Utilizing Lean Six Sigma to Improve Material Handling Operations in the Production of Heavy-Duty Engines at Volvo Powertrain

A Six Sigma Black Belt Project

Master of Science Thesis
in the Quality and Operations Management Master's Program

MAJEED ASSAF
PATRIK JUKIC

Department of Technology Management and Economics
Division of Logistics and Transportation
CHALMERS UNIVERSITY OF TECHNOLOGY
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MAJEED ASSAF
PATRIK JUKIC

Lars Medbo: Supervisor, Chalmers University of Technology

Hanna Karlsson: Supervisor, Volvo Powertrain, Skövde

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Department of Technology Management and Economics
Division of Logistics and Transportation
Chalmers University of Technology

SE-412 96 Göteborg, Sweden
Telephone: + 46 (0)31-772 1000

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Abstract

Volvo Powertrain is facing problems with the current material handling operations in the production site for heavy-duty engines. There are variations leading to ergonomic inefficiencies as well as non-value adding activities, which are leading to negative impacts on productivity. This thesis has been conducted in order to come up with solutions to the current hindrances in material handling for the main engine line as well as provide financial calculations for the benefits of the proposed solutions.

The thesis has been structured in order to utilize Lean Six Sigma principles and continuous improvement methodologies as a foundation for problem investigation and analysis, as well as concepts from material handling and ergonomics. The DMAIC (Define-Measure-Analyze-Improve-Control) framework was utilized during this process improvement project. The project aims to provide a future state for an improved material handling process and lead to financial contributions for Volvo Powertrain. The perspective towards problem understanding and investigation has been taken from three diverse standpoints, namely in terms of variation, ergonomic inefficiency and the risk due to physical load on the operators by taking different factors into consideration. Within the DMAIC cycle a pilot project was conducted to compare the performance level of the material handling process from the current state versus that achieved post-solution implementation. The result of this project has essentially led to a more improved performance level within material handling within each of the different standpoints taken for the analysis. Moreover, the findings have also led to financial contributions achieved through a more stable and capable process in the heavy-duty engines main production line. Which could be applied within other production lines as well as industrial environments when applicable.

Key words: Lean, Six Sigma, Ergonomics, Material Handling, Variation, Efficiency, Waste, and Financial Analysis.

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Gothenburg, June 2015

"I would like to take this opportunity to express special thanks to my family for their support, especially my father and mother who always believed in me and encouraged me to follow my dreams."

American Dream Majeed Assaf

"I would like to express my gratitude towards my beloved family and girlfriend Ana Josipa, for their support during my education as well as the completion of my Masters Thesis, without them I would not be where I am today."

Bog i Hrvati Patrik Jukic

Contents

1. Introduction

This thesis work is carried out at Volvo Powertrain, Volvo Group Trucks Operations in cooperation with Chalmers University of Technology as the final project of the Master of Science program.

This chapter will provide an overview of Volvo Powertrain as well as a general problem description for the thesis. The aim of the project will also be explained along with the constraints set by the authors to converge towards the problem. The research questions will also be provided as a foundation for this project work. Finally, this part will also describe the delimitations of the study.

1.1 Company Profile

The Volvo Group is one of the largest suppliers of equipment in the automotive industry for buses, trucks and cars, as well as heavy-duty engines for use in marine and industrial vehicles. In addition, Volvo Group is also involved in more service-oriented industries such as financing solutions, insurance, rental services, preventive maintenance, aside from IT and other customer assistance services.

Whether services or products Volvo Group has close collaboration with their customers in order to determine the features that will not only meet expectations but also exceed them and go beyond their expectations.

The Volvo Group's different areas shown in Figure 1 are integrated to provide the highest level of emphasis on their customers. The Volvo Group's different parts fully utilize the resource sharing and global reach of the brand.

Group Trucks, which is responsible for the majority of the company's cash flow and turnover, is further subdivided into: Group Trucks Sales, Group Trucks Operations as well as Group Trucks Technology.

- Group Trucks Sales has the most direct contact with the end customer and is mainly focused on marketing and advertising campaign strategies as well as sales operations.
- Group Trucks Operations is more oriented towards the manufacturing standpoint of the brand and thus activities in this area are more along the lines of production and management processes for different automotive components and products.

- Group Trucks Technology carries out the research and development for the brand and thus is involved mainly with breakthrough projects and innovations geared towards product development.

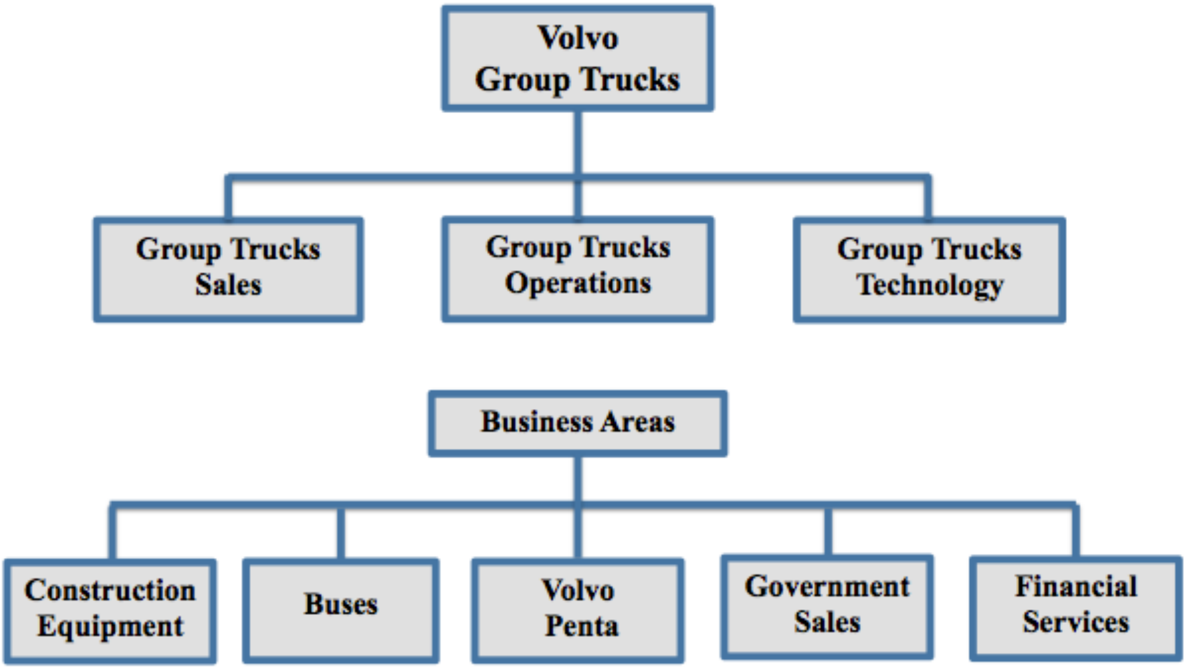


Figure 1: Volvo Group Organization (Volvo Group Website)

In addition to Group Trucks there are other parts of the brand within the cluster of Business Areas that are: Construction Equipment, Buses, Volvo Penta, Government Sales and Volvo Financial Services.

The focus on this thesis project will be on the Volvo Group Trucks Operations cluster of the company, specifically at Volvo Powertrain in Skövde, Sweden. Volvo Group Trucks Operations, Powertrain Production at Skövde manufactures diesel engines and engine components, which are delivered to Volvo's factories around the world in Europe, North/South America and Asia. Production is divided into three main processes that are casting, machining and assembly. As well as other secondary support functions such as maintenance and logistics. The products assembled at the Skövde site are Heavy Duty Engines that are of three types, one is a 13-liter engine called HDE13; another is a variant of the 13-liter engine named HDE13V and also a 16-liter type named HDE16. This project will be limited to the investigation of the HDE13 engines produced in the facility main line. The site surface area of 265 000 m^2 is made up of six factories and has about 2,600 staff.

At the Volvo Powertrain site in Skövde, the production line is made up of several different areas such as material handling, assembly as well as internal logistics operations. There are also specific external supplier operations taking place on a global scale, which are responsible for the procurement of the different types of raw material and components, which are currently used in the production process. They have for some years been focusing on implementation of lean with the value stream in focus within the production process as well as secondary operations within the production line.

1.2 Problem Description

The lean project efforts carried out at the production site to reduce waste and improve the performance of the production process have achieved success in several areas. However, there are still inefficiencies within the material handling operations. Operators within material handling currently gather components from different types and sizes of pallets, however the process of picking materials specifically from large pallets is leading to both productivity and ergonomic losses. The combination of ergonomic and time-losses is contributing to the inefficiency in the material handling operations, but the exact impact has not been quantified into solid data thus far. More specifically, this is leading to financial losses, which have also not been determined at this point in time. Therefore, the material handling process in the main engine production line will be the focus in this project. The problem will be constrained to the investigation of the performance in the material handling of the HDE13 main line. In order to take on this challenge, a Lean Six Sigma methodology will be used as the foundation of this report to provide more concrete estimations of these inefficiencies as well as denote financial calculations for the benefits of the proposed solution. The Lean principles will mainly be utilized in order to identify the different types of waste (Muda, Muri, Mura) along the value stream as well as their causes.

1.3 Purpose

The purpose of this thesis work is to investigate the material handling operations for the components placed on large pallets. The process inefficiencies have been broken down by the authors with the aim of measuring how the losses in the current state can be reduced and create more stable and profitable material handling operations. The losses in the current state have not been quantified, thus a key objective is to provide effective means of calculating the performance inefficiencies in the process. The problem will be studied from an ergonomic and productivity perspective as well as provide financial analysis of the potential benefits for the proposed solution in the form of a pilot project.

1.4 Problem Analysis & Research Questions

Volvo has previously made efforts in making the material handling; assembly and other production processes more lean and thus have reduced the impact of non-value adding activities on the value stream. However, despite the previous improvement projects that have been carried out, a new challenge is being faced currently which is the variation losses from both an ergonomic and productivity perspective when dealing with components that are delivered and placed in large pallets. Therefore, in order to address this problem this thesis work will have to take several perspectives into consideration towards finding a feasible solution. To guide this study investigation as well as formulation of the solution to the problem faced at Volvo Powertrain, we have considered the following research questions:

RQ 1: How is literature describing ergonomic and variation losses within material handling and what are the primary highlighted characteristics?

RQ 2: How are the findings from literature aligned with Volvo's material handling and what improvements could be suggested?

RQ 3: What considerations have to be in mind in order to provide a solution that will improve future material handling?

1.5 Delimitations

The focus of this study will be on the material handling process in the assembly line of 13-liter engines HDE13. However, areas such as supply chain distribution from external suppliers are outside of the scope of this study. This study will also not cover production of other products at the site, but could potentially be applied horizontally to other product and component categories if a similar need for improvement exists.

2. Methodology

This chapter provides an overview of which approaches will be taken as a methodological structure for the study. The general research approach will be described in terms of both qualitative and quantitative sources for analysis, the methods used for gathering different types of data from measurements, observations and interviews will also be explained. In addition, the benchmarking procedure used will be expanded upon. Conclusively, the reliability and validity of the approach taken will be clarified.

2.1 Research approach

The study will follow the methodology of a case study approach in the structure of a Six Sigma continuous improvement project. The DMAIC cycle will be utilized and thus a quantitative or qualitative approach will be taken depending on the requirements for each of the Define, Measure, Analyze, Improve and Control phases. A combination of both quantitative and qualitative data will be needed during this project. During the Define phase a qualitative approach will mainly be taken in order to gain a clearer view on the perspectives of those involved, also to possibly learn from their insights and experience when defining the problem at hand. This qualitative research approach will be unstructured and the authors aim to gain rich, detailed data from those who are interviewed to acquire a better understanding of their perspectives and input within the context of the project (Bryman & Bell, 2011), However, as the DMAIC cycle progresses into the Measure phase and beyond, a quantitative approach will mainly be used to make measurements and necessary calculations based on reliable data and evidence (Bryman & Bell, 2011),

2.1.1 Qualitative analysis

During the Define phase of the project, the focus of the authors will be on qualitative research methods to make sure that the problem is defined in a way that conforms to that of the stakeholders' perspective. Even though as external participants the authors have the advantage of bringing a fresh outer view to the table, it is however crucial to not get carried away with our ideas but rather to clearly achieve an understanding on the current state as it is seen from those directly involved with it in their daily activities. Once a profound understanding of the point of view of middle/upper managers as well as those directly working in the production line has been attained; then the authors plan to assess this data from an academic and practical implementation perspective to deal with the challenges at hand (Bryman &Bell 2011).

2.1.2 Quantitative analysis

As the project progresses beyond the Define phase, a quantitative approach will be more prevailing in the analysis (George, M., Rowland D. et al.). Therefore, data gathered would be based on measuring different factors in the material handling area, which for example will range from ergonomic concepts to productivity and efficiency evaluations. Further along the DMAIC cycle in phases such as Analyze, Improve and Control the approach will primarily be based on the previously acquired sources of data.

2.1.3 Research Methodology and Design

A case study design will be used in the context of this project. This has been chosen because the focus of the study is on a specific problem at Volvo Powertrain therefore, the nature of this research will be based on both qualitative and quantitative analysis methods in the form of literature studies, interviews, observations and measurements.

The project aim is to improve the current material handling of products from large pallets to achieve a better level of productivity and ergonomic efficiency. Therefore, the authors believe that the qualitative approach would be well suited to identify the different types of waste as well as gain a better understanding of the value versus non-value adding operations along the main line flow. However, the quantitative study is needed within the DMAIC cycle in order to base decisions on facts for the improvement cycle.

The study began by first having been presented to the problem in the production through several meetings with stakeholders at Volvo Powertrain as well as observations of the current operations and activities taking place in the material handling flow. Beyond this point, the authors conducted literature studies as an overview of topics such as: Ergonomics, Material Handling, Automotive Manufacturing, as well as continuous improvement sources on Lean Management and Six Sigma. Then, the findings from the literature were used to understand more about which factors to take into consideration for the project as well as the different perspectives to be considered.

The DMAIC cycle will be useful in this case study due to the nature of the problem to be addressed by the project. More specifically, the Define phase benefit is to be able to understand more about the how and why aspects of the current state accurately. As well as to be able to identify the core factors that should be considered in the scope of this project. Moreover, the Measure and Analyze phases will serve as the foundation of the quantitative aspect of this improvement project. In the analysis part findings will be assessed based on both the literature and empirical studies conducted. Finally the Improve and Control phases of the Six Sigma methodology will be used to create a more desirable future state and provide a means to maintain the acquired standards in the future. Therefore, the relevant tools from Lean Six Sigma will be made use of in the respective phases of the DMAIC cycle depending on the factors studied and analyzed during the project. At the end of the DMAIC cycle, as part of the Control phase, the case study will also lead to a pilot project to be carried out in order to gain insights on a more realistic grasp of the provided solution and have solid evidence to compare the improved state performance to that of the current one.

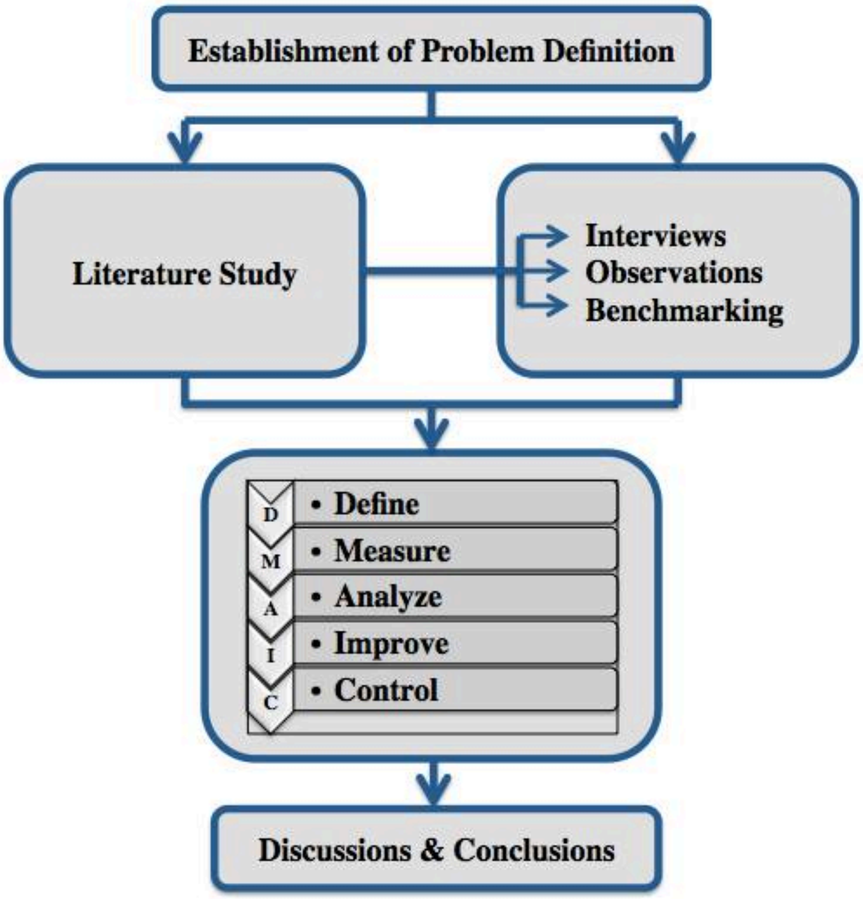


Figure 2: Thesis Structure and Methodology (Authors' construct)

2.2 Data Collection and Measurement

An overview of the methodologies and concepts utilized for the collection of data as well as verification of the measurement system used will be described in this part. Moreover, ethical perspectives considered by the authors will be mentioned in order to conduct the project in a morally sound manner that will not potentially harm participants directly or indirectly. The concepts considered to solidify data validity and reliability also are provided. In such respects for example, issues like triangulation as well as source credibility.

2.2.1 Literature Study

When the problem had been generally described the review of literature studies was initiated. The authors believed that grasping a theoretical understanding from literature within this area would be crucial before progressing into further phases such as data collection and deeper problem analysis. The literature study entailed the use of different sources depending on their relevance to the goals of the project as well as to gain a more solid theoretical background on the topic. Since the Lean Six Sigma framework would be used as a foundation for the thesis, it has been important to identify the aspects of the DMAIC cycle which would be most effective to utilize in the given problem focus. Moreover, literature studies also focused on concepts such as material handling in order to quantify the physical impact on those involved in the material handling operations; more specifically to determine the force on the spine by means of biomechanical formulas. In addition previous studies on ergonomics were explored to determine how unnecessary movement could impact the productivity of the process. Change management literature was also used to provide a means of adapting the new requirements of the future state to the material handling process.. The Chalmers database was used for the literature study as well as the Volvo network resources to gather essential documents and data throughout the project.

2.2.2 Interviews

A large amount of the data gathered during the project was done through formal and informal interview methods depending on the situation and the participant. During the Define phase of the project, managers at Volvo were interviewed in a structured way to ensure that the authors would be able to gain specific insights from their experience in the context of the problem to be addressed (Appendix 12). However, when out in main assembly line, the blue-collar workers were interviewed in an unstructured way that was more spontaneous as the problem was investigated. However, the viewpoints of those working in this main assembly line were quite valuable because they are in fact the ones directly involved in the material handling and ergonomic process. Therefore, the qualitative data gathered from interviewing was most prevalent during the Define phase of the DMAIC cycle. However, as the project progressed the interviews done were more focused on gaining perspective of quantitative factors as a basis for analysis.

2.2.3 Observations

Observations were also utilized in order to understand the human interaction with the main line process as well as to gain a more clear view of the operations taking place in the focus of the problem. Therefore, the authors observed and interacted with the machine operators and blue-collar workers to understand more about how they currently work and use this information based on their insights to create a view of the different challenges that have potential for improvement. In terms of ethical considerations, the authors ensured that the participants understood the reason for the observations as well as the goal that the thesis project aims to achieve. Therefore, there was no deception and the participants were not misled or harmed during the study.

2.2.4 Benchmarking

The benchmarking aspect of the project was mainly used in order to learn from other existing operations within material handling and be able to compare their efficiency to that of Volvo Powertrain. Therefore, the aim was to learn from the success stories of similar improvement initiatives as well as potentially utilize and adapt some of them towards an improvement in the Volvo Powertrain main line. Visits were therefore carried out to Volvo Cars in order to investigate their material handling operations in comparison with those at Volvo Powertrain. These visits were also beneficial for creating a foundation on which to conduct the pilot project upon finding the solution to the inefficiency at Volvo Powertrain.

2.2.5 Measurement system

The measurement system utilized in terms of factors such as productivity and ergonomic efficiency was assessed by considering the repeatability of the measurement as well as the stability of the results obtained when gathering data. According to Bryman and Bell (2011), in order for a measurement system to be accurate the obtained data results should be consistent independent of whom the measurement is conducted by. Therefore, subjective judgment should be minimized and even eliminated to obtain as accurate results as possible. Moreover, during measurement relevant literature sources were also utilized to make the study based on previously tested methods and concepts. So previous research carried out within ergonomics and productivity measurement was taken into consideration when developing the measurement system used in the project.

