding of the current situation in section 4, information has been collected from Volvo documentation. In addition, weekly meetings with experts and our supervisor have been held. Within these meetings, we received information and diligently wrote notes. In the context of our metholody it is crucial to acknowledge the risk of subjective when engaging in conversation with individuals within the same company. To reduce this risk, numerous interviews was held in order to get a broader perspective. The information utilised in section 4 is also employed in section 5 for the purpose of comparison. By gathering data on the present situation, valuable insights were gained to facilitate the development of an improved and new concept seen in section 6. Section 6 introduces a new concept built upon the existing situation as a foundation.

Investigations have been conducted to enhance key performance indicators (KPIs). Valuable insights have been derived from benchmarking and drawing inspiration from other companies by closely observing their factory operations through YouTube videos. Additionally, valuable information provided by Volvo regarding various transportation methods, equipment, and tools has been analysed and incorporated into the concept.

The methodology chosen for the research project serves as a guideline and includes mainly qualitative research. Qualitative research focuses on collecting and analysing non-numerical data, such as words, images, and observations, in order to understand the experiences, thoughts, and perspectives of individuals or groups (Creswell, 2009). The goal of qualitative research is to gain an in-depth understanding of complex social phenomena, rather than to test hypotheses or establish generalisations. Examples of qualitative research methods include interviews, focus groups, ethnography, and content analysis.

The qualitative research methodology employed in this report involved utilising focus groups to gather valuable insights from subject matter experts across various domains. A focus group is a systematic and structured conversation that involves a carefully selected group of individuals, aimed at eliciting a collective perspective on a specific research topic (Coe et al. 2017). For this report, focus groups were the primary qualitative research method and included engineers, ergonomic experts, and equipment engineers, among others. The goal was to obtain diverse perspectives and evaluate the feasibility of the recommended technical solution. To ensure the accuracy of the gathered data and mitigate the risk of misinformation, the interviewees were given the opportunity to review our notes and confirm the accuracy of the information contained therein.

When conducting research, it is essential to ensure its quality, reliability, validity and generalisability. The methodology used in this research project involved a combination of research, observation, benchmarking, focus groups, simulation testing, and comparison analysis. The project employed both quantitative and qualitative research methods, which are widely accepted in the scientific community. Quantitative research is a reliable and valid method, which requires standardised methods and instruments for data collection and analysis. In contrast, qualitative research focuses on understanding the experiences, thoughts, and perspectives of individuals or groups, providing a deeper understanding of complex social phenomena. The research process also includes various techniques, including benchmarking and simulation testing, to ensure the accuracy and reliability of the results. To ensure the generalisability of the findings, the research team used a range of data sources, including Volvo documentation and observations, visits to research and test plants, and interviews with subject matter experts from various fields. By employing these research methods and techniques, the project aimed to obtain valid and reliable results that could be generalised to larger populations and contribute to the improvement of the assembly process in Volvo's factories.

The recommended technical solution got tested and presented in the simulation program Catia. Simulation is a computer-based modelling technique used to evaluate the performance of complex systems or processes (Carone, 2014). This approach is particularly useful when conducting real-world testing proves challenging or cost-prohibitive, as it provides a cost-effective means of evaluating real-world systems. The objective of using simulation is to determine whether the recommended process is efficient, effective, and safe for employees. To ensure accurate information and data, collaboration with specialists within the company has been done. Our supervisor at Volvo, along with other team members, have provided us with necessary guidance and support to access the correct data and information related to the project. Interviews have been held with experts in the manufacturing process with the roles:

Senior Manufacturing engineer, Chassie engineer, Global manufacturing engineer, Virtual manufacturing engineer, Geometry engineer and Global process leader. From these discussions we have been given information and also feedback of our solution along the work. Furthermore, information and data from suitable literature on academic databases such as Google Scholar has been used.

4. Current situation analysis

In order to devise an optimal solution for the factory in Slovakia, an analysis of the solutions decided for the factories in Torslanda and China is imperative. This approach would enable a comprehension of the elements that align most suitably with the unique conditions prevalent in each respective country.

Section 4.1 describes the intended implementation of AGV in factories, while Section 4.2 elaborates on the planned layout. Additionally, Section 4.3 outlines the manual setup in China and the automated setup in Torslanda.

4.1 Cycle time

The factory in Slovakia operates with a cycle time of 80 seconds, allowing tightening station 1 and station 2 the same duration for drive-in, decking process, tightening process, and drive-out. Based on Volvo's standard calculations, taking into account the cycle time of 80 seconds and an availability rate of 95%, the effective available cycle time is determined to be 76 seconds. This calculation is made to mitigate the risk of downtime.

Based on Volvo Cars' documentation, the AGV requires 30 seconds to drive into tightening station 1, while station 2 has a shorter drive-in time of 5 seconds. Consequently, station 2 possesses a higher capability and allows for more time dedicated to the tightening process.

5 seconds is assumed for drive out time of AGV. This results in a time for tightening of 41 seconds in tightening station 1. For tightening station 2 the drive in time and drive out time separately requires 5 seconds. This results in a tightening process time of 66 seconds (see *table 1*).

This cycle time will apply regardless of automated or manual setup.

Tightening station 1	Time required
Drive in time to station 1	30 sec
Tightening process	41
Drive out time of station 1	5
Total time:	76 sec
Station 2	
Drive in time to station 2	5 sec
Tightening process	66 sec

Drive out time of station 2	5 sec
Total time:	76 sec

Table 1. Time required for different processes in tightening station 1 and tightening station 2

4.2 AGV

In order to enhance flexibility and accommodate future modifications, AGVs are planned to be implemented for the battery decking process in all three factories: Sweden, Slovakia, and China. The AGVs will be utilized for transportation throughout the entire manufacturing line. Initially, the AGVs will transport only the battery to the decking station. Subsequently, the car body with the assembled battery will proceed with the AGV after the decking station. *Figure 13* illustrates the process of battery decking onto the car body using an AGV.

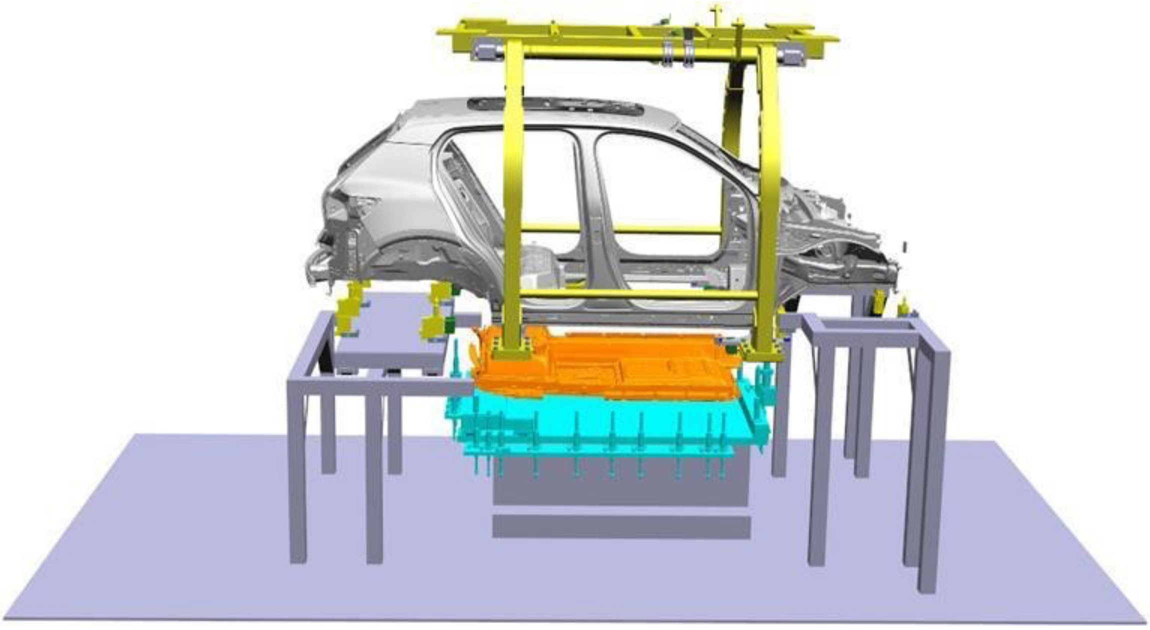


Figure 13. Assembled process for the battery with a AGV (Volvo cars, 2023)