2.3 Reliability, Validity & Replication

According to Bryman and Bell (2011), only deciding on when a quantitative or qualitative research approach should be used is not sufficient when carrying out a case study project. There are three other key criteria that will need to be considered that are reliability, validity and replication. Reliability is mainly concerned with the quantitative aspect of the study and thus on whether the results obtained by the authors are repeatable. Which, in turn can indicate whether or not the measurements are stable. In order to ensure the reliability of a study several people should obtain the same result when conducting the study. There are three key points to consider that determine whether or not a measure is reliable that are stability, internal reliability and inter-observer consistency. Stability is focused that the results related to a measure from several respondents does not change over time. Internal reliability is concerned with the consistency between researchers by means of some form of mutual agreement on measurements and observations. Inter-observer consistency is related to the necessary involvement of much subjective judgment in the data gathering, measurement and observation activities, which could lead to a lack of consistent decision making between the observers.

According to Bryman & Bell (2011), validity is the extent to which a measurement is actually capable of studying that which it is supposed to be studying in reality. Such as, whether the measurement factors utilized are effective at really measuring the focus of the project. Validity can be further divided in regards to Measurement, Internal, External and Ecological Validity. Measurement validity is concerned with whether or not a measure that is devised of a concept really does reflect the concept that it is supposed to be denoting. Internal validity is about whether a conclusion linking two causal relationships between variables is in fact accurate or not. External validity is concerned with the extent that the results of a certain study can be generalized beyond the specific project focus. Ecological validity is about the extent to which the results of a study can be applied to more common daily situations outside the context of the project. Also, in the aspect of replication the study should be replicable and thus the procedures and steps used should be described with relatively rich detail because if that is not the case then replication becomes impossible.

The reliability of this study is strong because the measurement system used for quantitative analysis has been well assessed in terms of its accuracy by ensuring that the variables used to describe the state are based on test-retest methods that confirm stability. Moreover, the correlation between different factors has been assessed based on logically sound and empirical criteria. Subjective judgment between the observers does not exist in this case, as the study will be based on factual studies and measurements. If this study were attempted to be replicated, the data collection process as well as measurement of productivity can be carried out in a similar context at Volvo or other companies in the automotive industry. In order to ensure the validity of the findings, triangulation was used by combining both qualitative and quantitative methods. Therefore, the concepts from the interviews, observations and measurements were assessed among each other to make sure of consistency of the findings pointing towards the same direction in the context of the problem at hand. Moreover, to ensure reliability, several sessions were held with the stakeholders at Volvo Powertrain to gain from their feedback on progress as well as identify the areas, which could need more focus, also to ensure that their requirements are fulfilled. By making use of several measures through triangulation the results of findings will be more accurate (Bryman and Bell, 2011). When it comes to replication, the authors have made sure that the steps taken during the study have been described meticulously and can thus be repeated in the future when necessary.

3. Theoretical Framework

This part will describe the theoretical framework used in order to address the challenges of this project as well as to address the problem with suitable knowledge and competence areas. Studying the ergonomic efficiency as well as identifying productivity hindrances such as different types of waste will be backed up by literature and other sources. The literature findings from Six Sigma will be used as the foundation for the structure and tools used throughout the project during the DMAIC cycle. Moreover, the findings from Lean management will address the different types of waste in the process (Muda, Mura, Muri) as well as their potential causes. The ergonomic and material handling aspect of the study will mainly focus on the impact suffered by those involved in the main line due to lifting and unnecessary movement.

3.1 Six Sigma

According to Jones & Foster (2010), Six Sigma is a data-driven philosophy used to influence management decisions and spark action across an organization. Six Sigma reduces waste, increases customer satisfaction and improves process performance while being focused on measurable financial results of the proposed solution.

In the context of this project it has been crucial to use Six Sigma for measurement of the inefficiencies as well as to determine the means of potential improvement. More specifically when addressing the material handling operations, the principles of the Six Sigma methodology will be used to understand the variation and create a current state baseline for comparison to future state performance standards.

The Six Sigma philosophy represents the goal that any product characteristics that are important to the customer should be defective or unsatisfactory as few instances as possible, specifically, no more than 3.4 times per million opportunities. This end in itself is not the primary concern of this project. Rather than having this goal for the improvement, the use of Six Sigma in this project will mainly be done because the principles and tools of the philosophy are well suited for problem analysis. The statistical concepts used in a typical Six Sigma improvement initiative are valuable in addressing the problem at hand from a process engineering and economic perspective. Additionally, these concepts will be targeted towards reducing losses related to ergonomic inefficiency as well as variations in the material handling process.

At the foundation of Six Sigma is the DMAIC cycle (Define-Measure-Analyze-Improve-Control), which will be utilized for structuring the project as well as making use of the statistical and analytical tools that can be applied in the context of this study. DMAIC stands for the five phases of a Six Sigma project; Define (the problem), Measure (current data), Analyze (the data and identify root causes), Improve (the process) and Control (the process for maintaining the improved state). According to Bergquist (2006), the DMAIC cycle is a highly structured problem-solving approach that can simultaneously provide a large degree of freedom within each phase of the cycle as long as the main procedures of each step are adhered to as is recommended in the improvement cycle. There are various tools and methodologies utilized during a DMAIC improvement project for quality improvement.

During the DMAIC cycle for this project a combination of both Improvement and Management tools will be used. This will mainly depend on the requirements of each phase of the DMAIC cycle. In addition, principles from other disciplines such as ergonomics and material handling may be used in some cases in combination with these continuous improvement methodologies. There are three key points of the Six Sigma methodology that will be applied in the context of this project.

The first is that continuous improvement efforts for achieving more stable and predictable processes are key for the business success of any organization (Snee, 2004). Particularly, in the material handling operations at Volvo Powertrain, the current variation in the process should be reduced to have a more stable flow in the HDE13 main line, which will in turn lead to contributions from a business process perspective as well.

The second key point is that for an improvement project to be possible, there must be effective means of measurement and analysis, as well as tools that can be applied to improve and control the process performance standard at a more desirable level. Thus, Six Sigma entails a valuable procedure to address this key point; the following will be used during the project:

- ✓ Business Process Mapping: This principle will mainly be used during the early phase of problem definition and scoping. For a thorough problem definition structure tools such as Effective Scoping, SIPOC (Supplier-Input-Process-Output-Customer) and the

P-Diagram will be utilized in the Define phase of the project. Effective scoping is a means of converging from a broad to a specific focus on problem definition. The SIPOC tool is used to explain the process in a high level overview. Finally, the P-Diagram is used to take the inputs from the process, which is the material handling operations in this case, and relate them to desired outputs while taking uncontrollable influences into consideration.

- ✓ Statistical Analysis: Statistical analysis is applied in order to effectively measure and analyze process performance indicators as well as create a foundation for further improvement (George et al.2005).

The third key point of Six Sigma to be utilized in the assessment of the material handling operations is that in order for the improvement to be sustained beyond the duration of the project, commitment towards monitoring the future state is fundamental. This factor will be most useful in the control phase of the DMAIC cycle once process improvement has been achieved.

3.2 Lean

During the past decades, the principles of Lean Production leading to success stories from manufacturing companies have led to a strong interest of companies around the world (Bergman & Klefsjö 2010). Therefore, the use of lean tools and methodologies has spread across companies on a global scale. The lean concept is also focused on the value delivered to the stakeholder that is in this case Volvo Powertrain. Waste is defined as any activity that uses up resources without adding value. According to Lean, wastes can be categorized into three types that are Muda ("non-value adding operations"), Muri ("overutilization/overburden") and Mura ("variation"). In most cases, these waste are interdependent and thus the cause of one form of waste will lead to another within the process.

Lean deals with identifying different forms of waste and eliminating them by determining their root causes. Any activity that does not add value to the customer is therefore considered as waste. In this context, Lean principles will mainly be used in the material handling area of the HDE13 production line at Volvo Powertrain. Therefore, the value identification in the process will be constrained to only involve the operations taking place in this part of the production.

3.2.1 Muda

Muda is any activity that takes place during the process that does not add value to the customer. There are seven main types of waste in the form of Muda in addition to an intangible waste in the form of "Unused Creativity" as described by Womack and Jones (2003). The different forms of waste can be categorized as follows:

1. Transport
2. Inventory
3. Motion
4. Waiting
5. Over Processing
6. Over Production
7. Defects
8. Unused Creativity

In this case, not all types of waste are as relevant as each other according to the problem to be addressed in this project. For this reason some types of Muda will be more applicable than others. This is also because when using the Lean philosophy to eliminate different types of waste, the focus of the project should not be primarily on identifying and reducing; instead the lean tools should be used to identify the value in the process. This approach will thus make the value adding activities more efficient while simultaneously decreasing the wastes. The main forms of Muda that will be addressed of those explored earlier are: motion and over processing. This is because only these forms of waste are applicable in the material handling operations of the HDE13 production line at Volvo Powertrain.

3.2.2 Muri

The second form of waste is Muri, which means when people, equipment or facilities are performing at a standard that is requiring them to exert more energy when working without adding value to the process. This form of waste is mainly caused due to a lack of a standardized process for the work procedure and operations. Which then forces the equipment and employees to work harder to try to keep up with process performance levels (Liker, 2004). In this project, the Muri type is also associated with the unnecessary motion taking place as well as the over processing in material handling regarding ergonomics.

3.2.3 Mura

The third type of waste is Mura, which exists when there is an unbalanced or uneven workflow leading to inconsistencies. Mura can be applied to mechanical and human contexts. In both cases, variation is a hindrance in potential process performance which leads to more unstable and unpredictable output. In this case, the Mura of the material handling process is from a human factors perspective because of the variation linked to the time required for gathering the components.

3.3 Ergonomics

According to Wilson & Corlett (2005), Ergonomics or Human Factors is a fast-moving discipline often involving the use of concepts from several scientific backgrounds. Furthermore, Chapanis (1996) has defined ergonomics as an interdisciplinary field with engineering, statistics, economics, industrial design and operations research all contributing in addition to physiology, psychology and work environment methodologies. The ergonomist is concerned with improving the work of others, determining the factors affecting human-machine interaction and forming hypotheses based on these findings (Dempsey et al. 2000). As well as continuously questioning the working procedure through data collection and analysis from the process in focus.

In most cases in reality there must be a compromise in order to find the most cost-effective solution under the difficult circumstances that come along when theory is not totally in sync with the problem faced in the real world. It is also necessary to develop benchmarks for which to carry out best practice and an effective means of communicating the findings to the different stakeholders involved. In most cases, the role of the ergonomist lies on a path between the roles of pure scientist or practitioner and the emphasis of the approach could vary depending on the nature of the problem at hand.

It can be gleaned that Ergonomics and Human factors are used to create a win-win situation for both the individual and the organization through focus on improvement within one or more of the following areas: Physical, Cognitive, Social and System Ergonomics.

Physical Ergonomics is concerned with the impact on the individual's physical well being in the work environment. These could be considerations such as workload, reach, health and safety, workplace layout, manual material handling, equipment design, environment and tools. On the other hand, Cognitive ergonomics are more focused on mental workload such as information processing, problem solving capabilities, sensing, perception and decision-making (Wilson & Corlett 2005). Social ergonomics are focused on organizational and psychological factors such as teamwork, team structure, satisfaction, motivation, job and team design, as well as work patterns. Finally, systems ergonomics concentrate on the overall view of the process and thus carries out analysis to determine the design and evaluations that are most likely to succeed when integrating physical, cognitive and social human factors (Wilson & Corlett 2005).

During this continuous improvement project the previously mentioned areas within ergonomics and human factors will be considered but some areas will be more prioritized depending on their relevance to the project goals. Specifically, Physical and Systems Ergonomics evaluation will be more applicable towards the problem in this case.

According to Stanton et al. (2004), human factors and ergonomics methods are crucial towards finding best balance that suits both the organization and the individuals involved in its daily activities. These methods serve as a structured approach towards the analysis and evaluation of the faced problems. In the context of material handling in this case, the ergonomic method will be used to find the best balance between ergonomic efficiency for the well being of those involved as well as from a financial aspect for the organization.

3.3.1 Ergonomic Material Handling

Theories on the physical impact on those directly involved in the material handling process will be utilized. In areas such as how musculoskeletal workload, health and safety procedures, workplace layout and manual material handling affect them. Such ergonomic inefficiencies have the most impact over time. Thus the working environment will most likely not result in injury directly, but it is rather the continuous work over time with small inefficiencies that add up and lead to the risk of potential injury.

According to Helander (2006), the statistics from injury due to work in industrial and manufacturing environments can lead to significant costs for an organization in addition to the negative effect on the employees. However, there are biomechanical principles that can be used to quantify the physical impact on those who are involved in the manual material handling. The biggest problem from manual lifting is because the force from a lifted load becomes ten times larger in the spine. This could lead to back injury, which is the most common injury in industrial and manufacturing work environments. When a correct lifting technique is used this can reduce the impact of the lifting force on the spine, however, a proper lifting technique is not possible in all manufacturing environments due to time constraints as well as the size/shape of the object that is lifted.

In order to calculate the impact of manual lifting the following NIOSH (National Institute for Occupational Safety and Health) equation for calculating the recommended maximum force with respect to the weight of the object will be used, Namely the RWL (Recommended Weight Limit) in Equation 1 (Helander, 2006). An explanation of the NIOSH equation variables will be described based on figure 3; once the Recommended Weight Limit has been calculated the Lifting Index in Equation 2 is used to provide an estimate of the hazard associated with the manual lifting job.

Equation 1: RWL= LC x HM x VM x DM x AM x FM x CM
Equation 2: LI = (Load of weight L)/(Recommended weight limit RWL) =L/RWL
L: Weight of the object lifted (kg).
LC: Load Constant = 23 Kg
HM: Horizontal Multiplier = 25/H
VM: Vertical Multiplier= (1-0.003|V – 75|)
DM: Distance Multiplier= (0.82 + 4.5/D)
AM: Asymmetric Multiplier= (1 – 0.0032A)
FM: Frequency multiplier= Obtained from Table 6.
CM: Coupling multiplier= Varies from 1.00 (good) to 0.90 (poor) depending on the grip difficulty with respect to the component.
H: Horizontal location of hands from the midpoint between the ankles. Measure at the origin and the destination of the lift (in cm). Most objects cannot be lifted closer than 25 cm from the ankles.
V: Vertical location of the hands from the floor. Measure at both the origin and the end-point of the lift.
D: Vertical travel distance between the origin and the destination of the lift (in cm).
A: Angle of asymmetry—angular displacement of the load from the sagittal plane.
Measure at the origin and at the destination of the lift (degrees).

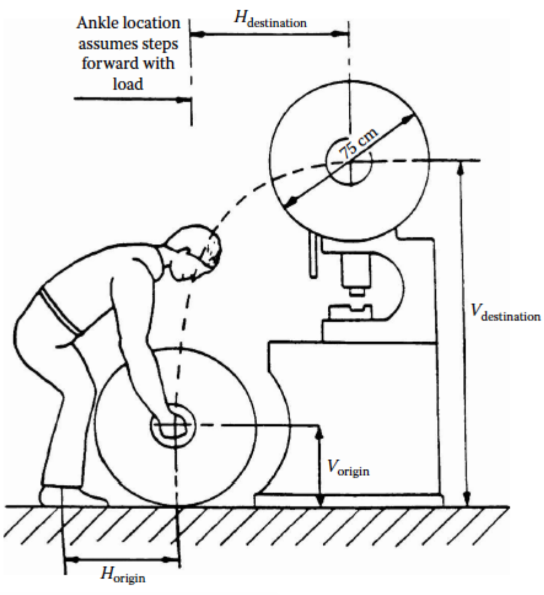


Figure 3: Illustration of RWL Equation Variables

Frequency Multipliers (CM)

Frequency (lifts/min)	Work Duration (h) <1 V < 75	<1 V > 75	<2 V < 75	<2 V > 75	<8 V < 75	<8 V > 75
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

Table 1: Frequency Multiplier

In order to make accurate calculations of biomechanics the Recommended Weight Limit formula calculations are performed twice, once from the point of origin and then from the final destination. However, if the point of destination does not require controlled lifting, for example if the object is dropped into place or easily released without effort; then the calculation from the destination biomechanical load is not necessary. Moreover, the frequency of lifting intensifies the force exerted on the spine and can be used in the equation based on the number of lifts per minute as shown in table 1, which is used to determine the FM (Frequency Multiplier) for Equation 1.

These equations for manual lifting effects will be utilized to determine the biomechanical impact that the current material handling process has on the workers in the main line of HDE13. Thus, the calculations will provide a measurement for the baseline of these effects, as they are in the current state in comparison to that of the future improved state the project strives to achieve.

3.4 Change Management for Improvement Processes

In this improvement project, upon finding a solution to the problems at hand there will be a necessity to create a future state that will be maintained in the organization. Therefore, during the DMAIC cycle the final phase of Control will most likely need to take into consideration the challenges of implementing a change as well as the different factors to be considered in order for the change initiative to succeed.

According to Nadler and Tushman (1997), for the implementation of a change towards a desired future state there are three main transition phases to be assessed. Initially, the current state should be described to map out how the current functions are interacting. Thus, this state will be considered as the material handling process as it currently is being carried out. The DMAIC cycle to be carried out during the project can be considered as the transition state. The objective however, is to create a more desired future state that will describe how the process should function once the improvements are implemented. This state will need to have a certain degree of detail so that deviations do not take place because of a lack of consistency or effective management.

A key issue that should be addressed is that of organizational control, because a change initiative could disrupt the natural flow of operations in the organization, it is necessary that precautions be taken along the DMAIC cycle so that the existing systems of the organization are not undermined. Traditionally organizational operations are designed to maintain the existing state or to facilitate the management of the future state, but they are usually not equipped well enough to effectively manage the transition state. Thus, this challenge associated with the transition should also be taken into consideration.

The change aspect of this improvement project will be most suited to the control phase of the DMAIC cycle. In order for the improved state to be maintained in the long run, it is necessary that the implemented changes are followed up on after the project duration is over. In order to do so, the control phase will provide a means to effectively measure the impact of the change from a productivity and ergonomic perspective, as well as to be able to quantify the financial gains acquired from the project over time.

DMAIC

Define-Measure-Analyze-Improve-Control

DMAIC is a data-driven quality strategy used for continuous improvement. It consists of five interconnected phases forming the DMAIC cycle that are: Define, Measure, Analyze, Improve and Control. It can be thought of as a roadmap towards process improvement by means of quality management and statistical tools. DMAIC projects strive to reduce variation so that the improved target for performance can be attained. Within each phase there are specific tools that are put into use during DMAIC as will be the case throughout this project for improving the material handling operations.

A project begins by *defining* the problem to be addressed followed by *measurement* of the process baseline in the current state. Then, the data obtained is *analyzed* to determine the aspects that should be *improved*. Finally, at the end of the DMAIC cycle is the *control* phase that is concerned with monitoring and maintaining the improvements post-solution implementation. Thus, in the case of material handling operations for the HDE13 production line, the DMAIC cycle will be an integral part of project structure as well as the use of its principles, practices and tools within each of its phases.

4. Define

The define phase is the first phase of the DMAIC cycle for continuous improvement. The goals of this part are to provide a clear definition to the problem at hand as well as describe the scope of the project such as the focus areas to be addressed as well as the constraints used to delimit the project. Moreover, the expected outcome will also be expanded upon in this phase. By using several tools and methods, the outcome of the define phase will include a more clear understanding of the problem as well as those involved in the improvement project.

4.1 Interviews and Observations

After being provided with a basic introduction to the problem from Jonas Håkansson, the Internal Logistic Process and Technology Manager at Volvo Powertrain; As well as Hanna Karlsson, the Pre-Production Engineer responsible for the project. The next step was to interview some of the group members in the main line of the heavy-duty engines that were involved in the process. This was done in order to gain the views of management on the problem as well as those that are directly involved in the production process.

The initial interviews from the managers provided a better overall picture of the different challenges that were to be addressed in the project (Appendix 12). This helped to understand the expectations of the managers in terms of final results and outcomes. They were encouraged during the interviews to elaborate on the problem from their personal experience in order for the authors to find out as much as possible about how their views were similar or contrasting. A contrasting view of the problem was then further explored during the interviews to have a broad perspective on the challenges to be faced from diverse standpoints. At this point, the problem of productivity and ergonomic losses in material handling was defined generally as the focus of the project.

Then the interview process was directed towards those working in the production line. Those directly involved in the production process were considered to be a valuable source of input towards gaining a better understanding of the problem at hand. Moreover, their experience provided insights on the material handling aspects that they find problematic in their working process as well as their perspective on management's effort to find solutions to these issues. They were even identified, as a stakeholder in the outcome of the project because the improvement suggestions provided by the authors will directly affect their working procedure in the future. The information received from their part confirmed the problem stated in the interviews with the managers and in some instances revealed hidden problems in the material handling process that the managers were unaware of. The authors did however keep in mind that interview results are not equivalent to facts and thus it was necessary to conduct observations that would confirm or dismiss the information gathered in the interviews. Thus, the material handling process was observed over several visits to Volvo Powertrain and was studied from a productivity perspective as well as that of ergonomic efficiency to determine the parts of the process having greatest impact on the material handling inadequacies.