4.3 Layout

The process layout is depicted in *figure 14* which illustrates the battery being dropped onto an
AGV at the top left corner, then following the stream towards the right to undergo pre-assembly and sealing at the respective stations. Following these stations is the first tightening station, where the car body arrives from the paint shop. A space protection for GPA 2.0 follows after the first tightening station, which is designed to be flexible and accommodate

the production of other car models in the future. The second tightening process follows this station, and the car then continues on to geometry control and the subsequent station.

The anticipated working time for each station in the process is 95% of the cycle time, allowing for a degree of tolerance in the duration. As a result, in Slovakia, this equates to 76 seconds out of a total of 80 seconds. The reason for this is that there may be occurrences of downtime during the process.

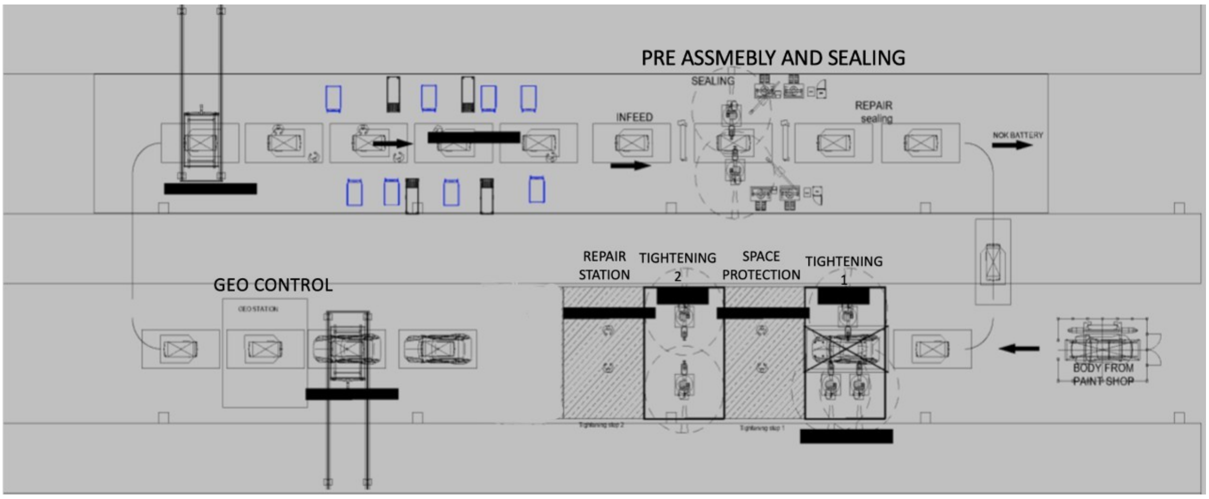


Figure 14. Layout (Volvo cars, 2023)

4.4 Manual and automated solution in the factories

We have collected information from the Torslanda and China plants through documentation provided by Volvo. Section 4.3.1 describes the automated tightening process planned for Torslanda. In section 4.3.2 the manual tightening process planned for China is described.

4.4.1 Automated tightening in Torslanda

In the Torslanda factory, the tightening process is set to undergo complete automation. The robot tightening 1 will consist of four robots (see *figure 15)* assigned to tighten a total of 16 screws, while robot tightening 2 will employ two robots to tighten the remaining screws, resulting in a total of 26-32 screws being addressed in the process.

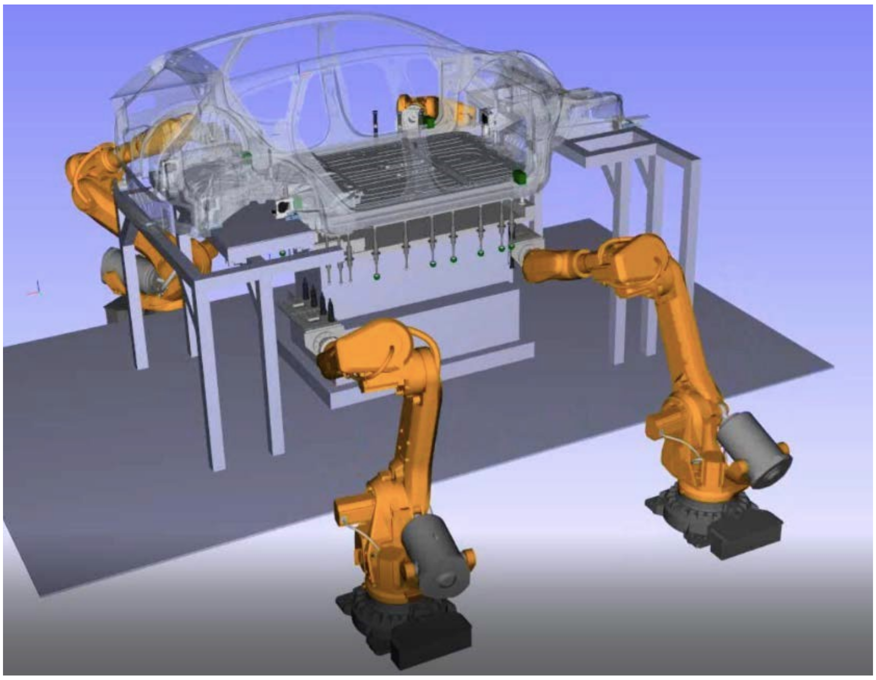


Figure 15. Robot tightening with AGV setup in Torslanda (Volvo cars, 2023)

Using robots in the factory's tightening process is considered the best solution due to the high labour costs in Sweden and the need for a shorter cycle time of 60 seconds to complete the task. To ensure the operation stays within the required time frame, the use of robots is necessary instead of human operators.

4.4.2 Manual tightening in China

In China, the tightening process will be solely executed manually by operators. At tightening station 1, three operators will utilise a nutrunner with a reaction arm to tighten 15 screws. At tightening station 2, each screw will receive more time, and thus, two operators will be responsible for tightening 13 screws, also using a nutrunner with a reaction arm. The manual setup is efficient and eliminates the need for a final repair station, as operators can promptly address any issues as they arise. Hence this setup is more flexible and adaptable if any change needs to be implemented. The manual tightening setup is illustrated in *figure 16.*

Figure 16. Manual tightening with AGV setup in China (Volvo cars, 2023)

The main driver for opting for a manual setup is the significantly lower labour cost in China. The labour cost in Torslanda is four times as much as in China and Slovakia. However, employing this alternative requires careful assessment of ergonomics since operators will be involved in the process. To meet ergonomic standards, the process necessitates the use of a pallet with spindles.

5. Comparison of automated and manual setup for tightening stations in Slovakia factory

In this section an investigation on automatic or manual setup for the planned layout presented in section 5 will be done. The new platform can produce cars that require between 26-32 screws. For simplicity reasons, the investigation is based upon 28 screws.

The process of tightening involves two stations, which may be operated manually or automatically, in this case with robots. However, it is crucial to understand that each station cannot facilitate both manual and automated operations simultaneously. This is because it would violate safety regulations and increase the risk of potential incidents. For instance, if a robot is employed, an operator cannot be in close proximity due to Volvo cars′ safety regulations.

5.1 Automated and manual setup

This section analyses the representation of the automated and manual setups for the proposed layout. In 5.1.1 an automated setup with robots for the tightening station is presented and in section 5.1.2 a manual setup is presented. The alternatives take into account the cycle time, the required number of operators and robots, as well as technical solutions. 41 seconds is used for the tightening in station 1 and 66 seconds for tightening in station 2, as presented in section 4.1.

5.1.1 Automated tightening with robots

Assuming the factory in Slovakia is automated, the same layout as planned for Torslanda would be utilised. Based on observations it takes 10 seconds for one robot to tighten one screw.

Station 1

For station 1 in a fully automated tightening process the cycle time will be 41 seconds (see *table 2.* As previously stated, a minimum of 10 screws must be tightened to maintain the car's structural integrity. However, using 16 screws is ideal to minimise the risk of one of the essential screws being faulty. Based on chart 2 the amount of robots that are required is therefore four as the tightening process is estimated to take 41 seconds and the amount of screws is 16.

Station 2

According to cycle time calculations the cycle time for station 2 is 66 seconds. For this station two robots will tighten 6 screws each.

Tightening process -	**Station 1**	**Station 2**
automated		
Time for tightening	41 sec	66 sec
Robots	4 robots	2 robots
Total number of screws	16 screws	12 screws
Time required for tightening one screw	10 sec	10 sec
Screws per robot	4+4+4+4	6+6

Table 2. Calculations for automated tightening process

5.1.2 Manual tightening

For the fully manual setup there will be operators at both stations. According to information from Volvo cars it takes 10 seconds for one operator to tighten one screw.

Station 1

The cycle time at the first station is 41 seconds, thus necessitating the deployment of three operators. In order to achieve full manual operation at the first station, the operator must tighten a minimum of 10 screws in accordance with the divorce guidelines. In the manual setup, it is not as crucial to tighten additional screws beyond those required as in the automatic setup. This is due to the operator's ability to adjust and repair the tightening process in the event of any issues. Therefore, a decision has been made to limit the tightening of screws to 10 in the first station.

Station 2

In station 2 the rest of the screws will be tightened, in total 18 screws. As seen in *table 3* these screws require 3 operators.

Tightening process - manual	Station 1	Station 2
Time	41 sec	66 sec
Operators	3 operators	3 operators
Total number of screws	10 screws	18 screws
Time required for tightening one screw	10 sec	10 sec
Screw per operator	4+3+3 screws	6+6+6 screws

Table 3. Calculations for manual tightening processes.

5.2 Comparison matrix

The comparison matrix illustrated in *table 4* displays a visualisation of the KPIs for the automated setup with robots and the manual setup. The investment cost and space requirement for robot tightening and manual tightening between the different countries are very similar. Therefore Torslanda and Slovakia share the same numbers for robot tightening and Slovakia and China for manual tightening.

The numerical data exclusively focuses on the tightening stations, as the automation or manual operation of these stations does not impact the other stations in the process.

	Robot tightening	Manual tightening	Comments
Investment (battery decking station)	Confidential	Confidential	Robot tightening requires 28,9% higher investment
Geometry control	OK	OK	Both setups will include geometry control station
Space (m2)	306 m2	97 m2	Robot tightening requires bigger space
Ergonomics	Not applicable	Rich pallet, OK	Rich pallet is ergonomical OK for manually setups
Flexibility to grow - new architecture	OK	OK	All setups have a space protection for new car

Table 4. KPIs for robot tightening and manual tightening

5.3 Recommended setup for Slovakia factory

According to the comparison matrix, the manual tightening setup has lower investment costs and space requirements compared to the automated tightening setup with robots. However, whether the automated setup is better also depends on the labour cost. As mentioned in section 4.4.2 the labour cost in Slovakia and China is four times of the cost in Torslanda.

Based on this analysis, we can conclude that the best solution for the Slovakian factory is the manual setup.

6. New concept proposal

Starting from the current situation, a new concept proposal has been created to achieve an efficient flow in a simpler manner and generate cost savings in investments. The subsequent sections will present the layout of the new concept and provide detailed explanations of its various stations.Valuable insights have been derived from benchmarking and drawing inspiration from other companies by observing their factory operations through YouTube videos. Additionally, valuable information provided by Volvo regarding various transportation methods, equipment, and tools has been analysed and incorporated into the concept.

6.1 New concept layout

The proposed approach is illustrated in *figure 17* and involves the exclusion of an AGV and instead, a conveyor belt will be utilised to transport the battery through the pre assembly station and sealing station until the stop position on conveyor belt. From there a ceiling mounted lift will transfer the battery from the conveyor belt to the bolting table. The painted car body will be transferred from the B-shop via hangers and connect to the process directly to the decking station. In the decking station the car-body and battery will be forced together and the screws will be tightened by automated nutrunners. These nutrunners have the capability to tighten all the screws at once, thereby allowing for consolidation into a single tightening station. After tightening the car body and battery as one unit will continue with the hangers through space protection, final repair station and geometry control station. In the following sections 6.1.1 until 6.1.9 the various stations will be explained more in detail. Appendix 2 shows an overview of the simulation.