4.2 Problem Mapping

After the initial interview and observation phase a mind map was created to acquire a deeper understanding of the problem as well as clarify the different views of the stakeholders. As there would be several perspectives the mind map would aim to align the different views as well as make use of the different input gathered. The main question to be answered during the formation of the mind map was: "What are the main problems currently faced in the material handling operations?" During the interviews conducted insights on the problematic area were provided from those involved in the material handling process of the main line at Volvo Powertrain. The first key point is that there are significant ergonomic inefficiencies in the current state. Moreover, this is leading to reduced potential productivity due to time losses. Even though lean management tools have been utilized in the past, there is still potential for further improvements in this area. There is also a need to develop a solid method for gathering data and measuring the exact efficiency of the existing state. The results of the created mind map based on the different input gathered are illustrated in figure 4. The conclusion from the mind map served as an effective method to gain a broad perspective on the problem at hand. Through the study of the mind map it became clearer what the problem perspective of the employees was, as well as what they believed to be key missing factors negatively impacting the performance level of the material handling process. It showed how the different perspectives could unite towards a common goal even though those involved were both from management and those working in the main line.

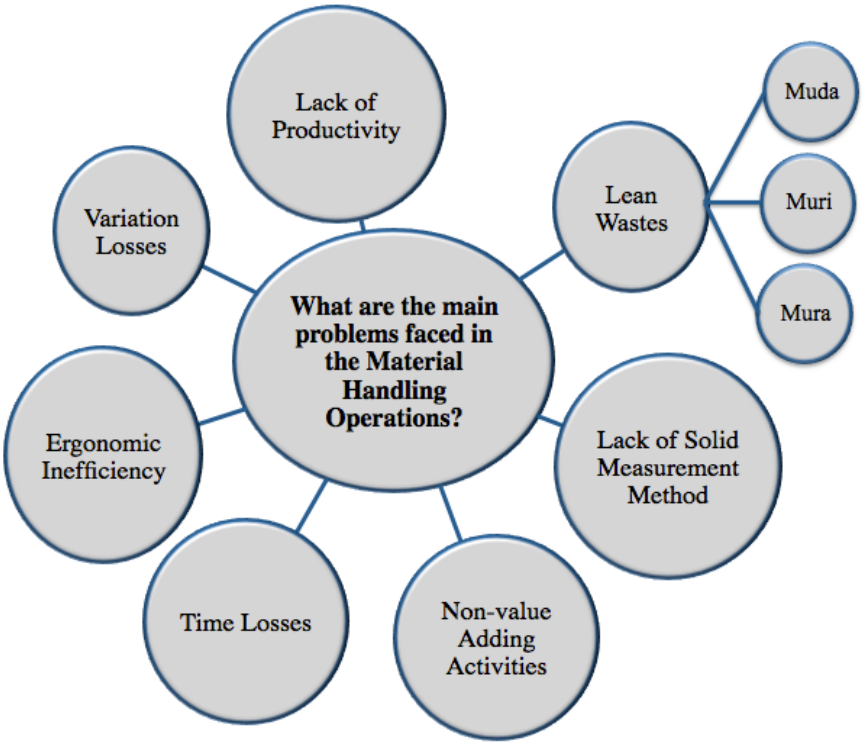


Figure 4: Mindmap (Authors' construct)

4.3 Project Scoping

There are three different methods that were used to set the scope of the project that are Effective Scoping, SIPOC analysis and the Parameter-diagram. Effective scoping is a tool used to determine how to quantitatively assess the problem and identify ways suitable for measuring achievements. Moreover, the tool also helps to gain a deeper understanding of the different aspects that are related to the problem as well as how they potentially could be improved. Therefore, it is a useful tool to effectively converge towards the aim of the project. The effective scoping method was used in connection to the SIPOC to determine the boundaries and scope of the project. SIPOC (Supplier-Input-Process-Output-Customer) is a methodology used for identifying information critical to the problem at hand to be able to constrain the focus of the project. Thus, it is a process that also represents the parts explored from effective scoping (George et al. 2005).

The effective scoping method is also useful in defining the different parameters of a continuous improvement project. The required output of the process called big Y can be defined relative to the desired outcome of the project. The different factors used to measure the outcome are referred to as small y. Effective scoping thus helps create a strong relation for the factors measuring the achievements of the small y's and the big Y's representing what should be improved during the project. The effective scoping focus was on the current state of processes at Volvo Powertrain and its outcome has been summarized in a SIPOC (Figure 5).

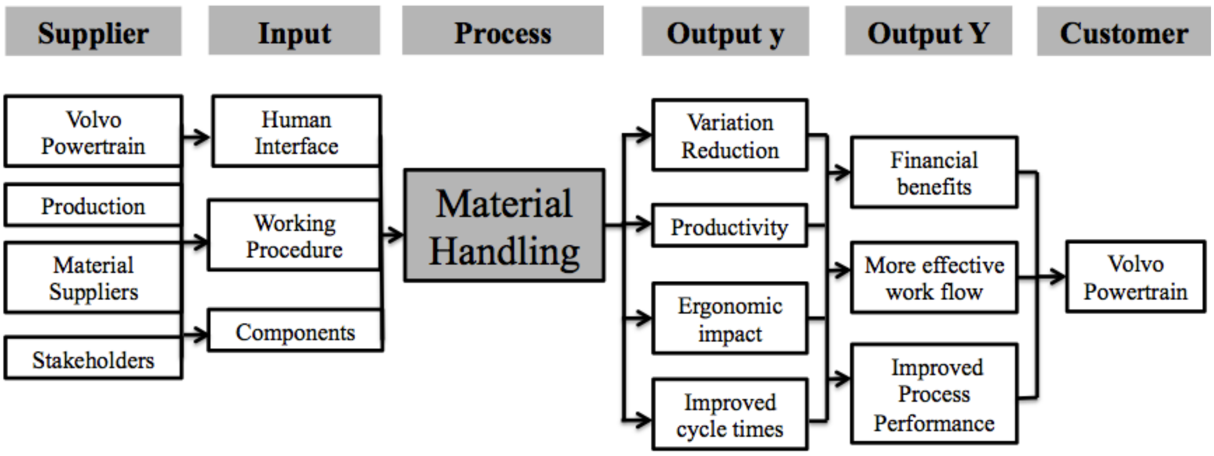


Figure 5: SIPOC (Authors' construct)

The supplier in the process of material handling is in this case made up of the stakeholders at Volvo Powertrain who are involved in the production of the heavy-duty engines HDE13 in the main line, specifically the employees from the internal logistics and production department. However, the workers involved in the main line are also a supplier in the scope of the project. The input of the material handling process on the other hand is mainly the workflow and methodology of those directly working in the production facility. Therefore, studying their activities is key to gain insights for addressing the challenges faced in this area. The output from this process can be separated into two main categories that are the small y's and the big Y's. There are four small y's identified, the first is the aspect of variations currently existing in the material handling process. The second is the overall productivity of the process in its current operational standards. The third is the ergonomic impact currently affecting the workers in the main line as well as its consequences. Finally, the fourth small y is the aim of improving the cycle time of the material handling so that a better and more profitable state can be reached.

The small y's are directly connected to the key performance indicators (KPIs) of the material handling process, which are represented by the big Y's in this case. The first big Y is the financial gains that could be achieved by the proposed solutions for Volvo Powertrain. These will be defined based on a cost-benefit study of the future state for the proposed solution. It is thus crucial before being able to move forward with the solution that the financial impact is assessed. The second big Y is the results obtained in process workflow in the main line. This is dependent on the comparison obtained by measuring the current state time and variation standards in relation to that of the expected future state through the proposed solution. The third and final big Y is the achievement level reached of overall process performance, which is determined by taking both ergonomics and process productivity into consideration. This synergetic effect should be used to identify the overall improvement in the material handling process.

In addition to the SIPOC tool the authors decided to also conduct a Parameter-diagram study to gain a better understanding of the input-output relations of the studied process. The P-diagram (Figure 6) also provided a means to represent the uncontrolled factors in the process.

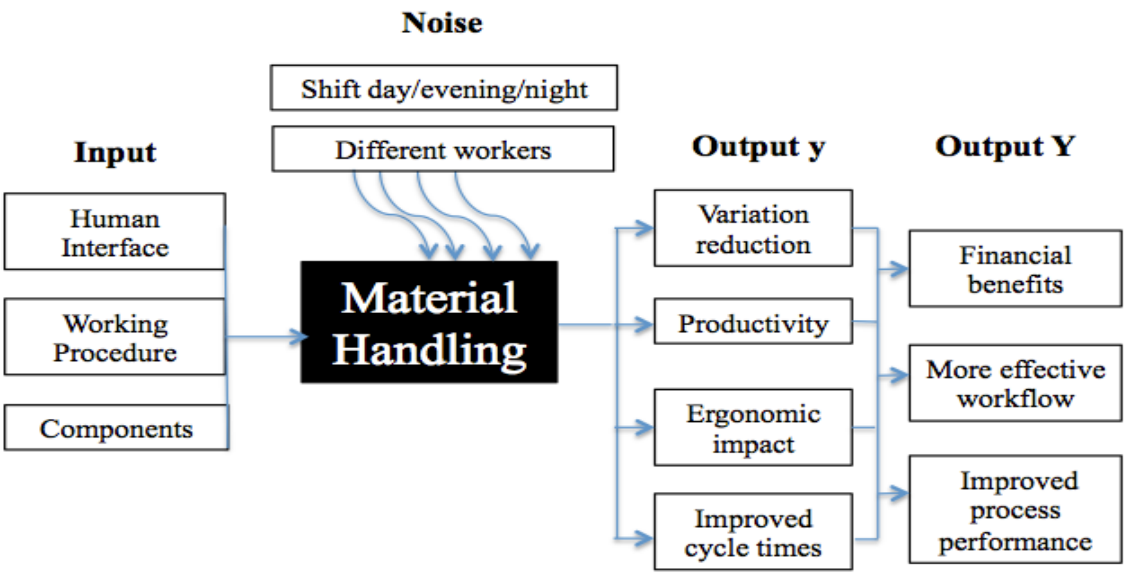


Figure 6: P-Diagram (Authors construct)

The P-Diagram shows the noise factors that exist in the process. These factors cannot be controlled because there is currently not an exact measurement to determine their impact on the output of the process. In this case, the first noise factor is the variation in relation to the different shift times of the material handling process. In the current situation it is not possible to determine the way the different shifts are exactly varying in the material handling process output. In terms of whether there is higher productivity during the different times as well as the reasons for this variation is not a factor that can be controlled in this case. Another noise factor is inter-worker variation in the material handling process. Because workers in the production line rotate among the different stations, the material handling results on each station can vary depending on the worker present. This can be due to a difference in age, height and slightly different working procedures for each of them. Therefore, when assessing the current state this factor cannot be controlled.

The three tools applied in the define phase, effective scoping, SIPOC and the P-Diagram each contributed by providing a different perspective on the problem focus. Effective scoping was used in combination with the SIPOC in order to make use of the questions exploring the problem as a structure to the discussions with the stakeholders and problem owners. Thus, the SIPOC represented the results from the effective scoping and was a beneficial means to prepare for further process mapping. Then the P-Diagram was used to address the different uncontrollable noise factors in relation to the input-output of the process. Overall, even though the SIPOC and effective scoping provided a better understanding of the small y's and big Y's of the project, the use of the P-Diagram was necessary to further define the parameters that despite possibly having an impact on the process could not be controlled during the project.

5. Measure

The measure phase is the second phase in the DMAIC cycle. During this phase the priority is to measure the current state and establish a clear understanding of the current performance level in the process. Therefore, this baseline will become the standard by which improvement is assessed and measured throughout the rest of the DMAIC cycle. It is crucial that the data and measurements done during this part of the project are accurate because they will be the foundation of the remainder of the project.

The authors will thus need to collect data in order to identify the root causes to the problem that is evident in the material handling process. By identifying these root causes the measure phase will facilitate the further analysis of the data gathered. However, a plan must be created to determine how to effectively measure and collect the data from the process. Factors such as where the data should be gathered from as well as the reliability of the measurement methods chosen for use; also the amount of data that should be collected to represent the current process accurately. The data collection plan is critical as the data that is gathered must be reliable and accurate. Further along the measurement phase, there should be a means to ensure that the gathered data is reliable which can be achieved by testing, re-testing and further refining the measurement methodology. This is necessary to guarantee that decisions are based on solid facts rather than inexact estimations and assumptions.

5.1 Process Mapping

Process mapping is a method used to clearly map out a process based on facts and visualizations (George et al., 2005). During this part the authors also involved the people directly working in the material handling in order to gain insights on potential improvement based on their experience. In this case, the authors decided to use process mapping because currently there wasn't a well-established means for determining the efficiency or lack thereof in the material handling process. There is currently no historical evidence of time studies on productivity in this area, thus the authors will conduct such studies to be able to clearly determine and gather accurate data from the process. For this reason it was necessary to establish a more clear process map since there were several zones and stations of material handling which combined made up the whole process. Therefore, the first goal was to create an overview of the layout flow in the main line to have a high-level layout map that represents the elements and interactions involved shown in figure 7.

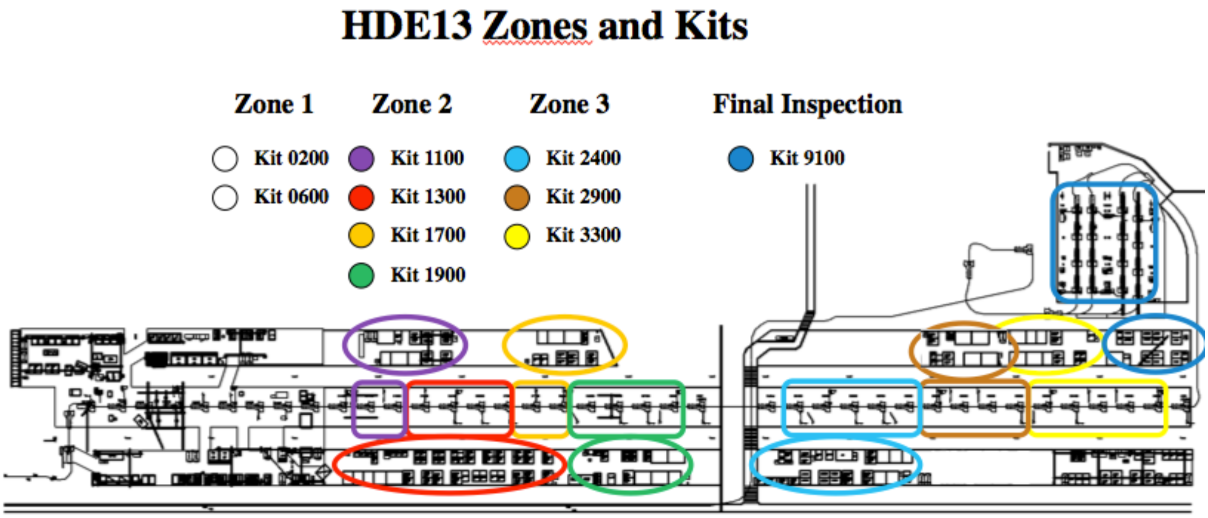


Figure 7: Material handling layout in Main Production Line of HDE13

A series of process walks were carried out to interview people working in the main line and to observe the material handling from an objective point of view as much as possible. During the interviews we learned that the most problematic issues were in the components that are being delivered and placed on large pallets in the main line. In the main line process there are currently four cycles of material handling when components are picked and gathered onto wagons in each kitting area and station. Each of these cycles is a prerequisite for the assembly process further on in the production line. Thus, the assembly line productivity for HDE13 engines is dependent on the efficiency of the material handling taking place during these four cycles. In the current state approximately nineteen HDE13 engines are produced and assembled per hour. Which indicates a cycle time standard of roughly three minutes per material handling cycle. Any variation taking place when gathering components from the pallets is a source of waste that is hindering the productivity of HDE13 production.

This difficulty was also leading to a loss of valuable time needed for the workers to get a hold of the components from these pallets along the main line. At this point, the primary concern was to identify exactly which components were leading to the greatest inefficiencies and were more difficult to handle from an ergonomic standpoint (figure 4). Out of all the different components in the main line process, we identified approximately 30 different types of components leading to inefficiency in material handling that were placed on large pallets. However, the authors realized that it would not be possible to make measurements on each and every one of these components. Thus, it was decided that the measurements for improvement would be focused on having components that have each low, medium and heavy weight as well as small, medium and large sizes. Moreover, components were chosen according to whether the pallets were fixed or were mobile. The components were then further sorted based on several characteristics as indicated in Appendix 13.

In Zone 1 of kits 0200 and 0600 illustrated in figure 7, the cycle of material handling includes between 10 to 15 different components picked from large pallets during each cycle. The number of components depends mainly on the degree of customization of the engine being produced further along the main line. However, based on the authors' observations as well as the input gathered from the workers at these stations, this station time could be improved if the variation in the picking process were reduced. The input gathered as well as the observations of the working procedure clearly indicated that the amount of products picked from large pallets was highest in this zone. Therefore, a solution in this area would potentially lead to the most impactful result in time savings and improvement of workflow productivity. When measuring the variation it is not possible to select all of the components being gathered because the measurement would become too complex for further analysis in the scope of the study. Moreover, there are certain part families that can be analyzed based on the study of one dominant component with higher frequency that is a reliable representation of the remainder of components in the family. The components chosen for analysis from Zone 1 were the Bracket, Filter and Duct. As shown in Appendix 13, these components each have the highest frequency of yearly turnover in the production line and thus a measurement of their ergonomic impact could be further implemented horizontally in the remaining components in the zone.

In Zone 2 of kits 1100, 1300, 1700 and 1900 shown in figure 7, the components placed on large pallets all belonged to the fuel filter housing family. However, in this zone only between 4 to 6 different components were picked for the material handling from large pallets per cycle. Moreover, the frequency of picking even the most dominant component among the fuel filter housings was not high in comparison to the components in the other zones as shown in Appendix 13. Thus, an improvement in this zone of the material handling would have a negligible impact in comparison to possible improvements in other zones. However, the nature of the inefficiency is still the same so the findings from analysis of the more problematic components in other zones could potentially be adopted to improve the material handling operations in Zone 2 as well.

In Zone 3 of kits 2400, 2900 and 3300 from figure 7, the separators in their different types were the only components involved in the material handling operations that were placed on large pallets. Even though this zone only involved between 2 to 4 different components in each cycle, the input gathered from the team working in these stations pointed out that the ergonomic inefficiency is leading to a lot of difficulty when the lower levels of the pallets are reached and components need to be gathered. Some of the pallets in this zone were also higher than in zones 1 and 2, making it harder for gathering during the cycle. Thus, the fourth component chosen for measurement was the Separator with highest picking frequency from Appendix 13.

As a result of this categorization the measurement phase was determined to have focus on four components for measuring ergonomic and productivity inefficiencies in material handling. Then once the solution could be determined to solve the challenges of these components, it would also be possible to be further implemented horizontally in the remaining types of components. Overall, the four components chosen for the measurement phase were Separator, Bracket, Filter and Ducts. Among them these four components are a solid representation of different weights and sizes as well as being a good exemplification for the component families being represented by each of them marked in green in Appendix 13. Moreover, these components were chosen because of the high frequency of yearly use in the production process. Which will lead to the ability to gather more data measurements on each of them. However, there are some components that will not be explored during this study as they are currently placed temporarily in the main line and are liable for change in their position in the layout in the near future. (See red marked rows in Appendix 13).

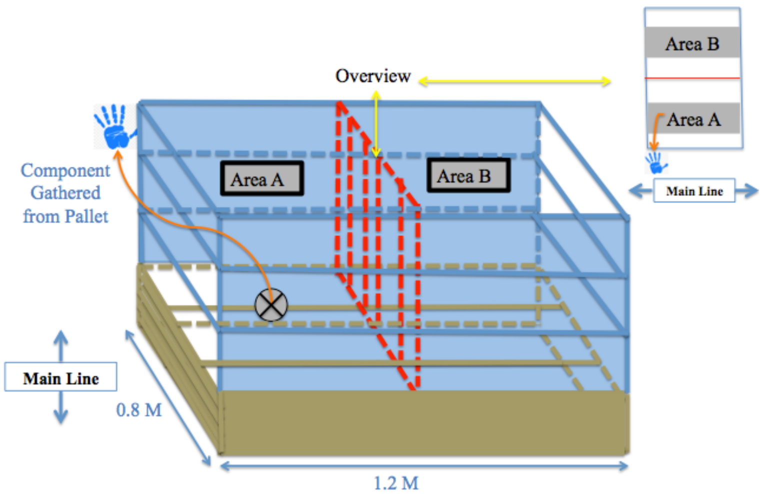


Figure 8: Pallet Division Areas A and B

A large pallet in this case is defined as a standard EU pallet. The input received was that gathering the material could be difficult from an ergonomic perspective when the mid-lower layers of the pallets are reached as well as the required horizontal reach to be able grab the components. To measure variation when picking from these pallets the authors decided to divide the pallet into two equal parts, namely Areas A and B such that the components in area A would be those placed closer to the worker when the components are being gathered as shown in figure 8. In the case of some components though, it was necessary to further divide the pallet into Areas A, B, C and D (figure 11); which will be further elaborated upon later in the measure phase. Moreover, the different layers of the pallets were also used a basis for categorizing data and measuring the time losses due to variation in the components measured during the project.