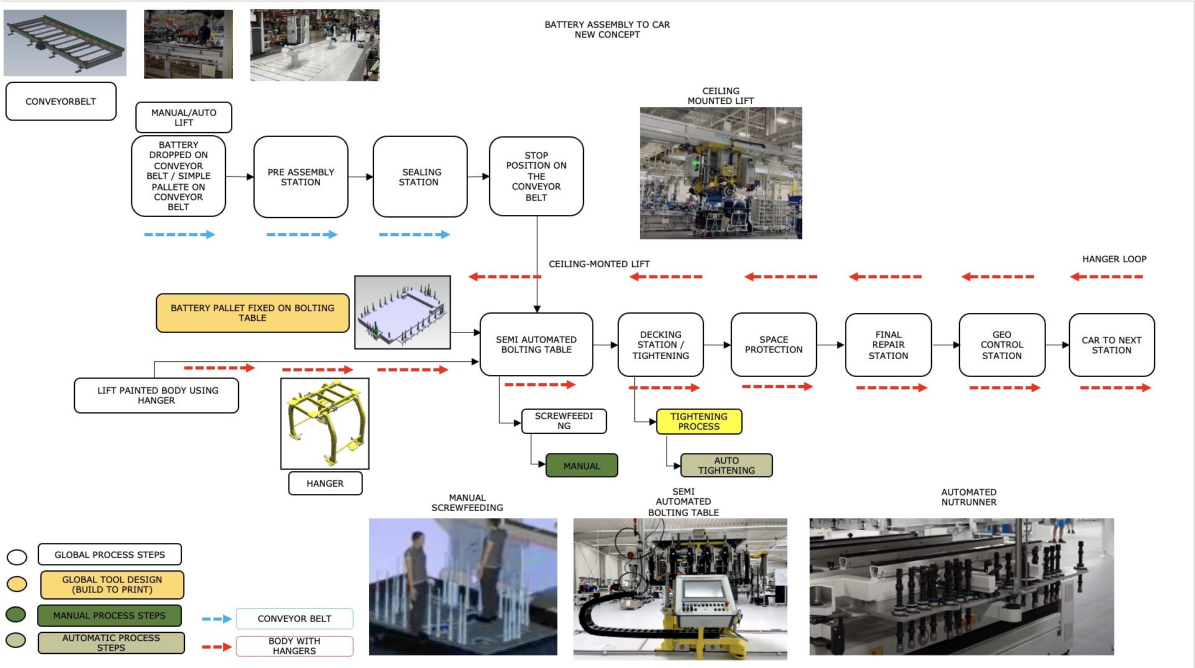


Figure 17. New concept layout

6.1.1 Battery dropped on the conveyor belt

In the new concept, the initial stage involves dropping the battery onto the conveyor belt at the first station. A hanger is used to pick up the battery from the prior line and place it onto the conveyor belt. Due to product demands and ergonomic aspects different options for the design of the conveyor belt will be presented in this section. It is of utmost importance to handle the undershield of the battery with care as it is highly delicate. Therefore, during transportation, it is critical to ensure that the undershield is not touched or disturbed. To ensure ergonomic considerations, such as suitable height for the operators and a safe working environment is crucial when designing the conveyor belt due to it going through pre assembly station. It is also important to provide the operators with good access to the battery, as attaching cords is one of the tasks carried out in the pre-assembly process.

Roller bed conveyor

The battery assembly line, which is the earlier line, has planned to use a conveyor belt to transport the battery. To obtain further details on the conveyor belt's configuration in the battery assembly line, an interview was conducted with a global manufacturing engineer at Volvo.

As per the interview, the company intends to employ a roller bed in the battery assembly line (see *figure 18*). This is primarily attributed to the battery's product requirements and investment considerations. Notably, the undershield of the battery is highly delicate, and thus, it is imperative to prevent it from coming into contact with the conveyor belt. Additionally, embossing is set to be performed underneath the battery, which will serve as its lowest point and is highly sensitive. There will be an interface at the battery's corners, approximately 50mm in size. To secure the battery in place on the conveyor belt, it is planned to feature wheels on the sides with vertical rotational axes (see *figure 19*).

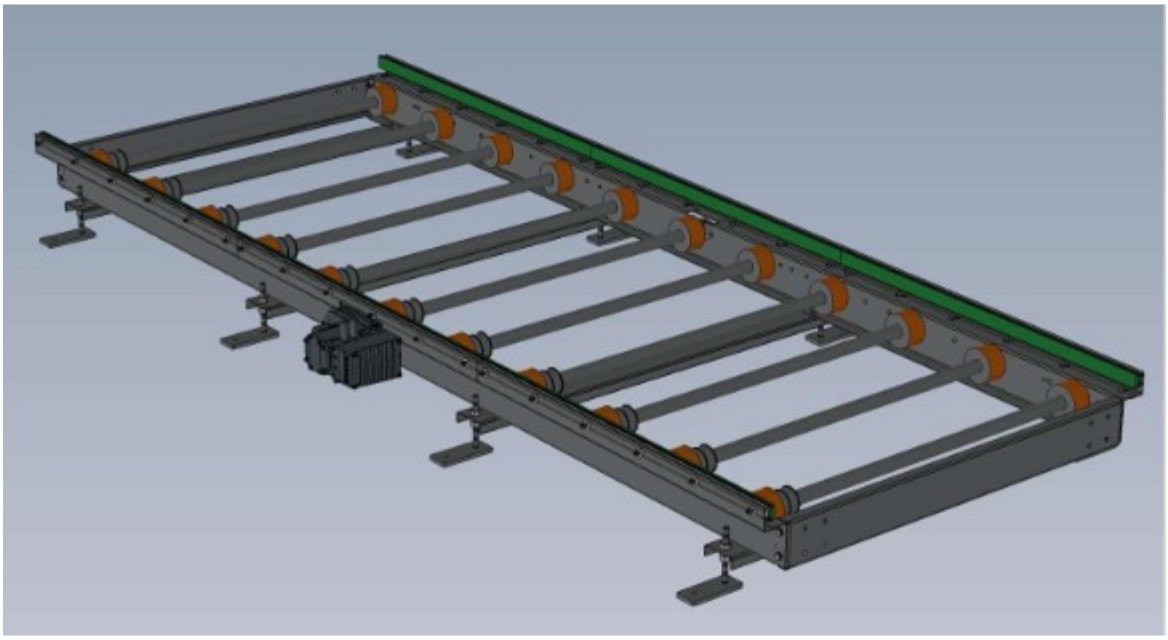


Figure 18. Planned example design of the conveyor belt for battery assembly line (Volvo cars, 2023)

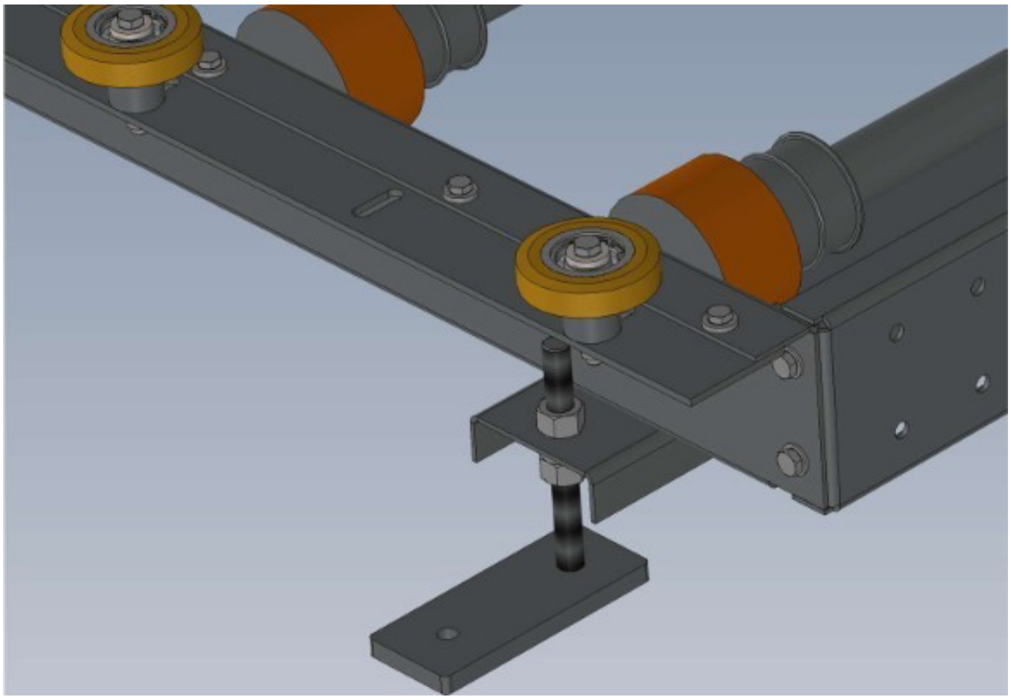


Figure 19. Wheels with vertical rotation axes (Volvo cars, 2023)

When selecting the appropriate conveyor belt, various observations have been conducted, and as a result, a distinct type of roller conveyor belt has been identified. From the observation done a different kind of roller conveyor belt has been seen. This has rollers on the sides (as seen in *figure 20*) which could be suitable for the battery transportation due to the interference only on the side. This has a lower risk for incidents and would also enable space under the battery and in the front and back.