5.2 Measurement System

Once the process had been mapped out and the components to be measured determined, the next step was to decide which approach to take when measuring the process to provide a baseline of the current state (George et al. 2005). One of the key steps in the measure phase is to have a characterization of the measurement system to be utilized depending on the goals of the project. There were two main aspects to the measurement of the process. The first is from a time-efficiency and workflow productivity standpoint to determine where the current process performance stands at the current state. Therefore, in this measurement the aim is to determine a reliable means that would represent the times required for picking each of the four components from the large pallets, specifically to determine how the mid-lower parts of the pallet are more problematic. The second aspect of measurement is the ergonomic and human factors hindrances taking place in the current state potentially leading to negative physical impacts on the well-being of those directly involved in the material handling. Such as, by determining the impact of gathering material on the spine of those involved which could possibly lead to injury and other consequences. Once these two measurements have been attained the goal in the further phases would then be to calculate the financial impact of the baseline state on the project stakeholder Volvo Powertrain.

5.3 Workflow Productivity and Time-efficiency

A measurement method to determine the workflow productivity and time-efficiency of the material handling was being explored. In order to achieve reliable data the measurements were done by timing the span it takes from when the worker moves away from his or her picking wagon to go and collect the component then place it on the wagon. In the kitting zones there are lit buttons for each component to be gathered per order. Thus at the instant before the blue-collar workers gather the components they press on the button to turn off the light. As a reference for the time studies this button was used to standardize the procedure by starting the clock as soon as the worker presses the button and stopping when the component has been removed from the pallet. Since previous studies had not been conducted to measure this span of time, the authors decided to do so on each of the different four components over several visits to Volvo Powertrain. Moreover, the time studies measurement for each of the components was carried out by the authors as two different observers as shown in appendices 1, 2, 3 and 4 then the average of both measurements was taken to ensure that the data gathered was accurate. This data was then represented in control charts for the productivity and time-efficiency carried out on each of the components. In addition to the productivity aspect of the study, the ergonomic effort put forth on the workers was also assessed to determine the waste associated with overburden and unnecessary movement. The main lean wastes identified and measured in the kit zone line's material handling were Mura and Muri, however, these two types of lean waste were also in combination contributing to negative impact on the process through Muda waste as well.

The first lean waste identified is Mura. The Mura in the process is also directly related to the other waste forms and is a result of their impact on the process because there is significant variation in the material gathering time from an ergonomic perspective. Therefore, the resulting material handling is currently not standardized and should be further improved in order to achieve lower amounts variation.

The second form of lean waste identified in the current material handling is Muri. This type of waste has taken place because of the Muda waste in the process. More specifically, the workers in the main line are in some situations needing to increase their reach and movement due to the unstandardized picking that takes place when the lower levels of the pallets are reached. This extra effort does not add any value to the process and should thus be reduced because it is unnecessarily requiring the workers to work beyond normal capabilities to keep up with the cycle time.

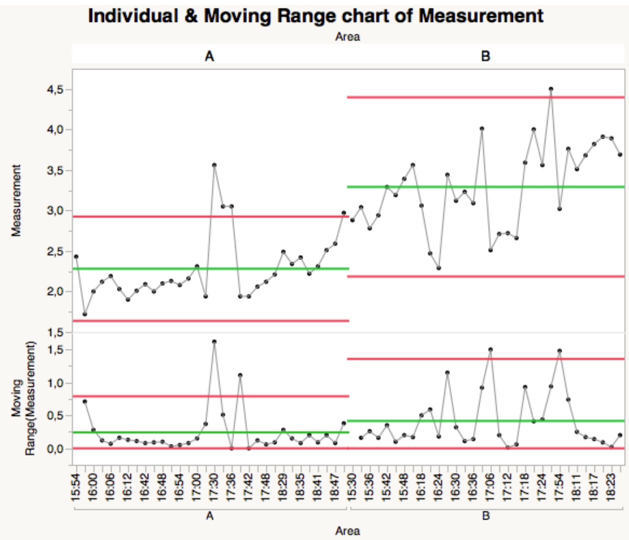
The combination of both Muri and Mura are the key factors contributing to the different Muda waste in this case. Which are motion and over-processing. The motion waste is evident in the picking process because when the products in the lower to middle parts of the pallets are picked it can take significantly longer in some situations, depending on the type of component being assessed. Moreover, this waste in motion can lead to a longer cycle time in material handling and in turn causes a need for the next station to wait for the incoming prior material to be gathered. In order to assess these waste forms the authors will measure the time needed during the picking process and utilize control charts and other quality improvement tools to assess these findings

However, the authors have found that the connection among these three types of wastes is strong and thus one form of lean waste is leading to a cascading effect in creating others as well. A solution to one perspective of lean waste will likely be able to reduce the impact of the waste in other forms. In order to successfully measure the current process baseline from a productivity perspective the authors will measure the time it takes to pick the different components in the kit zones of the main line from the different levels and areas of the pallets and make an assessment of this data gathered through statistical tools and process time study methods. Moreover, even though Volvo Powertrain does not have a specific grasp on how high productivity losses in the material handling are in the current state, there are some tools available through the Volvo Project network that have been previously applied towards quantifying lean wastes. Therefore, some of these tools will also be used in the measurement of the material-handling baseline in order to quantify wastes in this case. In addition, statistical software JMP will be used during the study to map out the data from time-efficiency and ergonomic standpoints.

5.3.1 Mura Measurement

For the Mura measurement control charts were used to gain a better understanding of the process baseline in the current state through determining the variation associated with each of the different components types. Two types of control charts will be used in this case, the first illustrates the time study variation in the material handling process as well as the mean time from all measurements for the different areas in the pallet. The second type is the moving range control chart, which plots the moving range over time and thus shows the process variation between the individual observations. Both these control charts also include lower and upper control limits (LCL and UCL) that are valuable to indicate the boundaries of the time studies that are considered as stable and also to identify whether outliers exist in the process. Outliers being values that could be abnormally high or low with respect to the control limits indicating that there may have been a special cause associated with this observation or that some unknown factor led to an inexact measurement.

For the Bracket in Zone 1, the time measurements of the ergonomic workflow during picking from the pallet were gathered by the authors and mapped out using control charts. The number of measurements conducted was equivalent to the total number of components on a whole pallet of Brackets because this would represent the picking process equally from both areas A and B. The pallet is made up of 4 layers and each layer had 16 brackets, thus a total of 64 measurements were needed for the pallet (Appendix 1). The control chart in figure 9 shows that there is significant variation when picking the components from area A of the pallet in comparison to area B. In addition to variation, the components picked from area B require longer time per component gathered; as shown in the measurement summary, the average of the data from picking in area A is 2.28 seconds whereas that in area B has increased to 3.29 seconds by an approximate factor of 0.5 per component.



Measurement Limit Summaries

Points plotted	Area	LCL	Avg	UCL	Limits Sigma	Sample Size
Individual	A	1,637708	2,280938	2,924167	Moving Range	1
Individual	B	2,185441	3,290938	4,396434	Moving Range	1
Moving Range	A	0	0,241935	0,79029	Moving Range	1
Moving Range	B	0	0,415806	1,358245	Moving Range	1

Figure 9: Bracket control chart of Area A and B

Upon gathering this data, the authors found that there are significant variations in the material handling of each of the measured components especially when the lower layers of the pallets were reached. It would in some cases take twice or three times as long for the worker to gather the component and place it on the wagon from the lower levels of the pallets compared to those on the higher levels when Area B was reached.

For the Filters in Zone 1, the measurement conducted on productivity and time studies was also represented using statistical tools. The pallet is divided into 2 layers, each having 80 filters. However, in this case the total of 160 filters were taken at the rate of 2 per cycle. For this reason, 80 time measurements were conducted for the study (Appendix 2). The control chart in figure 10 indicates the variation in the material handling time per cycle on the filters. The findings indicate that there is a significant variation that is greater when picking from Area B. Moreover, since the filters are picked at a rate of 2 per cycle it could cause even more difficulty for those involved in the material handling when they have to reach far into the pallet. In this case the control chart indicates a much higher variation in comparison to the bracket, in addition the mean value of time measured in Area A compared to that in Area B has more than doubled from 2.03 seconds to reach 4.33 seconds.

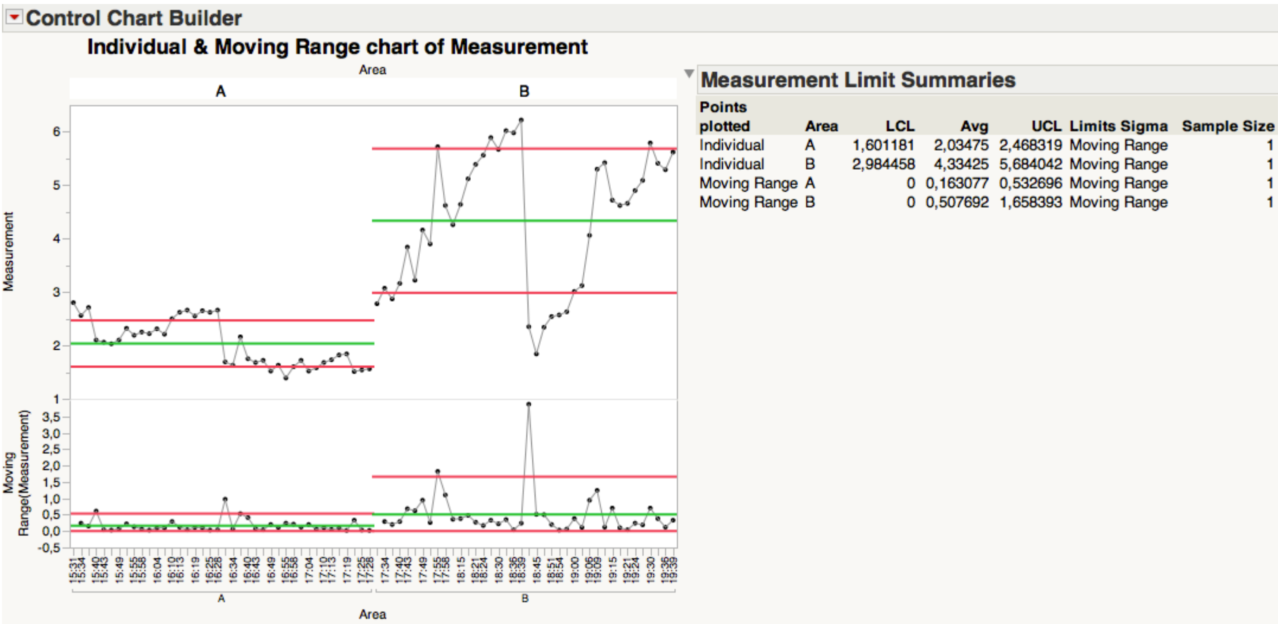


Figure 10: Filter control chart of Area A and B

The variation has increased significantly as well as the amount of outliers present in Area B. This could be because picking 2 filters per cycle makes the ergonomic factors even more impactful on the productivity of the workflow.

The time studies conducted for the separator in Zone 3 were carried out by further dividing the pallet into Areas A, B, C and D respectively. This was done because the pallet in this case was placed on the long side relative to the blue collar worker; the lit button used as a reference for time measurement is also placed nearer to the Areas A and C which would lead to some variation when gathering components from Areas B and D due to walking extra steps that are in fact unrelated to the variation due to Mura waste. Thus, the variation in this case of the component gathering would be more difficult to pinpoint. Therefore, the division of the pallet into only Areas A and B would be insufficient for the measurement to clearly display the Mura variation in the process. For this reason, the pallet was divided in this case as illustrated in figure 11.

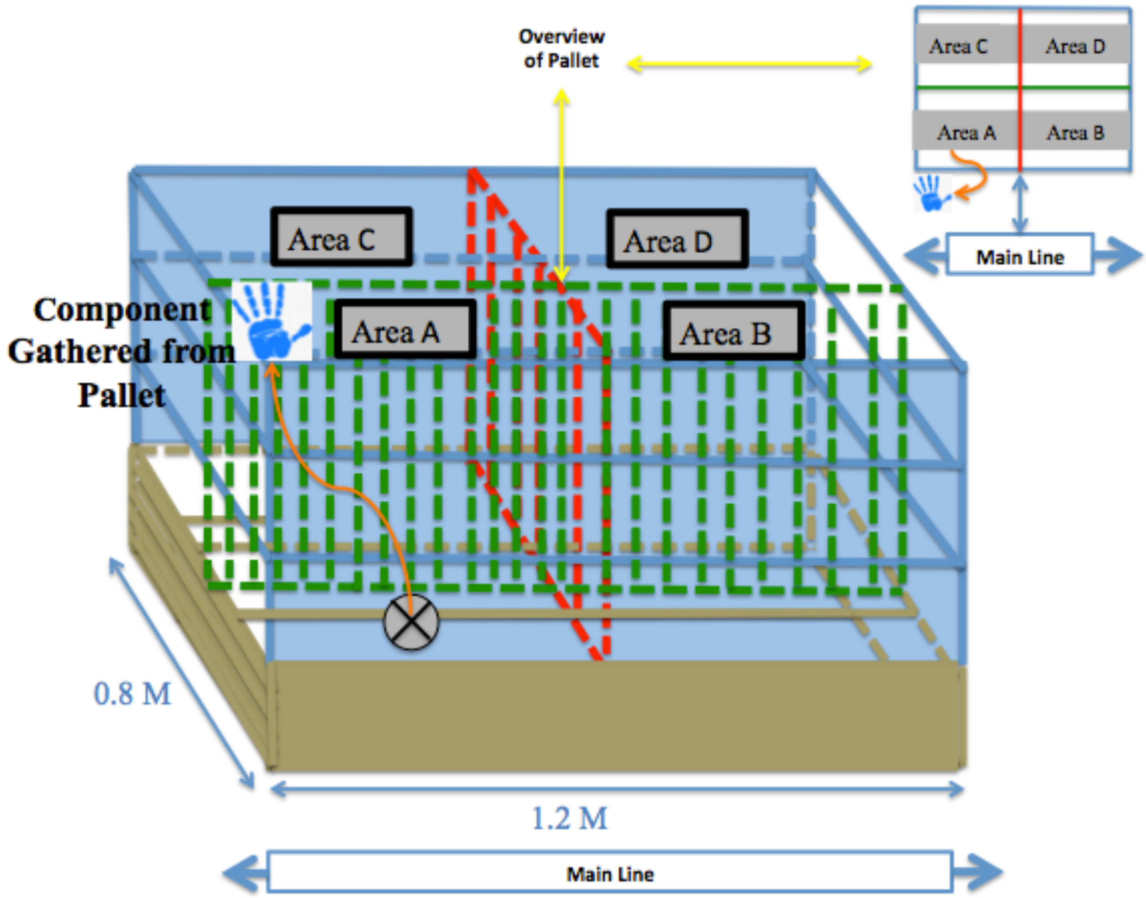
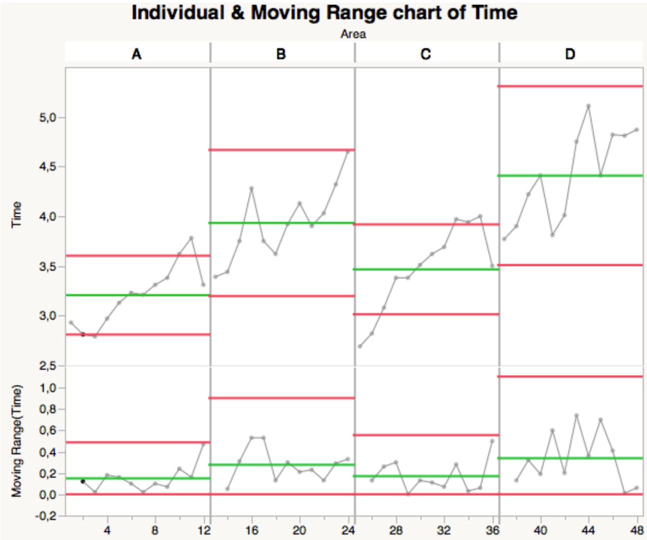


Figure 11: Pallet Subdivision for Separator

Based on the time measurements conducted (Appendix 3), the data for the separator was used to show the statistics of variation in this case by means of control charts. The pallet contains a total of 48 separators spread among 3 layers evenly at 16 separators per layer. Thus a total of 48 measurements were carried out for the time study of Mura waste in this case and is shown in the control charts of figure 12. The measurements plotted in the control chart indicate that the variation is considerable higher when comparing areas A and B which are along the length of the pallet rather than the variation between areas A and C that are along the breadth of the pallet. The same is evident as well when comparing areas C and D versus areas B and D.

Therefore, by placing the separator pallet along the long side with respect to the main line, the variation when picking further away from the pallet decreases in comparison to the previous components studied, namely the Brackets and Filters. Moreover, the figures indicate that Area D is the one with the highest time loss with a mean component gathering time of 4.4075 seconds versus Area A that has a considerably lower mean of 3.205 seconds.

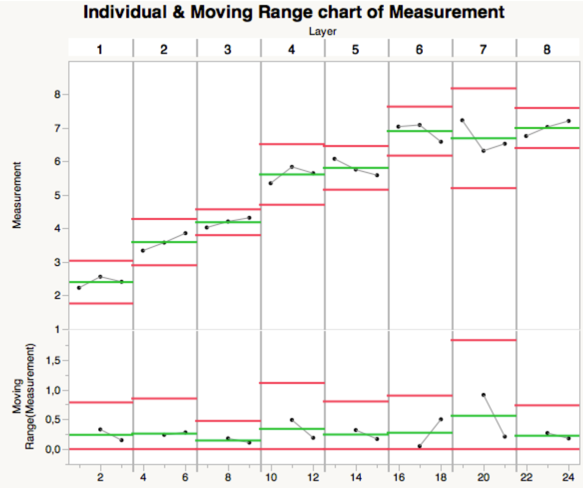


Time Limit Summaries

Points plotted	Area	LCL	Avg	UCL	Limits Sigma	Sample Size
Individual	A	2,809448	3,205833	3,602218	Moving Range	1
Individual	B	3,196904	3,931667	4,666429	Moving Range	1
Individual	C	3,013024	3,465	3,916976	Moving Range	1
Individual	D	3,508383	4,4075	5,306617	Moving Range	1
Moving Range	A	0	0,149091	0,48701	Moving Range	1
Moving Range	B	0	0,276364	0,902751	Moving Range	1
Moving Range	C	0	0,17	0,55531	Moving Range	1
Moving Range	D	0	0,338182	1,104682	Moving Range	1

Figure 12: Separator Control Chart

For the time study measurements carried out on the Ducts the pallet could not be divided into different areas, because the component itself was considerably larger than the others. So it was only possible to be placed on the pallet in one row per layer each carrying 3 Ducts. The whole pallet is made up of 8 layers, thus a total of 24 ducts were placed on each pallet, which lead to a total of 24 time measurements being carried out by the authors. The timing of the material gathering data is provided in detail (Appendix 4), such that average of the time from both operators was taken to determine the final time to be used in the Mura waste study. The data variation for material handling is provided in figure 13 indicating the variation among the layers. The findings indicate that there are significant time variations as the further levels of the pallet are reached. In the first layer the average time for gathering each duct was approximately 2,4 seconds, however this value increased steadily to reach an average of about 7 seconds when the ducts are gathered from the lowest layer. This is a variation loss of an approximate factor of 3 between the upper and lower layers.



Measurement Limit Summaries

Points plotted	Layer	LCL	Avg	UCL	Limits Sigma
Individual	1	1,761917	2,4	3,038083	Moving Range
Individual	2	2,902076	3,593333	4,28459	Moving Range
Individual	3	3,801158	4,186667	4,572175	Moving Range
Individual	4	4,709382	5,613333	6,517285	Moving Range
Individual	5	5,158623	5,81	6,461377	Moving Range
Individual	6	6,175529	6,906667	7,637804	Moving Range
Individual	7	5,204472	6,693333	8,182195	Moving Range
Individual	8	6,401797	7	7,598203	Moving Range
Moving Range	1	0	0,24	0,783968	Moving Range
Moving Range	2	0	0,26	0,849298	Moving Range
Moving Range	3	0	0,145	0,473647	Moving Range
Moving Range	4	0	0,34	1,110621	Moving Range
Moving Range	5	0	0,245	0,8003	Moving Range
Moving Range	6	0	0,275	0,898296	Moving Range
Moving Range	7	0	0,56	1,829258	Moving Range
Moving Range	8	0	0,225	0,73497	Moving Range

Figure 13: Duct Control Chart

5.3.2 Muri Measurement

In addition to the time studies carried out, a Muri Measurement tool provided by Volvo Powertrain was also used to determine the ergonomic wastes in terms of unnecessary motion and activity during the material handling process, which are standardized time values acquired through the use of the tool. The tool illustrated in appendix 5 estimates the time waste taking place due to different types of unnecessary motion; Such as the waste associated with bending over at certain angles to gather the component. The waste of time when additional steps are taken which do not add value as well as the waste when reaching far to collect the components from the pallet. The measurements carried out on each of the components Brackets, Filters, Separator and Cooling Duct; are provided in detail in Appendices 5 to 10 respectively. In order for the tool to be useful, it is necessary that the movement during material handling is observed and recorded in order to quantify the total waste of time when gathering the different types of components.

The Muri tool used for measuring overburden waste of ergonomics was provided by Volvo and has been used in their past improvement projects. Data is gathered based on the observation and study of the movement of the material handling worker. The result of the tool is a quantification of the approximate time wasted for each component gathered depending on unnecessary movement and effort as well as a total time waste which depends on the total number of components gathered from the pallets during the study.