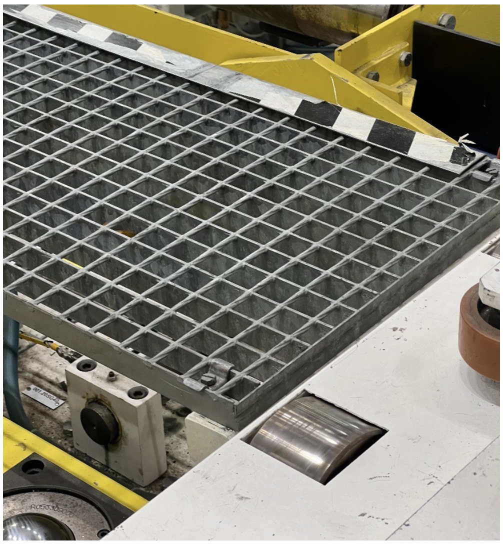


Figure 20. Conveyor Belt with rollers on the sides (Volvo cars, 2023)

Conveyor belt with simple pallet

If further investigation made by Volvo shows that the battery requires an easy pallet on the conveyor due to the pre assembly station, it is possible to have a return loop under the belt in order to transport the pallets back to the starting point of the conveyor belt, which is illustrated in *figure 21*. A conveyor belt with a simple pallet would help to protect the battery from any damage during the transportation which is a crucial aspect since the battery is highly delicate.

Figure 21. Easy palette on conveyor belt (Volvo cars, 2023)

Steel slat conveyor belt

A steel slat conveyor belt, as shown in *figure 22*, is a type of conveyor belt that is positioned in alignment with the floor and equipped with pins to secure the batteries. This solution offers several advantages. Firstly, it provides an optimal ergonomic working height, ensuring comfort and efficiency for the operators. Additionally, it enhances the accessibility for the operators working with the harnesses connected to the battery during the pre-assembly process. Overall, the steel slat conveyor belt proves to be a beneficial choice due to its ergonomic advantages and improved reachability for the operators. An option solution is to have four pins that keep the battery in position. Based on discussions with engineers at Volvo and the documentation they provided regarding prices for different solutions, it was determined that this design is more costly compared to a standard roller bed.

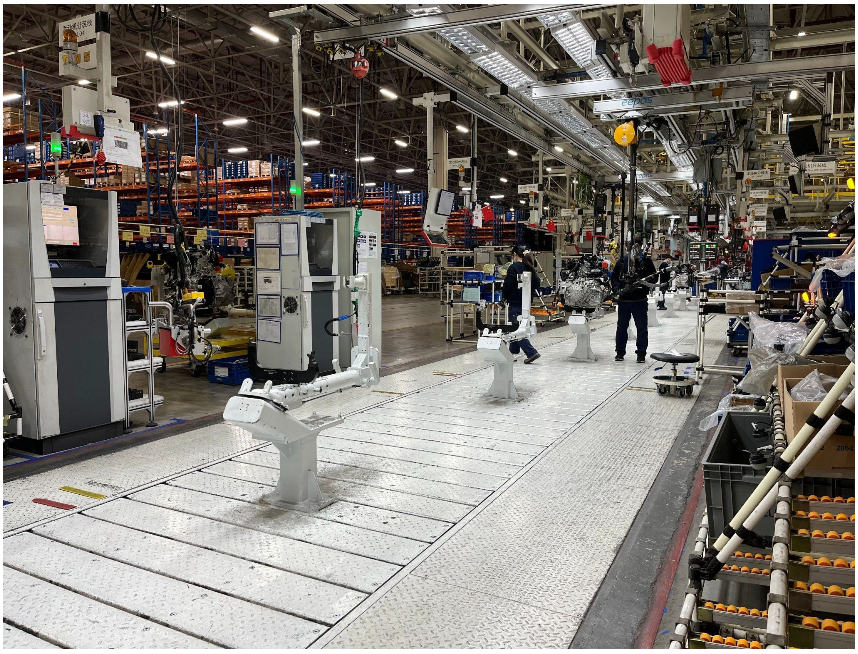


*Figure 22. Steel slat conveyor (*Volvo cars, 2023)

6.1.2 Pre assembly station and sealing station

The battery will undergo initial processing at both a pre-assembly station and a sealing station. Although these stations are not the primary focus of the thesis, the ergonomic requirements must be taken into consideration due to the manual labour involved. Specifically, the conveyor belt must be positioned at an appropriate working height. From the ergonomic requirements presented in section 3.6.4 a suitable working height for both male and female is 1100 cm. During manual operations, it is advisable to stop the conveyor belt to ensure the cords being installed do not become entangled in the roller bed and to prevent operators from encountering any hazards such as finger injuries. Once the pre-assembly and sealing station are completed, the battery will be conveyed to the designated stop position on the conveyor belt.

6.1.3 Stop position on the conveyor belt

Following the preassembly stage, the battery will be conveyed by a conveyor belt to the end of the line and brought to a stop position on the conveyor belt.

Ceiling mounted lift

A ceiling-mounted lift will transport the battery to the bolting table where it will be further assembled. The ceiling-mounted design is due to trucks driving in the aisle. Initially, the plan was for the conveyor belt to extend all the way to the decking station. However, after discussing with the global process leader, it became apparent that it was not feasible due to the passage of trucks.

To utilise the operators while the decking process is carried out the ceiling mounted lift will be semi automated that needs to be assisted. This saves investment cost for the lift and also utilises the operators. According to Chassi engineer the cost saving is approximately 5 million sek in comparison to a fully automated lift.

6.1.4 Semi automated bolting table

The battery will be conveyed to a partially automated bolting table prior to reaching the decking station. During the benchmarking process this bolting table was discovered while watching a YouTube video from inside the car company Fisker factory(Fisker Inc, 2022). In the video, it was observed that the process was highly streamlined, and the machine was able to tighten all screws within a short period of time. In discussions with a Chassi engineer at Volvo cars, a semi-automated bolting table is possible to use and is a suitable solution for the tightening and decking process. This bolting table is shown *in figure 23*.

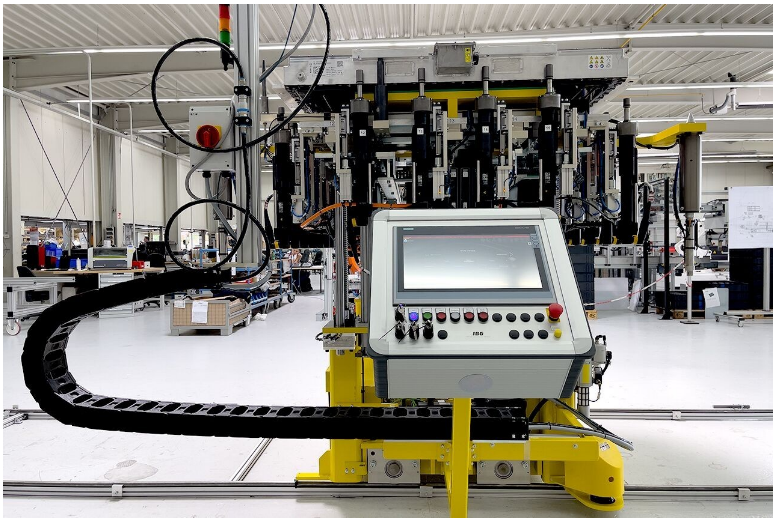


Figure 23. Automated bolting table (IBG, 2023)

6.1.5 Decking station

The battery will be positioned on the pallet located on the bolting table. Subsequently, the bolting table will be transported to the decking station. Meanwhile, the car body will arrive with the hanger, which will lower the body while simultaneously raising the pallet towards the body. A cycle time diagram over the decking and tightening process is visualised in *appendix 1*.