Prior to using the Muri tool, the authors realized that there were some types of movement waste that were inapplicable in the case of the material handling of this study. The third and fourth columns are used to quantify the height of the working arm when lifting up a component. Also measured dependent on the angle of the lift, which is between 60 and 90 degrees versus an angle greater than 90 degrees in each of the columns respectively. However, this type of ergonomic waste is not relevant for this project because in this case there is no need to vertically lift the components gathered above shoulder level. The fifth and sixth columns in the tool are used to measure the working range angle of the torso when the components are being gathered. In this case the time waste is dependent on whether the angle is between 45 and 90 degrees versus being greater that 90 degrees. If the angle is between 45 and 90 degrees then the Ergonomic waste is around 0.17 seconds, but if the angle is greater than 90 degrees then this increases significantly to approximately 0.5 seconds. However, because the workers were moving freely during the material handling they did not need to twist at the torso to reach the components. Thus, this type of ergonomic waste is also irrelevant in this case. Moreover, the waste of time due to transport in columns nine, ten and eleven of the Muri tool is also inapplicable in this study because once the material was gathered from the pallet it would be placed directly on the wagon which was nearby and did not require transport of the component by any distance. Therefore, these types of movement waste were not relevant in this case and did not lead to significant time losses in the form of Muri waste.

However, there are other types of movement and work procedures that were impacting the losses of time and ergonomic efficiency. Thus a description will be provided for the different types of ergonomic inefficiencies observed and to be considered during measurement. The first two columns in the Muri tool are used to measure the waste of time associated with the flexion angle of the waste to pick up the components from the pallets (Appendix 5). Also depending on the angle of the waste required to grab the component. The first column (marked in yellow) is in the case of an angle of hip bend between 15 and 30 degrees, which in turn leads to 0.17 seconds in time waste. On the other hand, the second column (marked in red) measures a time waste of approximately 0.5 seconds due to a bending angle greater than 30 degrees.

The seventh and eighth columns respectively represent the waste due to the need to reach far into the pallet when trying to gather the components. In this case the time loss is dependent on the distance of the reach necessary during the manual labor. In the seventh column the reach necessary is between 20 and 30 cm and results in a time loss around 0.17 seconds each time.

However, in the eighth column when the reach exceeds 30 cm then the time loss increases to 0.50 seconds per component gathered.

In addition, another relevant ergonomic waste factor is when unnecessary walking takes place during manual material labor for gathering from the pallet. As indicated in the twelfth and thirteenth columns of the Muri tool, the waste due to taking between 5 to 9 steps is 0.17 seconds, whereas when the walking increases to 10 or more steps the waste of time becomes 0.5 seconds. The final type of movement leading to time losses is the rotation of the hip angle illustrated in columns fourteen and fifteen of the Muri tool. In this movement type, when the rotation angle of the waste is between 15 to 45 degrees then the time loss is 0.17 seconds. However, when the angle increases to beyond 45 degrees then the time loss increases to 0.5 seconds.

During the measurement in this case, the study and observation of the material handling manual labor procedure was used to categorize components into different subgroups depending on the layer and area from which it was taken on the pallet. By doing so the measurements carried out could indicate the different types of movement waste that could be associated with the subgroups of component location in the pallet. Thus, the Muri Ergonomic Waste tool was used to observe and study all of the four different components used for the measurement and representation of waste in the main line. Namely, the Bracket, Separator, Filter and Duct.

The resulting Muri Ergonomic Waste is provided for the different components taken during the study, namely the Brackets, Filters, Duct and Separator, are summarized in the tables 2, 3, 4 and 5 respectively.

In the case of the bracket, the pallet was made up of 4 layers each holding 16 brackets, thus a total of 64 brackets are available on a pallet. Therefore, 64 instances for observation of manual labor of gathering the components were carried out. The movement of the workers has been categorized depending on the area of the pallet as well as the layer which the components were picked from. This was done in order to determine the different types of movement waste associated with picking from different areas and layers of the pallet. Which, in turn allows the authors to quantify the time waste associated with each category of the Brackets. The detailed measurements carried out using the Muri tool are provided in appendix 5 and 6, and is summarized in table 2 based on area, layer as well as the total waste, which was 52.89 seconds.

Brackets Muri Waste	Area A	Area B	Total
Layer 1	3.06	7.02	10.08
Layer 2	3.05	8.04	11.09
Layer 3	6.36	8.34	14.70
Layer 4	8.00	9.02	17.02
Total	**20.47**	**32.42**	**52.89**

Table 2: Muri Ergonomic Waste from Brackets (Seconds)

In the case of the filter, the standard pallet contains a total of 160 filters spread out onto two layers, each carrying 80 filters. However, per cycle 2 filters are gathered from the pallet. Thus, in this case a total of 80 measurements were carried out, 40 from each Area A and B of the pallet. The detailed measurement of Muri Waste is provided in detail in appendix 7 and 8, as well as the different unnecessary movement associated with each observation. The summary of the findings is provided in table 3 per area and layer as well as the total time waste quantified by the Muri measurement tool, which was 76.75 seconds in this case.

Filter Muri Waste	Area A	Area B	Total
Layer 1	8.96	26.63	35.59
Layer 2	15.72	25.44	50.12
Total	**24.68**	**52.07**	**76.75**

Table 3: Muri Ergonomic Waste from Filters (Seconds)

In the case of the separator, the standard pallet contains a total of 48 separators that are distributed among three layers of the pallet, each having 16 separators respectively (Appendix 9). However, in this case the pallet has been placed on it's width in the material handling process so, in order to determine more precise measures of variation, the Areas A and B explained earlier have been further subdivided into Areas A, B, C and D as illustrated in figure 16. The summary of the findings in table 4 for the Muri Ergonomic waste was estimated to be around 32.24 seconds with Areas C and D each having the highest amount of Muri Waste.

Separator Muri Waste	Area A	Area B	Area C	Area D	Total
Layer 1	0	0.34	1.36	1.7	3.4
Layer 2	1.36	1.7	3.02	3.36	9.44
Layer 3	3.36	3.7	6	6.34	19.4
Total	**4.72**	**5.74**	**10.38**	**11.4**	**32.24**

Table 4: Muri Ergonomic Waste from Separators (Seconds)

In the case of the duct, the pallet could not be divided into different areas as had been previously done with the other components because this component was considerably larger than the others and only 3 could be fit per layer. The pallet carried a total of 24 ducts distributed equally among 8 layers. The summary of the findings from appendix 10 is provided in Table 5, indicating that as the lower components of the pallet are reached the Muri Waste increases significantly to reach 3,51 seconds at the lowest layer.

Duct Muri Waste	1	2	3	4	5	6	7	8	Total
Time	2,01	2,01	2,01	3,00	3,51	3,51	3,51	3,51	**23,04**

Table 5: Ergonomic Waste from Ducts (Seconds)

5.3.3 Muda Measurement

As was mentioned earlier in the project, the lean waste of Muda in the material handling operations is due to a combination of both Muri and Mura effects. In this case the most impactful Muda type of waste is due to over processing. However, this type of Muda lean waste is not the only one currently affecting the process, but there are others such as motion. The measurement of exact Muda waste in the process is unknown at this point, but due to the strong correlation between the three lean wastes, an improvement in one type of waste reduction will also have a positive effect on the others as well.

5.4 Ergonomic Measurement

Besides the productivity aspect of measurement there is also the assessment of losses from an ergonomic standpoint. In the current state, Volvo Powertrain has not calculated ergonomic losses in the form of human physiological and biomechanical factors. An example is to assess the current process in terms of likelihood of injury, wear and tear from a biomechanical perspective for those directly working in the main line as well as the consequences that are associated with the probability of injury or inability to perform in the future.

To measure this impact of manual lifting, the previously mentioned NIOSH (National Institute for Occupational Safety and Health) equation will be used to calculate the force on the spine/body depending on the weight of the object lifted as well as the height and distance it is carried. This formula will be applied to components being handled that are of different weights and sizes to determine the physiological impact on the workers as well as the risks associated with lifting these different components in with respect to the frequency of lifting per minute. So the formula will be used on each of the selected components involved in the study.

In addition to the NIOSH equation, the views of those in the main line will be gathered to determine the activities that they find most demanding and difficult to carry out from an ergonomic and human factors point of view. This is done because in addition to the measurements on the components, it is also beneficial to take the previous experience of those working in the main line into consideration. Based on this measurement, the cost associated with losses from the ergonomic inefficiencies will be estimated by financial analysis further in the project.

Frequency Multipliers (CM)

Frequency (lifts/min)	Work Duration (h) <1		<2		<8	
	V < 75	V > 75	V < 75	V > 75	V < 75	V > 75
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

Table 6: Frequency Multiplier

In order to determine the dangers of lifting the different components and placing them in their final destination, which is in this case the picking wagon, the NIOSH formula provided in

Equation 1 is used to calculate the Recommended Weight Limit (RWL). It is a multiplicative model and several biomechanical and physical variables are included as weighting functions. The calculations are performed from the point of origin of the lift for the component until the component is placed on the wagon. Then once the Recommended Weight Limit has been calculated the formula in Equation 2 is used to calculate the Lifting Index (LI), where L is the weight of the object lifted in Kg. The lower the lifting index is, the less likely an injury will take place.

Equation 1: RWL= LC x HM x VM x DM x AM x FM x CM
Equation 2: LI = (Load of weight L)/(Recommended weight limit RWL) =L/RWL
L: Weight of the object lifted (kg).
LC: Load Constant = 23 Kg
HM: Horizontal Multiplier = 25/H
VM: Vertical Multiplier= $(1-0.003|V-75|)$
DM: Distance Multiplier= $(0.82 + 4.5/D)$
AM: Asymmetric Multiplier= $(1 - 0.0032A)$
FM: Frequency multiplier= Obtained from Table 6.
CM: Coupling multiplier= Varies from 1.00 (good) to 0.90 (poor) depending on the grip difficulty with respect to the component.
H: Horizontal location of hands from the midpoint between the ankles. Measure at the origin and the destination of the lift (in cm). Most objects cannot be lifted closer than 25 cm from the ankles.
V: Vertical location of the hands from the floor. Measure at both the origin and the end-point of the lift.
D: Vertical travel distance between the origin and the destination of the lift (in cm).
A: Angle of asymmetry—angular displacement of the load from the sagittal plane. Measure at the origin and at the destination of the lift (degrees).

In this case of material handling, there are some variables in Equation 1 for calculating the Recommended Weight Limit that should be defined specifically based on the material handling process, the first being the asymmetric multiplier (AM) which is used when the end destination is not in the same displacement from the sagittal plane of the lift, to determine this variable the angle of asymmetry from the point of origin, in this case the pallet, to the destination, which is in this case the wagon, should be determined. Based on the observations and measurements the operator most often tries to place the wagon in parallel to the pallet, so the angle of asymmetry is zero degrees.

The coupling multiplier is dependent of the difficulty of grip with respect to the component, the authors have realized that the grip is not very difficult with respect to the components, but it is not optimal either as in some cases the shape/size requires a two-handed grip. Thus the coupling multiplier is set at 0,95 for the equation for the Recommended Weight Limit. As indicated earlier, 0,9 and 1 are used for the coupling multiplier for poor and good grip respectively.

The frequency multiplier is determined from table 6 with respect to the lifts per minute as well as the approximate duration of continuous work without a break. In this case the cycle time of production is about 3 minutes such that 19 HDE13 engines are produced per hour. Moreover, the duration of continuous work is about 2 hours continuously. Based on this assessment, the Frequency Multiplier for this study if found to be 0.95 (Table 6).

The components considered during the study are placed on two different pallet heights. One type of the pallets has 3 wooden collars and the other type only has 2 wooden collars. The measurements of these pallets are illustrated in figures 19 and 20. For each of these pallets 3 different measurement levels will be used to calculate the Recommended Weight Limit. These levels are maximum, middle and minimum because the components in each of the pallets are placed at different heights (Vertical Displacement) and areas (Horizontal Displacement) for each layer and thus it is necessary that calculations of the Recommended Weight Limit are done at varied levels on both, the vertical and horizontal plane. Since there are 3 variations of each horizontal and vertical displacement, a total of 9 calculations will be carried out on each type of the pallets, those having 2 wooden collars and those having 3 wooden collars respectively using 3x3 factorial DOE (Design of Experiments).

5.4.1 NIOSH Measurement Calculations

The calculations obtained for the pallets have determined nine values of possible Recommended Weight Limit depending on the horizontal and vertical displacement of the component with respect to the operator (Appendix 14). Tables 7 and 8 provide the measurements carried out for each of the Maximum, Middle and Minimum levels for the 3x3 factorial measurement. Figure 14 and 15 provide an illustration of these three levels with respect to the material handling process at the current state. Based on these NIOSH equation measurements the statistical software JMP was used to calculate the RWL.

2-Collars	Max.	Mid.	Min.
H Transport	170 cm	110 cm	60 cm
H Pallet	120 cm	60 cm	10 cm
V Pallet	5 cm	20 cm	35 cm
V Destination	30 cm	30 cm	30 cm
Distance= VD-VO	25 cm	10 cm	5 cm

Table 7: 2-Collar Measurements

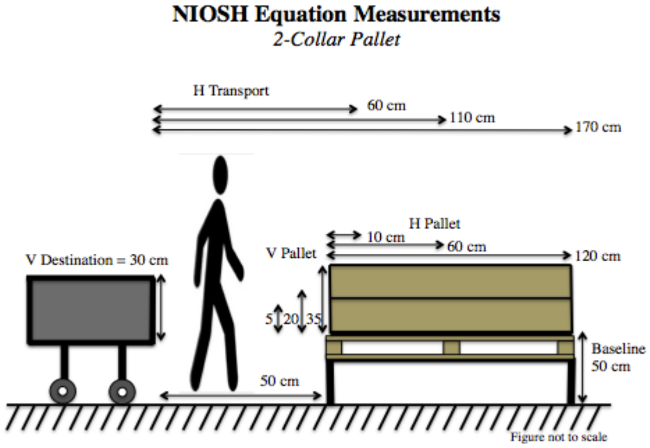


Figure 14: 2-Collar Pallet NIOSH Equation Measurements

3-Collars	Max.	Mid.	Min.
H Transport	170 cm	110 cm	60 cm
H Pallet	120 cm	60 cm	10 cm
V Pallet	5 cm	25 cm	55 cm
V Destination	60 cm	60 cm	60 cm
Distance= VD-VO	55 cm	35 cm	5 cm

Table 8: 3-Collar Measurements

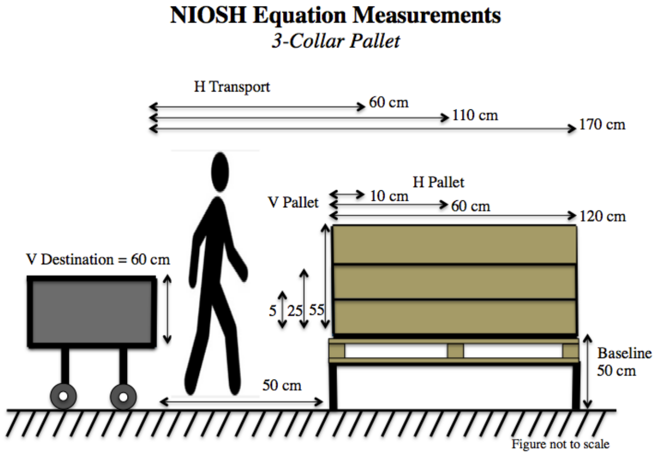


Figure 15: 3-Collar Pallet NIOSH Equation Measurements

3x3 Factorial 2 collars.jmp

	H Transport	V Pallet	RWL	HM: Horizontal Multiplier =25/H	VM: Vertical Multiplier =(1-0.003|V – 75|)	DM: Distance Multiplier =(0.82+4.5/D)	FM: Freq Multiplier =0.95	LC: Loading Constant =23	D Dist	V Dest	A: Angle of asymmetry	AM: Asymmetry Multiplier =(1-0.0032A)	CM
1	170	5	2,411	0,1470588235	0,79	1	0,95	23	25	30	0	1	0,95
2	170	20	3,237	0,1470588235	0,835	1,27	0,95	23	10	30	0	1	0,95
3	110	5	3,726	0,2272727273	0,79	1	0,95	23	25	30	0	1	0,95
4	170	35	4,620	0,1470588235	0,88	1,72	0,95	23	5	30	0	1	0,95
5	110	20	5,002	0,2272727273	0,835	1,27	0,95	23	10	30	0	1	0,95
6	60	5	6,832	0,4166666667	0,79	1	0,95	23	25	30	0	1	0,95
7	110	35	7,140	0,2272727273	0,88	1,72	0,95	23	5	30	0	1	0,95
8	60	20	9,171	0,4166666667	0,835	1,27	0,95	23	10	30	0	1	0,95
9	60	35	13,09	0,4166666667	0,88	1,72	0,95	23	5	30	0	1	0,95

Table 9: RWL Calculations 2-Collars

3x3 Factorial 3 collars.jmp

	H Transport	V Pallet	RWL	HM: Horizontal Multiplier =25/H	VM: Vertical Multiplier =(1-0.003|V – 75|)	DM: Distance Multiplier =(0.82+4.5/D)	FM: Freq Multiplier =0.95	LC: Loading Constant =23	D Dist	V Dest	A: Angle of asymmetry	AM: Asymmetry Multiplier =(1-0.0032A)	CM
1	170	5	2,17	0,1470588235	0,79	0,9018181818	0,95	23	55	60	0	1	0,95
2	170	25	2,46	0,1470588235	0,85	0,9485714286	0,95	23	35	60	0	1	0,95
3	110	5	3,36	0,2272727273	0,79	0,9018181818	0,95	23	55	60	0	1	0,95
4	110	25	3,80	0,2272727273	0,85	0,9485714286	0,95	23	35	60	0	1	0,95
5	60	5	6,16	0,4166666667	0,79	0,9018181818	0,95	23	55	60	0	1	0,95
6	60	25	6,97	0,4166666667	0,85	0,9485714286	0,95	23	35	60	0	1	0,95
7	170	55	4,93	0,1470588235	0,94	1,72	0,95	23	5	60	0	1	0,95
8	110	55	7,62	0,2272727273	0,94	1,72	0,95	23	5	60	0	1	0,95
9	60	55	13,9	0,4166666667	0,94	1,72	0,95	23	5	60	0	1	0,95

Table 10: RWL Calculations 3-Collars

The calculations carried out in Tables 9 and 10, provide nine measurements of the Recommended Weight Limit with respect to the different horizontal and vertical displacement levels of the component on the 2-Collar and 3-Collar pallets. The load on the spine of those involved in the material handling decreases as the Recommended Weight Limit increases, which in turn indicates a better standard of ergonomic efficiency.

The findings from table 9 and 10, indicate that the Recommended Weight Limit value obtained from Equation 1, is inversely proportional to the horizontal and vertical displacement of the component from the operator. For calculating the Lifting Index from Equation 2: LI = (Load of weight L)/(Recommended Weight Limit RWL) =L/RWL, the weight of each of the four components will be used to determine the Lifting Index ratio. This will provide the baseline for the current state with respect to the physical load on the operators from lifting the components.

Lifting Index 3-Collar Calculations .jmp

	RWL (Kg)	Filter Weight (Kg)	LI Filter	Separator Weight (Kg)	LI Separator	Duct Weight (Kg)	LI Duct
1	2,17	1,205	0,55	2,285	1,05	7,919	3,64
2	2,46	1,205	0,49	2,285	0,93	7,919	3,22
3	3,36	1,205	0,36	2,285	0,68	7,919	2,36
4	3,8	1,205	0,32	2,285	0,6	7,919	2,08
5	6,16	1,205	0,2	2,285	0,37	7,919	1,29
6	6,97	1,205	0,17	2,285	0,33	7,919	1,14
7	4,94	1,205	0,24	2,285	0,46	7,919	1,6
8	7,63	1,205	0,16	2,285	0,3	7,919	1,04
9	14	1,205	0,09	2,285	0,16	7,919	0,57

Lifting Index 2-Collar Calculations.

	RWL (Kg)	Bracket Weight (Kg)	LI Bracket
1	2,41	5,2	2,16
2	3,24	5,2	1,61
3	3,73	5,2	1,4
4	4,62	5,2	1,13
5	5	5,2	1,04
6	6,83	5,2	0,76
7	7,14	5,2	0,73
8	9,17	5,2	0,57
9	13,1	5,2	0,4

Table 11: Lifting Index Calculations

As shown in the tables 11 and 12, the Lifting Index (LI) shows a ratio that will be used as a baseline for improvement further in the project.

6. Analyze

The analyze phase is the third phase in the DMAIC cycle for continuous improvement. The focus of this phase is on making sense of the findings in the measurement phase through data analysis of the different aspects of the project. The chapter presents the methods used for data analysis by statistical tools and diagrams. The baseline state performance in terms of productivity based on the lean wastes found will be analyzed to determine key characteristics that could be negatively impacting the material handling operations. Moreover, the current state in terms of ergonomic performance and human factors will also be examined to identify the root causes leading to ineffective ergonomic conditions for those working in the main line of HDE13 heavy-duty engines. Based on this analysis the key factors to be further improved during the remainder of the DMAIC cycle will be identified.

6.1 Lean Waste Analysis

The Lean wastes found in the measure phase were further analyzed based on the Mura and Muri wastes for each component. Moreover, the waste was further studied and compared to the total waste found during the study. By breaking down the problem into different key focuses the analysis was conducted. Finally, the inefficiency is assessed in terms of the total loss taking place in the kitting zones in the current state. From a pure variation perspective the Mura analysis was done to divide the pallet according to the location of the components depending on layers and areas. The Muri analysis took into consideration the non-value adding activity from an ergonomic standpoint as well as the time associated with each of them. The NIOSH analysis indicates the negative impact associated with the physical and biomechanical lifting effects on the operators.

6.1.1 Mura Analysis

In the case of Mura, the baseline state found in the measurement phase will be further assessed depending on the variation from each of the components used in the study. The measurements from appendices 1 to 4 were used to create illustrations of the pallets with respect to the mean time required to gather the component from each layer and area as can be seen in figure 16. Based on this illustration the most problematic factors will be assessed and analyzed.

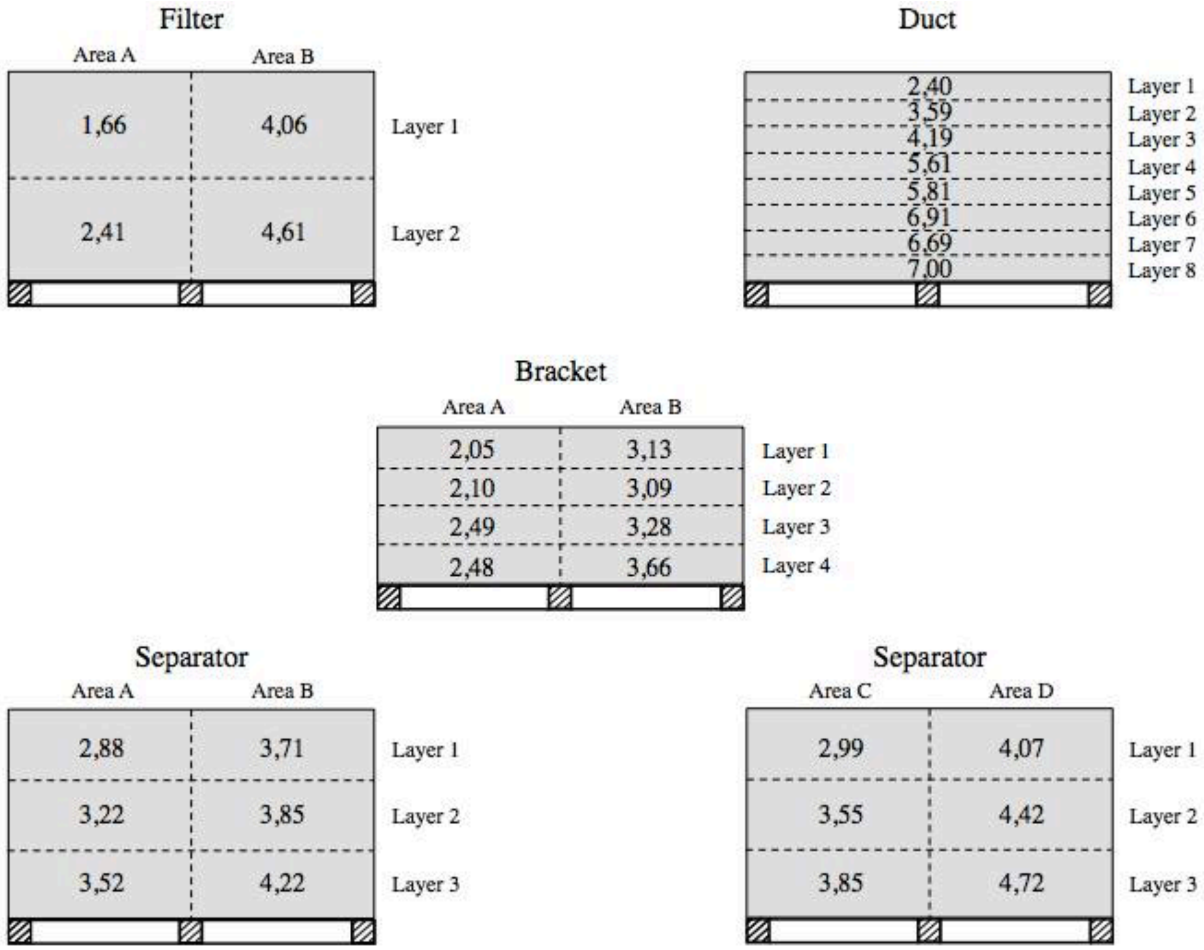


Figure 16: Time Study Analysis of Components

For the bracket, figure 16 shows that when the largest differences of mean values for gathering the components from within the pallet are compared, namely the variation between Area A of Layer 1 versus Area B of Layer 4, the time variation is approximately 3.66-2.05 = 1.51 seconds per component. This indicates that there is significant variation within the same pallet. Moreover, by assessing the incremental increase between the areas against that of the layers the time waste is more impactful on the horizontal displacement than that of the vertical displacement position of the component. This variation between areas is most likely because the time required for walking extra steps and reaching further is longer in comparison to bending at the waist to reach the component in the lower part of the pallet. This will be further elaborated upon in the Muri analysis section.

For the filter, the means values in figure 16 show an even greater variation when gatherin a component from Area A vs. Area B. When comparing the extremes of this variation, the mean time for gathering the component from Area A Layer 1 rather than Area B Layer 2 is measured at 4,61-1,66 = 2,95 seconds. This indicates that the variation is almost double of that found from the brackets and this could be due to several factors. The filters are gathered at a frequency of 2 per cycle in the production line, thus the impact of the inefficiency would most likely accumulate when moving into lower and further parts of the pallet. Moreover, the filter pallet is made up of 3-collars so the lower components require more effort to reach in comparison to those placed on 2-collars pallets as was the case with the brackets.

For the separator, the pallet was divided into 4 Areas and the means for each of the areas A, B, C and D are shown in figure 16. The time variation indicates that in this case the most extreme values, namely Area A Layer 1 vs. Area D Layer 3, is found to be 4,72 - 2,88 = 1.84 seconds. However, in this case the pallet, which is made up of 3-collars, was placed with the wide side towards the operator; which could be a contributing factor towards the variation being lower than that found for the filter. Thus, this analysis of the separator indicates that the pallets placed on the broad side can lead to lower picking variation than when placed on the short side for gathering the components. The variation reduction is possibly linked to the distance from the operator to the component is shortened, so the operator does not need to reach as far into the pallet.

For the duct, from figure 16 it can be seen that the variation is between the layers. There is a high variation in this case as the lower layers are reached, which could be due to the duct weighing more than other components from the study as well as being larger size. By taking the upper and lower layers, the extreme case of variation is found to be 7,00 - 2.40 = 4,60 seconds. In this case, the pallet is placed on its short side, which requires longer reach, also has a high weight and size; which is most likely a possible cause of the high variation in this Mura analysis.

6.1.2 Muri Analysis

The Muri waste studies conducted during the measure phase were further analyzed based on the wasted time due to different types of ergonomic inefficiencies. Figure 17 serves as an overview of the ergonomic waste types associated with each of the components. There are different types of ergonomic movement waste that are leading to time losses. The flexion angle of the waste is the first type; it can be separated into two magnitudes depending on the flexion angle. The first type when the waist is bent between 15 and 30 degrees is causing minor time losses in comparison to that from bending at the waist beyond 30 degrees. The second type of waste is due to the distance of reach when gathering the component from the pallet. In this case there are two subcategories as well, namely when the reach is between 20 to 30 cm, as well as when the reach exceeds 30 cm. The findings indicate that the most ergonomic time loss is due to the reach, which exceeds 30 cm, which occurs more frequently and takes more time. However, there are also losses from a reach between 20 to 30 cm but they are leading to much lower time losses. The third type of ergonomic waste is when the operator needs to walk further distance to reach the side-end of the pallet, which is in this case between 5 to 9 steps, mostly occurring when picking from area B. The fourth type of waste found was that associated with the rotation angle of the waste between 15 to 45 degrees. This type of waste takes place when the operator needs to reach the component by moving to be on the side of the pallet. The third and fourth waste types from walking and the rotation angle can be considered as secondary wastes because in some cases bending or reaching far into the pallet is not sufficient to reach the component, or is significantly more physically grueling.

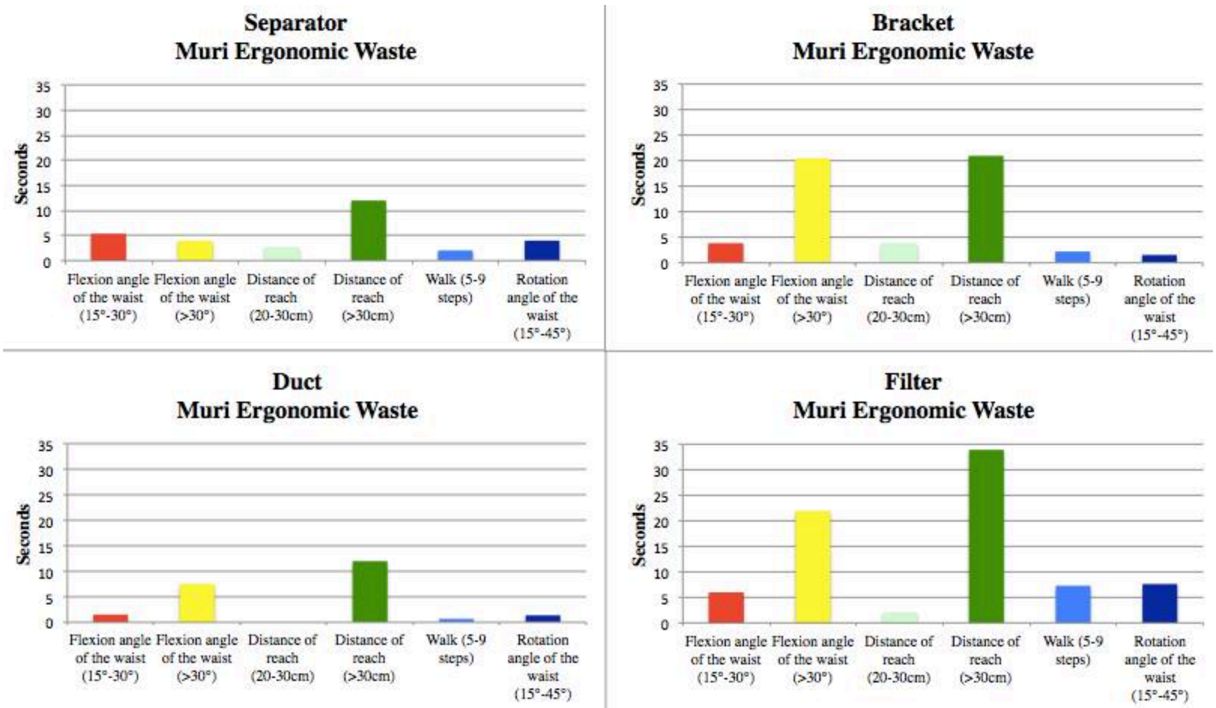


Figure 17: Muri Ergonomic Waste

For the Muri waste, the findings in the measure phase for the 4 components determine the summary of total Muri waste per component. For the bracket, filter, separator and duct the total Muri waste was found to be 52.89, 76.75, 32.24 and 23.04 seconds respectively. Resulting in a total of 184.92 seconds lost due to Muri waste. From figure 18, the ergonomic waste types having most impact on time losses for all components were found to be the flexion angle of the waste beyond 30 degrees (54 seconds) and the distance of reach greater than 30 cm (79 seconds). Thus, the findings indicate that the waste from these two movements is resulting in approximately two thirds of the total Muri waste. Due to this indication, the authors will have these waste types as a key focus for assessment of potential solutions towards an improved state. By taking this approach the secondary movement waste types will also be improved indirectly. Further analysis indicates that these movement types will have direct impacts for the physical strain on the operators in the material handling, which will further be assessed by means of the Recommended Weight Limit and NIOSH equations used in the study.

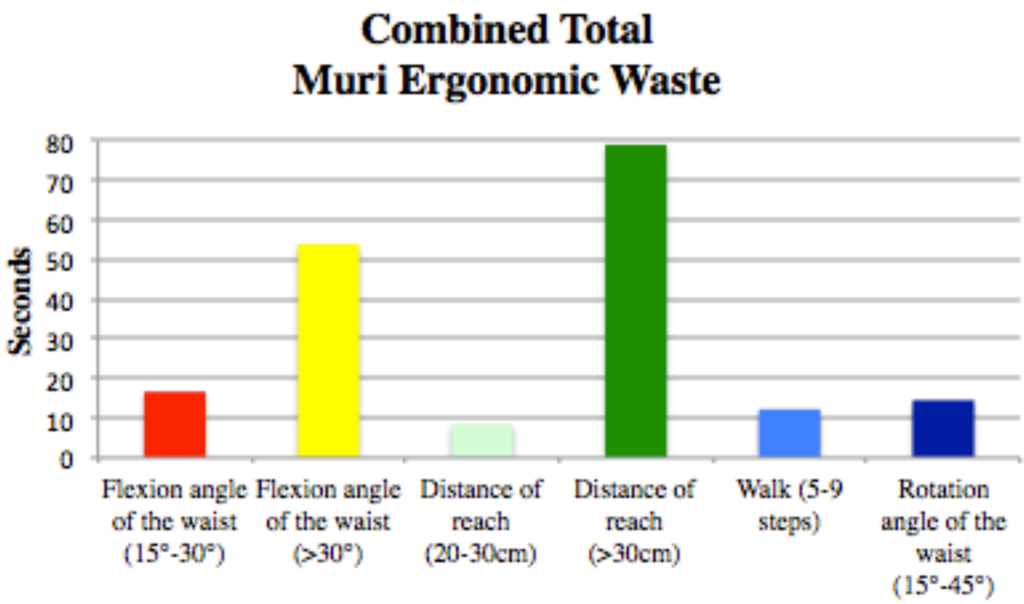


Figure 18: Combined Total Muri Ergonomic Waste

The outcome of Muri analysis shows that the best ergonomic efficiency is achieved when components are gathered from the closer areas of the pallet with respect to the operator. As shown in appendices 5 to 10, the lowest amount of overall Muri waste is when components are gathered from area A (Areas A and B in the case of the separator component) of the pallet with respect to the operator. More specifically, the most impactful movement wastes are lowest in this part of the pallet, namely the waste from flexion angle of the waste greater than 30 degrees and the distance of reach more than 30 cm. Thus, a foundation towards improvement would ideally be achieved by having all the components picked from the parts of the pallet that are closest to the operator (Area A), as well as by reducing the impact required to gather components from the lower layers of the pallet.

6.2 Ergonomics and Human Factors Analysis

The findings based on the NIOSH (National Organization for Occupational Safety and Health) equations used for determining the RWL (Recommended Weight Limit) and LI (Lifting Index) for the different components carried out on the different pallet types each having 2 or 3 wooden collars respectively indicate that there are key factors leading to biomechanical and physical load on those directly involved in material handling of the HDE13 main line. Thus the analysis in this respect will shed light on the factors that are responsible for this ergonomic inefficiency as well as it's link to the likelihood of injury.

6.2.1 Ergonomic Measurement Analysis

The Lifting Index (LI) and Recommended Weight Limit (RWL) values found in the measure phase by using the NIOSH equations indicate the ergonomic difficulty associated with gathering the components from different parts of the pallet. In terms of the horizontal and vertical displacement shown in figure 20, the Lifting Index of each of the components is illustrated depending on which area of the 2-collar or 3-collar pallets that they are placed.

The lowest Lifting Index is when the components are placed furthest away from the operator as well as when it is placed on the lowest part of the pallet. Thus the most physically demanding components are those gathered from this area. Moreover, it is found that the vertical displacement affects the Lifting Index more than that of the horizontal displacement. The measurements found for each of the components in figure 20 will be explained as an analysis of the baseline ergonomics with respect to the current LI.

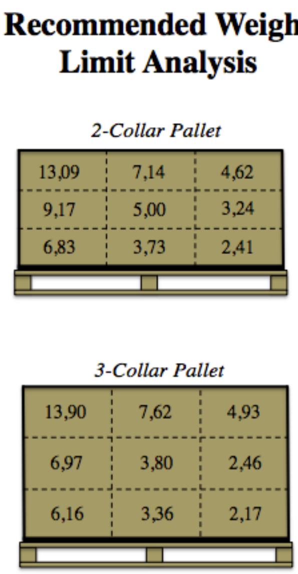


Figure 19: RWL Analysis (Kg)

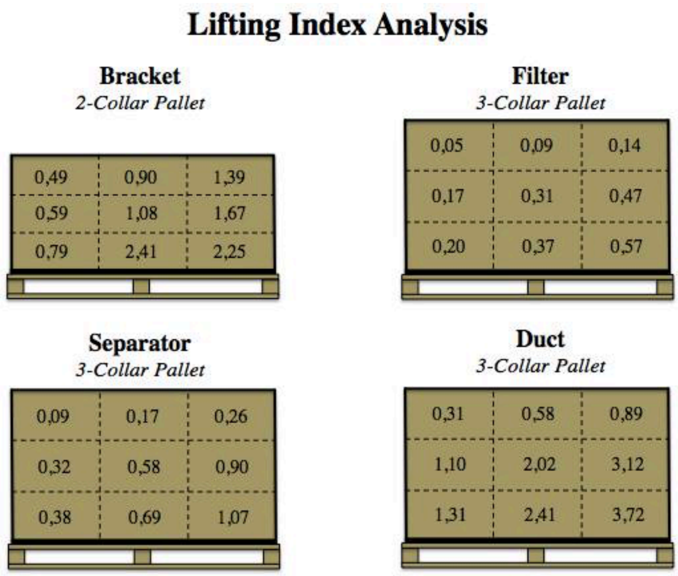


Figure 20: LI Analysis (Ratio)

The Recommended Weight Limit for the 2-collar and 3-collar pallets is independent to the weight of the component, but rather the factors affecting its value are the horizontal and vertical position of the components with respect to the operator (Figure 19). For both pallet types the highest Recommended Weight Limit was calculated at the components placed closest and furthest up on the pallets, 13,09 for 2-collars and 13,90 for 3-collars. Which indicates that picking from the highest parts from the 3-collar pallets is less strenuous for the operator than when picking from the upper part of the 2-collar pallets. Moreover, the difference between the extreme cases of the Recommended Weight Limit for the different pallet types is larger for the 3-collar pallets. Specifically when comparing a maximum Recommended Weight Limit of 13,90 kg vs. a minimum of 2,17 kg for the 3-collar pallets on the other hand this difference is much lower for the extremes of the 2-collar pallets with a max Recommended Weight Limit of 13,09 vs. a minimum of 2,41. Thus, these findings are purely dependent on the dimensions of the pallet and are independent to the weight of the component. The comparison of the extremes in these cases also indicates that an increase in the vertical height can increase the Recommended Weight Limit significantly and make the work less physically demanding for the operator.

On the other hand, the Lifting Index ratio= (Load of weight L)/(Recommended Weight Limit RWL) =L/RWL is dependent on the weight of the respective components taken during the measure phase. For the case of the 3-collar pallet components, the one with the highest weight, which was the duct at 7.92 kg, has also led to the highest Lifting Index ratio as well reaching a maximum of 3,64. In comparison to the maximum Lifting Index of the filter 0,55 and separator 1,05 the Lifting Index of the duct is much higher due to its weight and thus has a higher force load on the spine of the operator. In this case the difference of the extreme values of maximum and minimum Lifting Index for the components also increases as the weight of the component is higher.

By comparing the positions of the components with respect to the horizontal and vertical areas of the pallet, the calculations of Lifting Index for all the different components also show that as the components are placed in the higher parts of the pallet, the Lifting Index decreases and thus it is less strenuous for the worker to gather the components from these parts. Moreover, the incremental increase in the Lifting Index values is greater on the vertical plane for all three types than on the horizontal plane. This shows that the force load on the spine of the operators also increases more due to the vertical distance from the component rather than the horizontal distance.

For the brackets placed on the 2-collar pallet, the analysis also shows that the load of the force on the worker increases as the lower and farther components are gathered, which is indicated by the increase in the Lifting Index ratio. The vertical height increments of the Lifting Index are also higher in this case than that of the horizontal distance. The comparison of the maximum and minimum Lifting Index values namely 2,16 vs. 0,40 respectively is higher than that of the filter and separator most likely due to the lower height of the pallet and higher component weight of the bracket 5.2 kg.

6.3 Deductions of Analysis

From the Mura analysis, the perspective taken towards the current state was purely from a time variation standpoint. The findings from this type of lean waste indicate that time variations are higher as the further areas and lower parts of the pallets are reached to gather the components. Moreover, the analysis of the Muri waste takes a dualistic approach to the material handling that is from both ergonomic inefficiency and time loss. From the analysis of this part, the authors determined that the most common types of movement waste in the ergonomics is when reaching into the pallet (> 30 cm) to gather the components at a farther horizontal distance as well as the flexion angle of the waist (> 30 degrees) when the lower layers of the pallet are reached. Finally, the Recommended Weight Limit and Lifting Index analysis indicates also that the load on the spine is higher as the components are placed lower on the vertical plane as well as when placed at further horizontal distance from the operator. Therefore, all three analysis types indicate that the factors most impacting the material handling in the current state are the horizontal and vertical distance of the components with respect to the operator. Thus, in order to make use of this analysis towards a solution, the components should in the future state be placed closer to the operator as well as on a height higher than it is in the current state. By doing so, all three types of inefficiencies will most likely be reduced and the performance level of the material handling operations will be improved.