6.1.5.1 Tightening process

For the tightening process two alternatives were considered. The first option involves manual screw feeding and manual tightening, while the second option includes manual screw feeding and automated tightening. The two alternatives are presented in *table 5.*

Alternative 1

Alternative 1 includes manually screw feeding directly to the spindles by operators. The operators will tighten each screw directly after the screw has been fed to the spindle. To load and tighten one screw takes it 15 seconds. For the tightening station 2 the setup will be similar. Due to the time consumption of the manual work this setup would require two tightening stations. An open investigation to this alternative is to have a good working height when the screw is loaded and tightened directly after. The objective is to ensure that operators can comfortably perform these tasks while maintaining proper ergonomic conditions.

Alternative 2

Alternative 2 will have manually screw feeding and automated tightening. This will only require one tightening station since all the screws will be tightening at the first station. Firstly the screws will be manually loaded to the spindles. Then, the screws will be tightened with automated nutrunners. The automated tightening takes approximately 10-15 seconds.

	Screw feeding	Tightening station 1	Tightening station 2	Comment
Alternative 1	Manual	Manual	Manual	Fully manual setup
Alternative 2	Manual	Automatic	-	All the screws will be tightened in station 1

Table 5. Comparison between alternative 1 and 2 for tightening process

As outlined in Section 5 of our report, our primary recommendation for the Slovakian factory is to implement a fully manual setup as the first option. However, we acknowledge that the second option aligns more closely with the new concept, primarily due to the consolidation into a single tightening station.

6.1.6 Space protection

In order to accommodate future architectural developments and the production of new car models, the layout includes a space protection station. This feature allows for flexibility and adaptability, ensuring integration of different models. It enables the possibility of producing another car model within the same line.

6.1.7 Final repair station

Due to the absence of operators in the automated tightening process who can promptly address any potential failures, it is essential to incorporate a final repair station subsequent to the tightening station. This repair station serves as a crucial checkpoint to ensure the quality of the tightening process. In the event that the quality check indicates any deviations or issues, the cars will undergo necessary repairs and adjustments within this station to rectify the identified problems. This additional repair station acts as a safeguard to guarantee the optimal functionality and integrity of the tightened components.

6.1.8 Geometry control

In order to ensure that the decking process does not affect the geometry of the body, a Geometry Control Station has been incorporated. This station will be responsible for verifying and validating the geometry of the body after the decking process has been completed.

6.1.9 Car to next station

Once the car has completed all the necessary stations, it will be released from the hanger onto a skillet line, proceeding to the next station. Meanwhile, the hanger will return in a loop to retrieve the next body for the decking station. Implementing a loop system with the hangers is advantageous as it eliminates the need for the hanger to travel back and forth between stations. This approach significantly reduces time consumption, as it would otherwise take additional time to release and re-clamp the car each time it is picked up.

6.2 Differences from planned layout and new concept

In this section the main differences between the new layout solution and the planned layout will be discussed. This includes the conveyor belt that replaces the AGV and the reduction of the number of pallets.

Conveyor belt replace AGV

One notable difference between the new solution and the existing setup lies in the elimination of Automated Guided Vehicles (AGVs). As previously mentioned in section 4.1, Volvo had originally planned to employ AGVs for the transportation of batteries and the decking process in all their factories. However, with the implementation of the new solution, this need for AGVs is circumvented. Instead, the battery will be efficiently transported using a conveyor system, while the car bodies will be conveyed using hangers.

This shift in transportation methods stems from a comprehensive evaluation of alternatives due to the substantial investment costs associated with AGVs. As part of this evaluation, different transportation options were investigated. Among the potential alternatives, the conveyor belt emerged as a highly viable solution, offering both suitability for the task and a comparatively lower investment cost. Different designs of the conveyor belt were presented in section 6.1.1.

One fixed pallet

The second major difference between the layouts is that the new solution requires only one fixed pallet, compared to the planned layout which requires a pallet for each battery. During observations at the Torslanda factory, it was noticed that a large number of pallets were used, and considering their high investment cost, reducing their quantity would be advantageous.

A meeting was held with a geometry engineer who works with the pallets in the plant to obtain more detailed information. While there are several benefits of using pallets, such as easy transportation and the ability to work directly on them, they also have some drawbacks.

According to the geometry engineer, the pallet requires high maintenance and calibration. It needs to be measured once a year, which takes around 1-2 hours of work. In the new concept, where the pallet will be used more frequently, it would need to be measured approximately 2 times a year. Additionally, the pallet needs to be brushed four times a year as it becomes sticky due to the aluminium from the car and battery. This requires approximately 1 hour of work per pallet. All the preventive maintenance is carried out during the non-production time. If multiple pallets are used, the total maintenance time is substantial. This will be minimised in the new concept due to the use of only one fixed pallet.

Another advantage of utilising a single fixed pallet is that it helps minimise the spread. The spread refers to the variation or deviation between multiple pallets. When using multiple pallets, there is an increased risk of one of them being inaccurately calibrated. If the spread exceeds the acceptable tolerance range, there is a possibility that the screw may collide with the metal during the tightening process, leading to potential issues or complications. Consequently, maintaining strict control over the pallets becomes crucial to ensure optimal performance and prevent any undesirable consequences.

6.2.1 Comparison matrix on KPI’s

In *table 6* the different Key performance indexes for the current and the new concepts are presented. The two concepts are OK regarding geometry control, ergonomic aspects and flexibility to grow new architecture. The ergonomic aspect, in particular, involves a thorough investigation of various transportation methods, pre-assembly processes, and the tightening station where operators are engaged in manual tasks. The investment for each concept covers all the equipment and machines required for each layout. We will provide further details on these investments and the space requirements in the following explanation.

	Current situation (manual tightening)	New concept (Automated) tightening)	Comments
Investment	Confidential	Confidential	New concept require 27,5% lower investment cost
Geometry control	OK	OK	Geometry control station in layout
Space requirements	97 m2	90 m2	New concept require slightly less space
Ergonomic aspects	OK	OK	Manual setup includes rich pallet
Flexibility to grow new architecture	OK	OK	Space protection station

Table 6. Comparison matrix on KPI´s for current situation and and new concept

Investments

The estimation of investment costs has been done with the collaboration of chassis expert and senior manufacturing engineer. Due to confidentiality the exact investment costs can not be published. In *diagram 1* a comparison of the costs for the current concept and the new concept is visualised. To determine the costs for Slovakia, we have made comparisons with equipment and solutions already implemented in Volvo factories in other countries. The projected cost savings for the new concept, in contrast to the current state concept, amount to approximately 22.5 million SEK.