7. Improve

The improve phase is the fourth part of the DMAIC cycle. In this phase the previous findings from the analysis of the problem are put to use in order to come up with a solution to the challenge at hand. In this case, the improve phase will be in the form of a pilot project carried out as the solution to material handling operations has been implemented. Moreover, the measurement of the new performance standards will be assessed from the three perspectives taken into consideration previously in the project; namely Mura, Muri and pure ergonomic efficiency through NIOSH calculations. Finally, the benefits of the new state will also be compared to that of the current performance level in terms of variation and ergonomic efficiency. The improve phase will be completed by means of a financial cost-benefit study of the improvement project on a one year basis.

7.1 Determining the Solution

Upon the analysis of the current state from the diverse methods taken during the project, namely Mura, Muri and NIOSH analyses. The key causes of inefficiency were determined to be consistent in all these approaches. The primary cause of variation and inefficient ergonomics is the current positioning of the pallet with respect to the operator, making it difficult to be able to gather components. The components placed in the lower parts of the pallet and at a greater horizontal distance from the operator are the focus point towards further improvement. Thus, visits were done at the production sites of Volvo Cars to benchmark their material handling operations in comparison to those taking place in the HDE13 main line at Volvo Powertrain in Skövde. During the benchmarking process the authors discovered that at some areas of production there are carts that can be tilted to change the angle of the pallet with respect to the operator. These types of carts were found to be capable of directly impacting the problem focus of the study, by adjusting the horizontal and vertical distances of the component with respect to the operator towards a more desirable level in terms of variation reduction and ergonomic improvements. The carts found through the benchmarking process served as a foundation towards carrying out a pilot project to investigate the potential for improvement on the chosen components in this study.

7.2 Pilot Project

The pilot project carried out will use the tilt function mentioned earlier to be the foundation of improvement for the remainder of the study. The critical purpose of a pilot project is to stand as a fact-based means towards the improvement of the material handling operations. It will function as a small-scale method to measure the effects of the solution in terms of problem resolution and improved performance. The findings from the pilot project will thus be used as a gradual step towards improving the remainder of the material handling operations. The pilot project will particularly assess the process from diverse perspectives that are Mura, Muri and ergonomic efficiency. By doing so the performance standard of the material handling can be determined with the solution of tilt able carts and compare these results with those obtained earlier from the baseline state.

7.2.1 Mura Pilot

The variation due to Mura waste for the components used in the study was assessed post-solution implementation. As was done earlier in the measure phase the data gathered from the process for each of the components was displayed using control charts for time variation for the different areas and layers of the pallets. By tilting the pallets by using the special carts, the authors carried out the measurements for the components, namely the bracket, filter, separator and duct as shown in appendices 14 to 17 respectively.

For the bracket, the measurements from appendix 14 were used to create the control charts in figures 21. The measurements indicate that the mean time for gathering a bracket from Area A is now 1.40 seconds, and that for Area B is 1.64 seconds. This indicates that the solution provided has led to a low degree of variation as well as a reduction in the overall mean time for each area in comparison to the baseline state. Area A decreased from 2.28 to 1.40 seconds whereas that in Area B has decreased from 3.29 to 1.64 seconds Thus, the time found for each of the areas was reduced in comparison to the baseline as well as the inter-variation between both Areas A and B of the pallet.

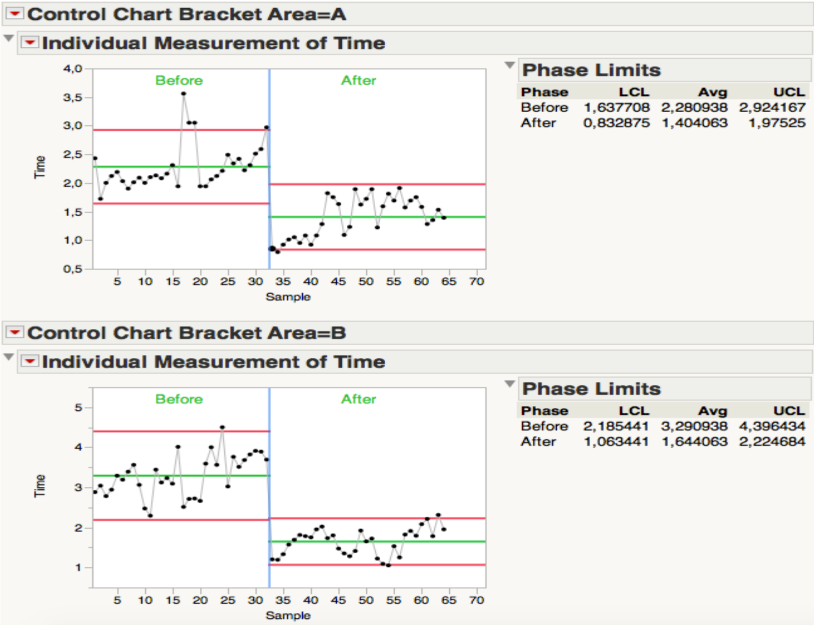


Figure 21: Bracket Mura Before Vs. After Pilot

For the filter, the measurements from appendix 15 were used to create the control charts in figure 22. By doing so, the authors determined that the time reductions for gathering the components in this case were also great in comparison to the baseline state. The mean time for Area A is found to be only 1.53 seconds and 1.93 seconds for Area B. The filters were picked at a frequency of 2 per cycle, but despite this the time reduction has become much lower than that found in the baseline state. In this case, the mean time required to gather the filter from Area A decreased from 2.03 to 1.53 seconds whereas that in Area B decreased even more from 4.33 to 1.93 seconds. Also, the variation has decreased for Areas A and B.

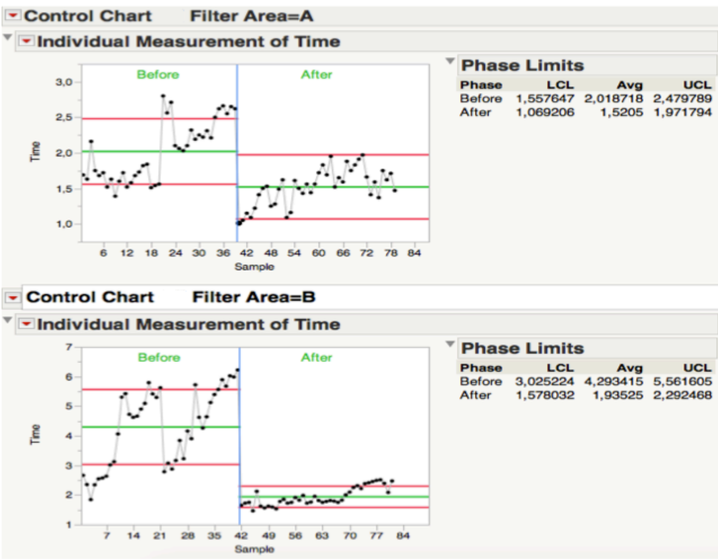


Figure 22: Filter Mura Before Vs. After Pilot

For the separator, the measurements from appendix 16 were used to create figures 23. In this case, the time required to gather the component was also reduced in Areas A, B, C and D to become 1.32, 1.35, 1.44 and 1.38 seconds respectively vs. 3.21, 3.93, 3.47 and 4.41 (Figure 14). Thus the solution has also led to lower variation among the different areas as shown in figure 23.

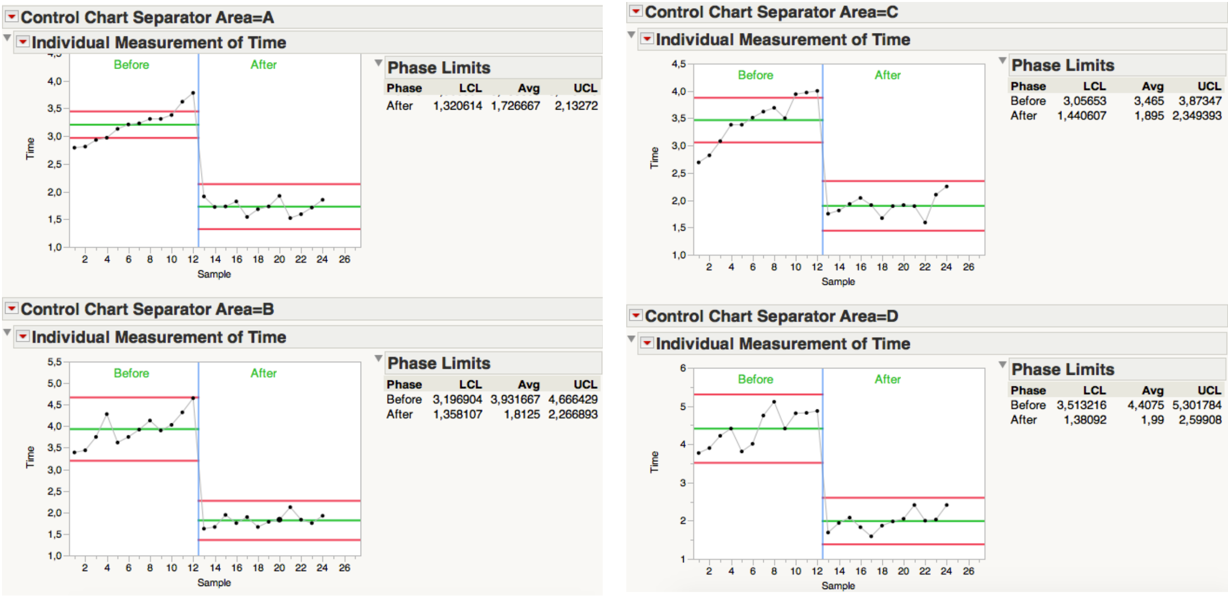


Figure 23: Separator Mura Before Vs. After Pilot

For the duct, the measurements were carried out solely to show the time variation between the layers, because for this component it was not feasible to divide the pallet into areas because of its size (Figure 24). For the layers 1 to 8 of the pallet, mean time per layer was found to be 1.9, 2.01, 2.25, 2.58, 2.71, 2.96, 3.25 and 3.52 seconds vs. 2.4, 3.59, 4.18, 5.61, 5.81, 6.91, 6.69 and 7 seconds. In this case the extreme mean time for the lowest layer was reduced significantly from 6.91 to 3.52 seconds per duct. Moreover, the overall mean times were reduced for all the layers when comparing the baseline measurements to those of the pilot project from 5.27 to 2.64 seconds.

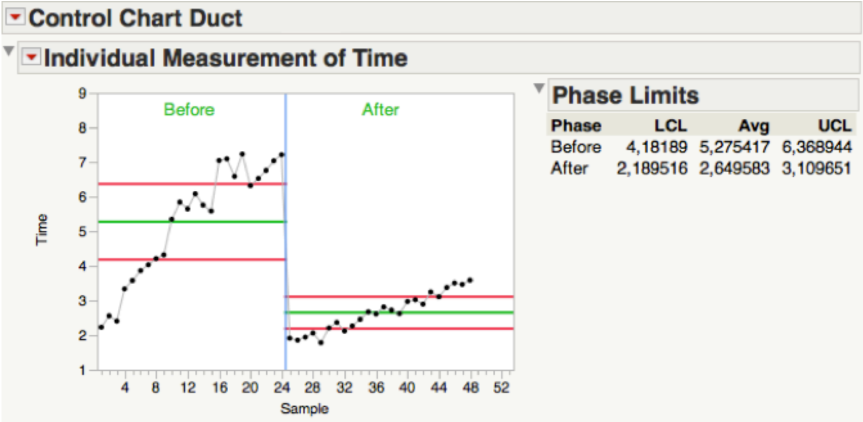


Figure 24: Duct Mura Before Vs. After Pilot

The control charts described discuss the improvement in general for each of the components in terms of improved time and reduced variation. However, as a more specific analysis of the Mura in this pilot the figure 25 is provided as an illustration of the exact improvements for the areas and layers for each of the components used in the study. The mean time measurements for each layer and area from the current state are those placed between parentheses and thus a comparison will be conducted to determine the total time improved through this pilot project in terms of Mura.

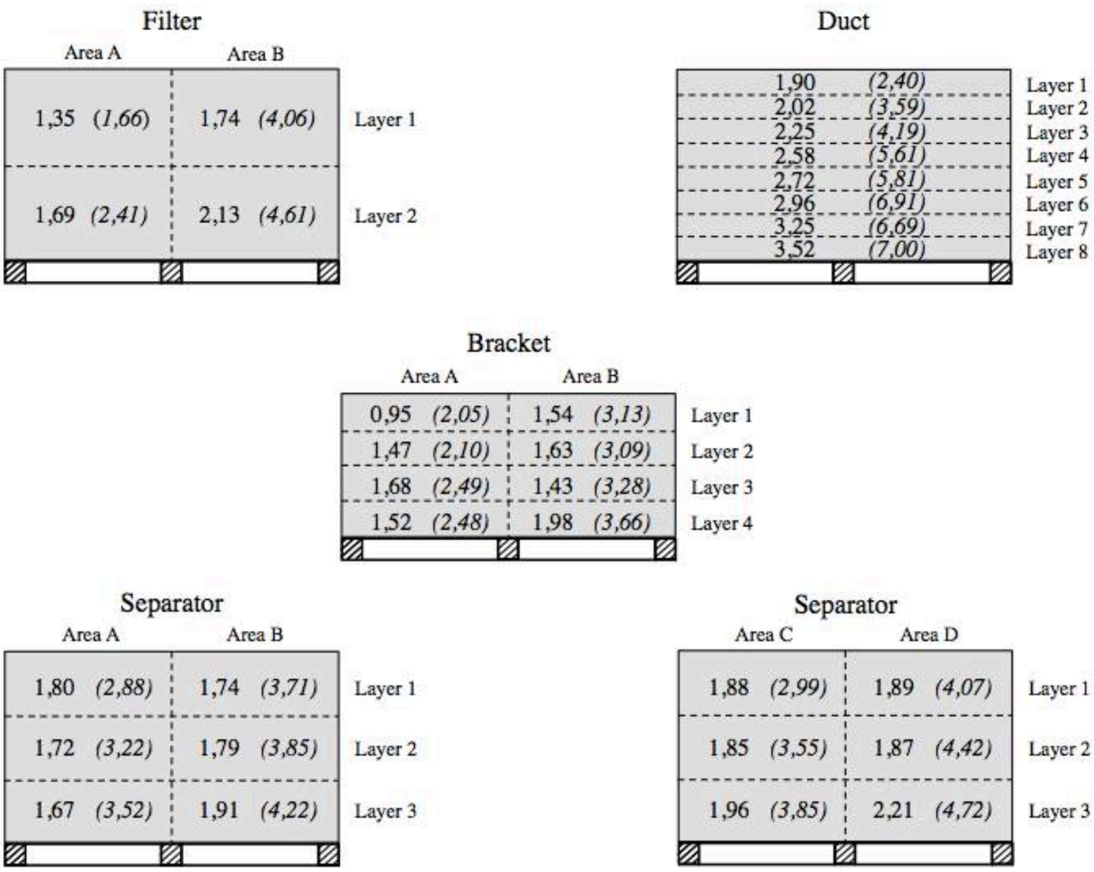


Figure 25: Mura Summary Before Vs. After Pilot

The Mura waste has been calculated for each part of the component pallets, each part being the segment made up of both layer and area positions. The figure values show the difference between the pilot project measurements and those found in the current state. Based on these differences of time and variation for the components the calculations in appendix 24 were done to determine the mean time improved per component is 1.92 seconds. This was done by finding the difference between each of the parts of the current and pilot state respectively and then the number of components in each of the parts was used to determine the time improvement per part of each component. Finally the total time improvement for all the four components was used to determine the mean time saved per component gathered of 1.92 seconds.

The findings from Mura in the pilot project time studies compared to that of the current state from figure 25 were used to determine the variation span reduction in table 12. This was carried out by comparing the extreme values of minimum and maximum means from the layers and areas of the different components. Thus the different in mean time between the best and worse cases for gathering the components prior and after the pilot project. As can be seen in table 12 the variation between the best and worse case has decreased significantly for the different component types.

Bracket	**Area A Min**	**Area B Max**	**Variation Span (Max -Min)**
Before	2,05	3,66	**1,61**
After	0,95	1,98	**1,03**
Filter	**Area A Min**	**Area B Max**	
Before	1,66	4,61	**2,95**
After	1,35	2,13	**0,78**
Separator	**Area A Min**	**Area D Max**	
Before	2,88	4,72	**1,84**
After	1,8	2,21	**0,41**
Duct	**Layer 1 Min**	**Layer 8 Max**	
Before	2,4	7	**4,6**
After	1,9	3,52	**1,62**

Table 12: Variation Span Current Vs. Pilot

7.2.2 Muri Pilot

The Muri approach was used during the pilot project to take a dualistic perspective of both time losses and ergonomic inefficiency into consideration. Thus the same measurement tool used earlier in the project was used for the pilot project for Muri analysis post-solution implementation, namely by having the pallets tilted for the components used during the study. The measurements conducted for each of the components are provided in detail in appendices 18 to 23 and will have been used as a foundation towards creating figures 26 and 27. The figures are used to illustrate the types of movement in material handling that are most responsible for ergonomic inefficiency and time losses. Moreover, the goal is to compare the pilot project Muri with those previously found from the current state before using the tilt able function.

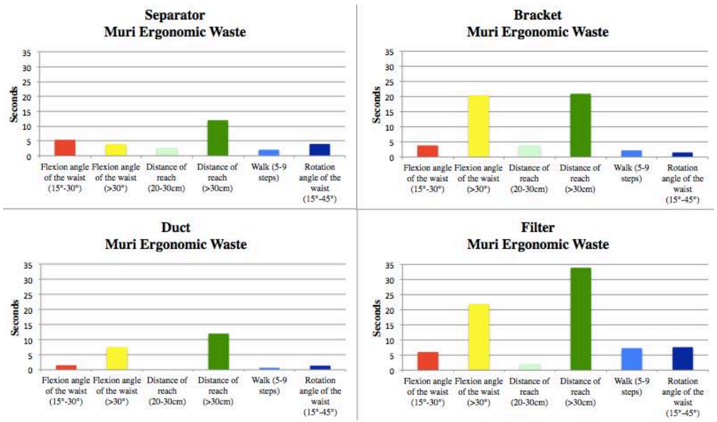


Figure 26: Muri Before Pilot

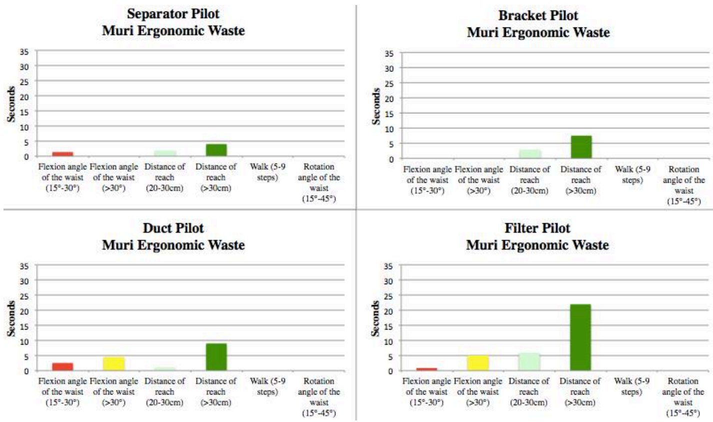


Figure 27: Muri After Pilot

The figures 26 and 27 of individual Muri for each component show that the pilot project has significantly reduced the ergonomic losses because the components are closer and on a more convenient height for the operator. In the case the largest two movement wastes found earlier that were a distance of reach greater than 30 cm, as well as the flexion angle of the waist greater than 30 degrees. By comparing the Muri figures of both the current state versus that of the pilot project, we find that both these types of waste have been reduced for all the components used in the study, irrespective of weight or size. Moreover, the secondary movement waste types such as the rotation angle of the waist and that due to walking certain distance have been totally eliminated in the pilot project.

As shown in figures 28 and 29, the total ergonomic waste in all forms of movement has been reduced in the pilot project. The total combined time loss from the current state was 185 seconds, whereas when the pilot project solution was implemented this total time loss was reduced to 58 seconds indicating a waste reduction by more than a factor of 3. However, as can be seen in figure 29, the most contributing ergonomic waste type is the distance of reach (>30 cm). The reason for this is because the tilt cart used in the pilot project is a prototype that can in its current design only be tilted on its width as can be seen further in figures 30 and 31. The authors recommend that for a future full-scale improvement of the material handling process the designed cart should be tilted on its length, to further improve the Muri ergonomic waste, especially that caused by distance of reach (>30cm).