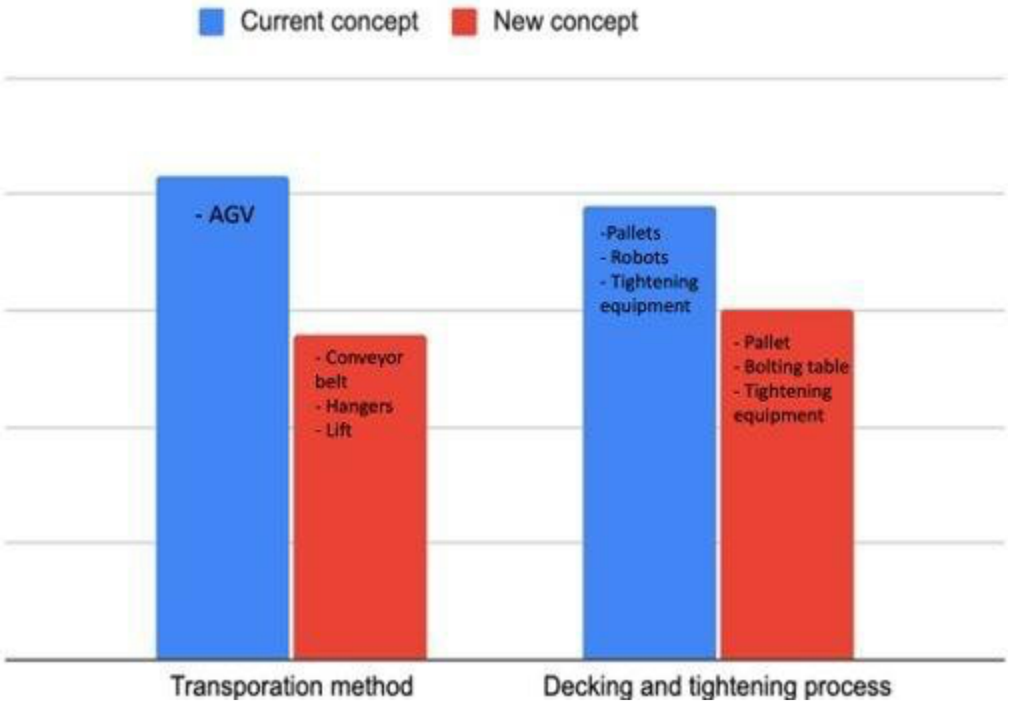


Diagram 1. Illustrates the cost difference between current concept and new concept

Space requirements

With the implementation of the new concept, the required space will be reduced as the tightening process will be consolidated into a single station, instead of two stations. This will result in additional space being available for other stations in the production line, thereby increasing the overall efficiency of the manufacturing process. For the current state the space required for a manual setup is 97 m2 and for an automated setup 306 m2. For the new concept the space required is 90 m2.

7. Discussion

Section 7 comprises a discussion on several topics. Firstly, in section 7.1, the decision to adopt an automated setup is discussed. In section 7.2, changes that were deemed interesting but could not be implemented due to company regulations are explored. Section 7.3 highlights the need for future work to determine the technical requirements for the new setup. Lastly, section 7.4 discusses the usefulness of the thesis results.

7.1 Automated tightening in new concept

Although the manual setup appears to be the most appropriate solution, as presented in section 5.4, for the Slovakia plant at present, an automated setup was chosen for the new concept. This choice was influenced by the complexity encountered when examining the fully manual setup, specifically in relation to the first tightening station. Implementing the manual tightening stations would necessitate the presence of eight operators, which could pose challenges in terms of coordination and efficiency. Additionally, managing the cycle time within the constraints of the fully manual setup would present further difficulties. Therefore, the decision to pursue an automated setup was driven by the desire to streamline operations, improve productivity, and mitigate potential challenges associated with the manual approach.

One aspect that can be considered is the potential for incorporating collaborative robots and equipment into the assembly process. It should be noted that the existing setup already includes some collaborative features, such as the manual screw feeding and the semi-automated lift that requires operator assistance. By introducing collaborative features, such as human-automation collaboration, the assembly process may benefit from increased flexibility, improved efficiency, and enhanced worker-machine interaction. The utilisation of advanced technologies, such as collaborative robots, could facilitate a harmonious working environment where human operators and automated systems work together to achieve optimal results. By thoroughly exploring the feasibility and implications of a collaborative setup in future studies, valuable insights can be gained, enabling the identification of optimal strategies for assembly optimization.

7.2 Thesis limitations

From benchmark, while watching YouTube videos, interesting aspects in NIO’s manufacturing process were found. NIO is a car manufacturing company in China that produces electrical vehicles. Some of their processes were not possible due to Volvo’s regulations. It was found that car company NIO is using batteries with screws already loaded to the battery. The proposed change would necessitate the removal of the screw feeding process, a laborious and complex operation that presents significant challenges in identifying a suitable alternative. NIO also has the battery assembly as the last process before the car is ready. This enables quick and easy battery replacement. This aspect is not taken in account before but is worth to discuss.

Volvo's engineers have stated that it is not feasible to incorporate a battery-assembling process as the last step in the production line. This decision was made due to the unique product requirements for Volvo's car design. The battery is an integral structural part of the car, and any direct contact with the body can potentially weaken it. In contrast, NIO has implemented a different approach in their production line. The NIO body is already designed to be sturdy and robust before the battery is assembled, which allows them to incorporate the battery-assembling process as the last step in their production line. This approach provides more flexibility in the production process, and allows for faster and more efficient assembly of the battery without compromising the integrity of the car's body structure.

7.3 Future work

In the meetings that have been conducted with engineers at Volvo during the thesis project, further investigations have been identified. This section will outline some of the open investigations that were discussed during the meetings. These investigations are required to determine the technical details of how the various processes will be carried out.

The safe and efficient execution of the assembly process hinges upon the proper design of the conveyor belt, with due consideration given to the well-being of the operators. The conveyor belt should be ergonomically designed and provide easy access to the battery to achieve this. The 6.1.1 section outlines several suggestions for conveyor belt designs, each with varying ergonomic standards and costs. Among these, the steel slat conveyor belt is the most expensive but also the most operator-friendly, whereas the cheapest option is the least ergonomic. A decision needs to be made regarding which conveyor belt design to use in the Slovakia factory, and an investigation is required to determine the preferred option.

A thorough investigation of the hanger loop is imperative to ensure that the assembly process runs smoothly and efficiently. Specifically, the hanger loop must be positioned in a way that allows it to cross paths with the ceiling-mounted lift without causing any interference. This requires careful consideration of the height at which the hanger loop is installed. An approach is to install the hanger loop at a higher floor than the ceiling-mounted lift. This would allow the hanger to pass over the lift without any interference. When talking to a global process leader this would be fully possible.

Additional investigation into the cycle time is required, as the existing cycle time diagram provides a high-level overview and necessitates further detailed analysis. This investigation should encompass various aspects, such as the speed of the lift, conveyor belt, and hanger, as well as a comprehensive examination of each step within the decking station. Conducting a more in-depth investigation will provide a clearer understanding of the cycle time and enable more accurate optimization of the process.

Extensive exploration of various screw feeding options has been conducted during the concept development phase. These investigations encompass automated, semi-automated, and manual approaches. In order to determine the most optimal solution, additional examinations and tests are required for the different options. It is worth noting that due to the significantly lower labour costs in Slovakia compared to Sweden, manual screw feeding could be deemed as an advantageous solution. However, it should be acknowledged that automated screw feeding may offer greater efficiency. It is important to consider that the cycle time in Slovakia is longer than in Sweden, which might render the implementation of a more efficient solution unnecessary. Further testing is necessary to make a conclusive determination.

The Operation Production Ratio (OPR) is a measure of production efficiency, calculated as (Total working time - Total stop time) / Total working time. A higher OPR value indicates greater efficiency, as there is less downtime during working hours. At present, there is no process implemented in the factories that can be measured or compared with data for the purposes of this thesis. However, a similar process involving a bolting table has been implemented in the Torslanda factory, with an OPR of 99.8%. Despite this limitation, further investigation is required to determine the OPR of the various processes in the proposed solution.

7.4 Usefulness of results

After presenting our concept for engineers in diverse roles and areas of expertise, it is evident that our proposed concept is feasible for implementation in the new Slovakia plant. The layout design is less complex than Volvo's initially intended layout, while also yielding potential cost savings of approximately 22 million SEK. However, further investigation is required to assess the practical viability of the proposed layout.

The implementation of the new concept has a higher likelihood at the Slovakia plant, considering it is a greenfield site currently under construction. On the other hand, implementing such changes in an existing factory would be more challenging and could involve significant time and cost implications. Therefore, it may not be practical to adopt the new concept in an established facility. However, the new concept holds promise for future new plants that are being developed, both for Volvo and other car companies.

8. References

Attwood, D.A., Deeb, J.M., & Danz-Reece, M.E. (2004) 'Ergonomic Solutions for the Process Industries.' https://ftp.idu.ac.id/wp-content/uploads/ebook/ip/BUKU%20ERGONOMI/BUKU%20INGGRIS/epdf.pub_ergonomic-solution-for-the-process-industries.pdf

Bullinger, H.J., Rally, P.J., & Shipfer, J. (1997). "Some aspects of ergonomics in assembly planning." Ergonomics, 40(1), 85-96. Retrieved from https://doi.org/10.1016/S0169-8141(96)00080-7

Carone, M. (2014). *Using Modeling and Simulation to Test Designs and Requirements*. www.mathworks.com.

Coe, R., Waring, M., Hesges, L. V., & Arthur, J. (2017). "Research methods and methodologies in Education." In Research Methods and Methodologies in Education | Online Resources.

Devezas, Tessaleno C., et al. (2017) Industry 4.0 : *Entrepreneurship and Structural Change in the New Digital Landscape.* Cham, Switzerland, Springer.

Devezas, T. (2017). Industry 4.0: Entrepreneurship and Structural Change in the New Digital Landscape [electronic resource].

Fisker Inc (2022) “Building the Fiskars ocean”,You-tube video, 2:15, https://www.youtube.com/watch?v=AAQJhqzTBGw&ab_channel=FiskerInc.

Habib & Guangqing(2018). *Performance Management for the Oil, Gas and Process Industries : A Systems Approach*. London, Auris Reference

Hassan, M.M.D. (1994). Machine layout problem in modern manufacturing facilities. *International Journal of Production Research*, [online] 32(11), pp.2559–2584. https://doi.org/10.1080/00207549408957084.

Håkansson, A. (2013). "Portal of Research Methods and Methodologies for Research Projects and Degree Projects." Retrieved from https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A677684&dswid=5786

Jacobsen, D.I. & Thorsvik, J. (2021) Hur Moderna Organisationer fungerar. Studentlitteratur Ab.

Lawry, J., & Larmine, J. (2012). *Electrical Vehicle Technology Explained.* Wiley.

Lebrouhi, B.E., et al. (2021). ”Key challenges for a large-scale development of battery electric vehicles: A comprehensive review.” *Journal of Energy Storage*, vol. 44, https://doi.org/10.1016/j.est.2021.103273

Liu, H. (2020). *Robot Systems for Rail Transit Applications*. Elsevier.

Page (2010) *The Power of Business Process Improvement: 10 Simple Steps to Increase Effectiveness, Efficiency, and Adaptability*. Accessed 17 May 2023.

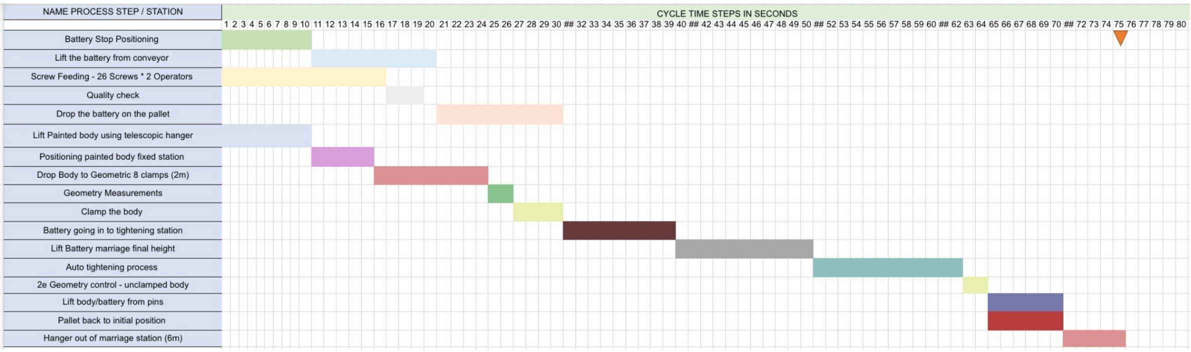
Raymond, J. (2008) “Benchmarking in Public Procurement.” Benchmarking: *An International Journal,* vol. 15, no. 6, 24 Oct., pp. 782–793, https://doi.org/10.1108/14635770810915940. Accessed 8 Dec. 2019.

Shinde, S. M., & Patil, R. B. (2012). "Design and Analysis of a Roller Conveyor System for Weight Optimization and Material Saving." *International Journal on Emerging Technologies*, vol 3, no. 1, pp 168-173.

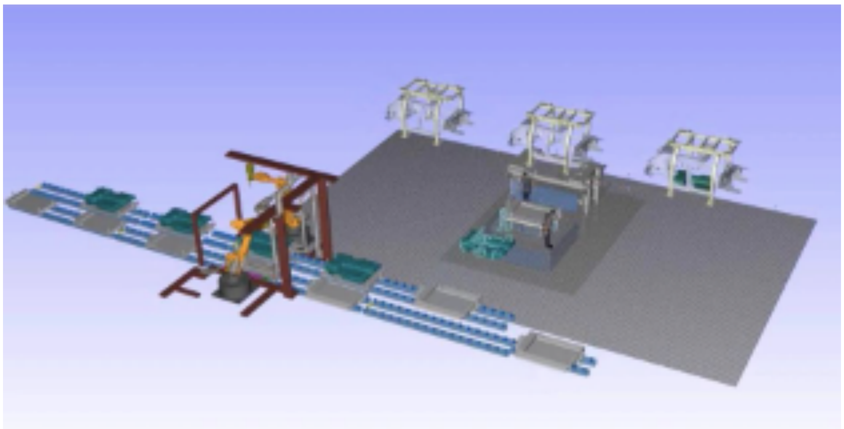
Simpson, T. W., Siddique, Z., & Jiao, R. J. (2005). *Product Platform and Product Family Design: Methods and Applications*. Berlin Heidelberg New York, Springer.

Appendix

A.1: Cycle time diagram for new concept



A.2: Overview of the simulation



DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

CHALMERS