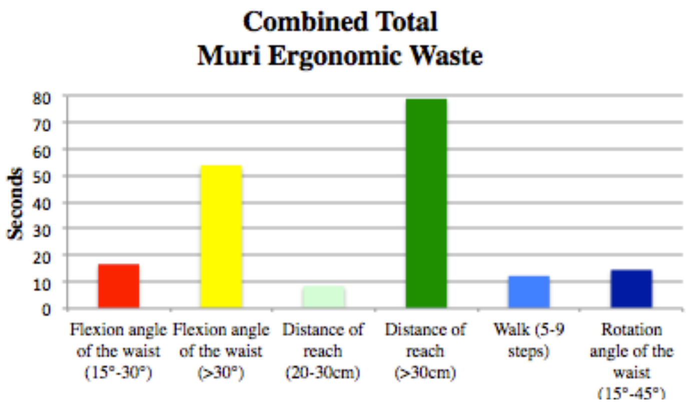


Figure 28: Total Muri Before

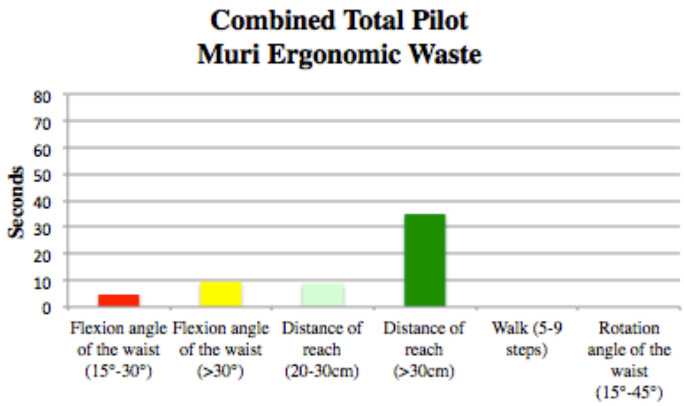


Figure 29: Total Muri After

7.2.3 Ergonomic Measurement Pilot

The ergonomic approach used for the improve phase is focused on determining the physical and biomechanical load on the operators post-solution implementation, namely by using the tilt function for the pallets. To do so, the equations for calculating the Recommended Weight Limit (RWL) and Lifting Index (LI) were used in this case when the pallet was tilted at a 45-degree angle for the different types of components. The measurements earlier for these equations were also changed according to the angle of tilt and position of the 2-collar and 3-collar pallets with respect to the operator (Table 12 and 13). For both the 2-collar and 3-collar pallets, the tilt function led to the reduction of H Transport and V Pallet in comparison to the non-tilted position of the pallet (Figure 30 and 31).

3-Collars	Max.	Mid.	Min.
H Transport	120 cm	75 cm	40 cm
H Pallet	90 cm	45 cm	10 cm
V Pallet	5 cm	16 cm	32 cm
V Destination	35 cm	35 cm	35 cm
Distance= VD-VO	30 cm	19 cm	3 cm

Table 12: 3-Collars Tilted Measurements

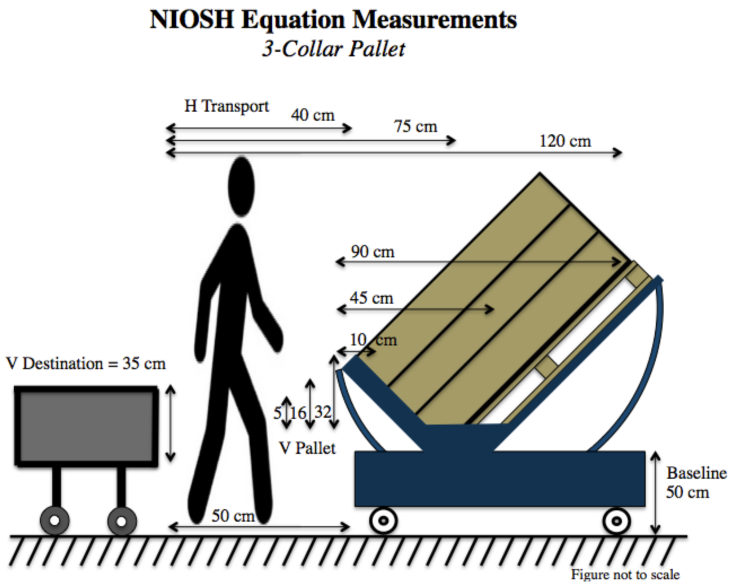


Figure 30: 3-Collars Tilted NIOSH Measurements

2-Collars	Max.	Mid.	Min.
H Transport	120 cm	75 cm	40 cm
H Pallet	90 cm	45 cm	10 cm
V Pallet	5 cm	14 cm	28 cm
V Destination	30 cm	30 cm	30 cm
Distance= VD-VO	25 cm	16 cm	2 cm

Table 13: 2-Collars Tilted Measurements

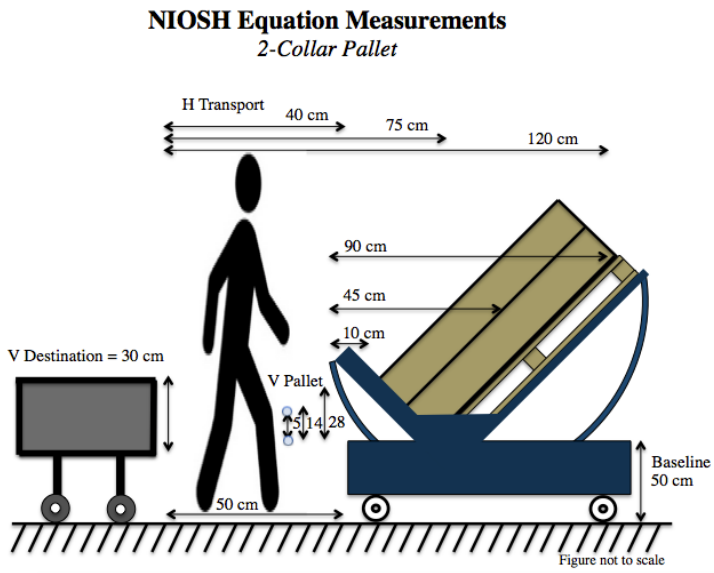


Figure 31: 2-Collars Tilted NIOSH Measurements

The measurements from the figures 30 and 31 were then used to calculate the Recommended Weight Limit for the tilted pallets and the calculated values are shown in tables 14 and 15 for the 2-collar and 3-collar pallets respectively. The results of the calculations for the each of the levels min, middle and max indicate that the Recommended Weight Limit has increased in comparison to the values found previously when the pallets were not tilted. This comparison will be elaborated upon and illustrated more specifically further in this analysis (Figure 32).

3x3 Factorial 2 collars pilot.jmp

	H Transport	V Pallet	RWL	HM: Horizontal Multiplier =25/H	VM: Vertical Multiplier =(1-0.003lV – 75l)	DM: Distance Multiplier =(0.82+4.5/D)	FM: Freq Multiplier =0.95	LC: Loading Constant =23	D Dist	V Dest	A: Angle of asymmetry	AM: Asymmetry Multiplier =(1-0.0032A)	CM
1	120	5	3,416	0,2083333333	0,79	1	0,95	23	25	30	0	1	0,95
2	120	14	3,890	0,2083333333	0,817	1,10125	0,95	23	16	30	0	1	0,95
3	75	5	5,466	0,3333333333	0,79	1	0,95	23	25	30	0	1	0,95
4	75	14	6,225	0,3333333333	0,817	1,10125	0,95	23	16	30	0	1	0,95
5	40	5	10,24	0,625	0,79	1	0,95	23	25	30	0	1	0,95
6	120	28	11,40	0,2083333333	0,859	3,07	0,95	23	2	30	0	1	0,95
7	40	14	11,67	0,625	0,817	1,10125	0,95	23	16	30	0	1	0,95
8	75	28	18,24	0,3333333333	0,859	3,07	0,95	23	2	30	0	1	0,95
9	40	28	34,21	0,625	0,859	3,07	0,95	23	2	30	0	1	0,95

Table 14: Tilted 2-Collars RWL Calculations

3x3 Factorial 3 collars pilot.jmp

	H Transport	V Pallet	RWL	HM: Horizontal Multiplier =25/H	VM: Vertical Multiplier =(1-0.003lV – 75l)	DM: Distance Multiplier =(0.82+4.5/D)	FM: Freq Multiplier =0.95	LC: Loading Constant =23	D Dist	V Dest	A: Angle of asymmetry	AM: Asymmetry Multiplier =(1-0.0032A)	CM
1	120	5	3,31	0,2083333333	0,79	0,97	0,95	23	30	35	0	1	0,95
2	120	16	3,76	0,2083333333	0,823	1,0568421053	0,95	23	19	35	0	1	0,95
3	75	5	5,30	0,3333333333	0,79	0,97	0,95	23	30	35	0	1	0,95
4	75	16	6,01	0,3333333333	0,823	1,0568421053	0,95	23	19	35	0	1	0,95
5	40	5	9,94	0,625	0,79	0,97	0,95	23	30	35	0	1	0,95
6	40	16	11,2	0,625	0,823	1,0568421053	0,95	23	19	35	0	1	0,95
7	120	32	8,73	0,2083333333	0,871	2,32	0,95	23	3	35	0	1	0,95
8	75	32	13,9	0,3333333333	0,871	2,32	0,95	23	3	35	0	1	0,95
9	40	32	26,2	0,625	0,871	2,32	0,95	23	3	35	0	1	0,95

Table 15: Tilted 3-Collars RWL Calculations

The values found earlier for the Recommended Weight Limit of both types of pallets were then used to calculate the Lifting Index for each of the different component types depending on their weight (Table 16), by using the equation mentioned earlier (LI= Component Weight/RWL). Moreover, once the Lifting Index values were determined they were used for a more thorough analysis carried out in figure 33.

Lifting Index 3-Collar Calculations Pilot .jmp

	RWL (Kg)	Filter Weight (Kg)	LI Filter	Separator Weight (Kg)	LI Separator	Duct Weight (Kg)	LI Duct
1	3,31	1,205	0,36	2,285	0,69	7,919	2,39
2	3,76	1,205	0,32	2,285	0,61	7,919	2,11
3	5,3	1,205	0,23	2,285	0,43	7,919	1,49
4	6,02	1,205	0,2	2,285	0,38	7,919	1,32
5	9,94	1,205	0,12	2,285	0,23	7,919	0,8
6	11,3	1,205	0,11	2,285	0,2	7,919	0,7
7	8,74	1,205	0,14	2,285	0,26	7,919	0,91
8	14	1,205	0,09	2,285	0,16	7,919	0,57
9	26,2	1,205	0,05	2,285	0,09	7,919	0,3

Lifting Index 2-Collar Calculations Pilot.

	RWL (Kg)	Bracket Weight (Kg)	LI Bracket
1	3,42	5,2	1,52
2	3,89	5,2	1,34
3	5,47	5,2	0,95
4	6,23	5,2	0,84
5	10,2	5,2	0,51
6	11,4	5,2	0,46
7	11,7	5,2	0,45
8	18,2	5,2	0,28
9	34,2	5,2	0,15

Table 16: Tilted LI Calculations

The Recommended Weight Limit and Lifting Index were used to compare the values found from the current state with those determined through the pilot project. Moreover, the values placed between parentheses are those from the current state as shown in figures 32 and 33. The illustration shows how each part of the pallets was affected by the tilting function.

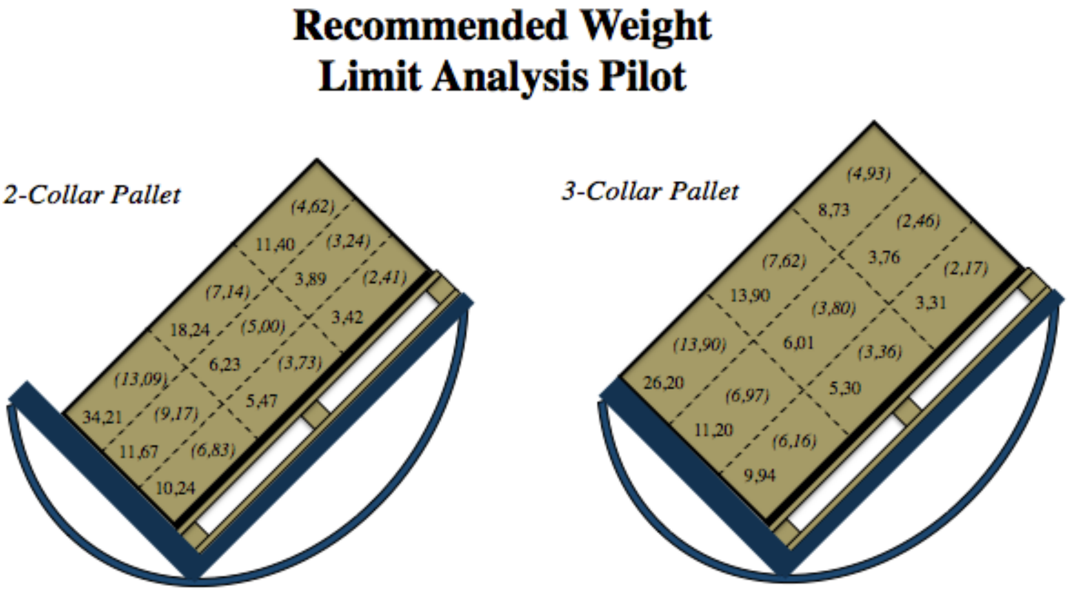


Figure 32: Total Recommended Weight Limit Before Vs. After

The Recommended Weight Limit values for both types of pallets have been greatly reduced by using the tilt function, which indicates that the physical and biomechanical load on the operators has also been reduced (Figure 32). More specifically, this has been attributed due to the reduction of the H Transport and V Pallet used in the Recommended Weight Limit equation when the tilt function has been implemented. There is an incremental increase of the Recommended Weight Limit in the different parts of the both pallet types but the most extreme improvement measures were found in the parts closest to the operator. Namely an increase of Recommended Weight Limit from the 2-collar pallet of 13,09 to 34,21 kg; as well as 13,90 to 26,20 kg for the 3-collar pallet. This shows that the ergonomic load on the operators has been reduced for both pallet types through the use of the tilt cart.

These values were then used to calculate the Lifting Index for the different types of component used in the study, thus depending on their weights. Thus the illustration in figure 33 shows the Lifting Index for the components depending on their position in the different areas of the pallet. These values of the Lifting Index will be used to calculate the total improvement of ergonomic efficiency in comparison to when the tilt function was not used.

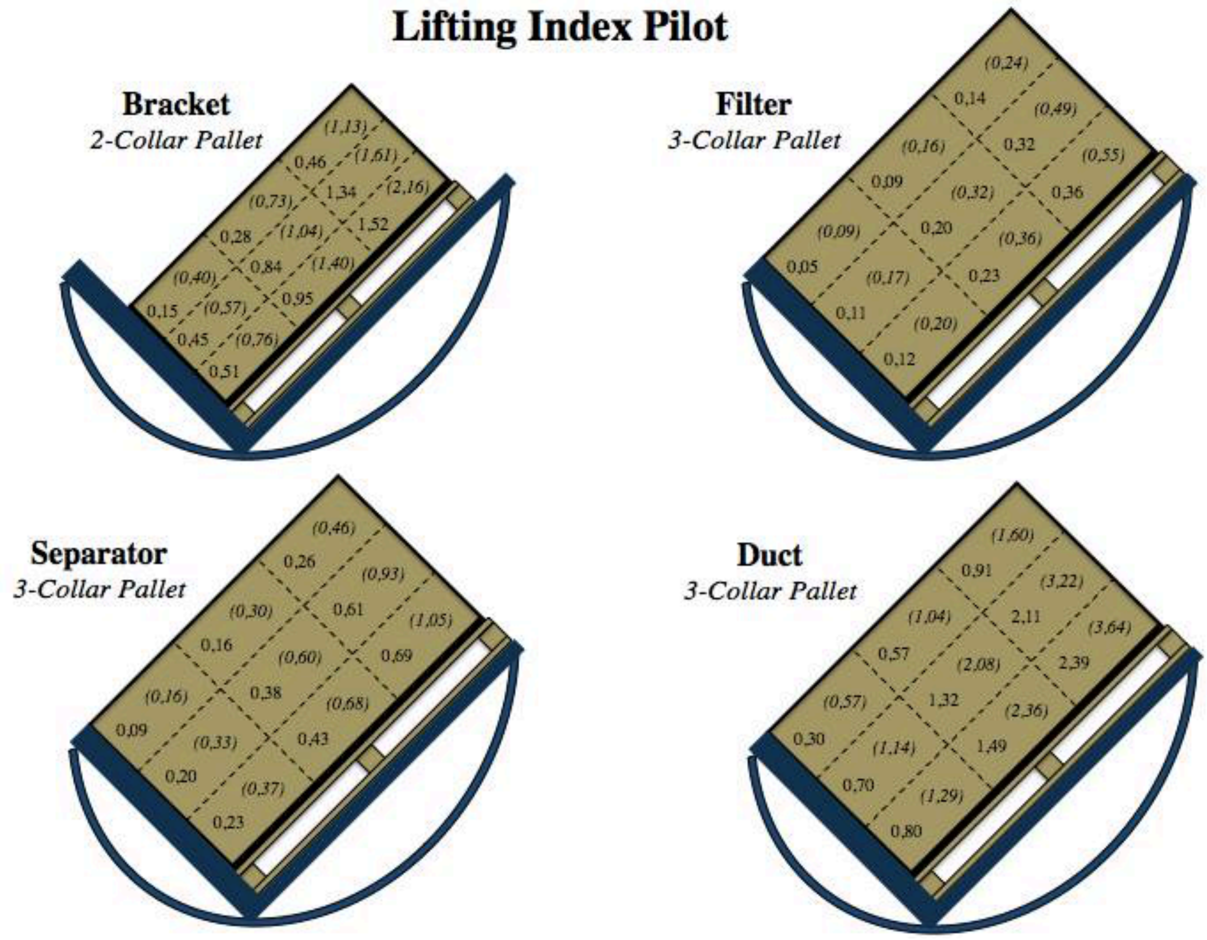


Figure 33: Total Lifting Index Before Vs. After

Appendix 25 shows the calculations used to compare the Lifting Index of the Current Vs. Pilot project for ergonomic efficiency. The values illustrated in the figure 33 show the total improvement in the Lifting Index for each of the different components. The Lifting Index ratio from the current state was calculated at a total of 34,2; whereas that from the pilot project was 21,76. Thus, leading to a reduction of 36,4 percent in total. This indicates that the load on the operators in the material handling areas used for the pilot project was reduced a third of its total magnitude when the pallets were not tilted. This reduction will lead to better ergonomic working conditions for those involved in material handling parts of the production line.

7.2.4 Pilot Project Deductions

Based on the findings from the pilot project carried out by using the tilt able cart for the components used in the study, the authors have inferred results from each of the three approaches used for problem analysis. From the Mura time studies, the results indicate a reduction in the variation for gathering the components as well as a lower overall mean time for the different component types. The calculations for the exact distinction from the current state to that found through the solution was a mean time improvement of approximately 1,92 seconds per component (Appendix 24). On the other hand, from the Muri waste standpoint, the pilot project was capable of significantly reducing the ergonomic movement waste by more than a factor of 3 from 185 to 58 seconds. Finally, the perspective taken for the study purely from an ergonomic perspective in terms of the physical and biomechanical load affecting the workers by using Recommended Weight Limit and Lifting Index equations led to a total improvement of the lifting index by 36,4 percent post-solution implementation. This value represents the magnitude of reduced effort from part of the operators when going through their daily activities in the production line. Moreover, it is crucial to shed light upon the fact that this pilot project has only measured the potential for improvement in four different component types, however this capability for improved performance is a fragment of that which can be achieved through a full-scale improvement initiative. These results indicate that an improvement in productivity to reduce the variation in the material handling operations can be achieved while simultaneously improving the ergonomic conditions in the HDE13 production line. Thus, a trade-off is not required to sacrifice productivity to achieve better ergonomic standards, which has been proven by the consistent results found in all the three perspectives used in this project; that were Mura, Muri and Ergonomic Efficiency. These deductions will be utilized as the foundation of financial analysis for the pilot project.

7.3 Pilot Project Financial Analysis

Based on the perspectives previously carried out to compare the performance standard before vs. after solution implementation by means of a small-scale pilot project, financial analysis will be carried out with the previous deductions as its foundation. Thus, the aspects considered previously in terms of Mura, Muri and Ergonomic Efficiency will be used to break down the benefits of future adoption of the proposed solution of using a cart equipped with a tilt able function for the material handling operations at Volvo Powertrain. Initially the implementations can be carried out primarily in the HDE13 main production line, then upon the success of the endeavor and realized improvements the solution could also be integrated horizontally in other areas at the Volvo Powertrain production site with a similar problem or lack of efficiency. For the financial analysis utilized in this study, there are two main concepts that will be assessed for future profitability that are the increase in productivity and the rate of injury that can be linked to inefficiency in material handling from an ergonomic aspect.

7.3.1 Productivity and Process Improvement

In the current state, the time saving of 1,92 seconds per component picked will be used to extenuate the analysis carried out into financial terms and monetary values. In the HDE13 line 19 engines are currently produced per hour, which requires 19 components of each type to be gathered per hour in material handling. There are also approximately 6 component types per kit that can be tilted, with a total of approximately 10 kits in the HDE13 production line. In addition, there are a total of 1840 working hours per year, each with a cost for Volvo Powertrain of X Sek/Manhour including overtime. There are both day and evening work shifts as well. Thus the following calculations were done for the financial analysis for productivity improvement figure 34.

Financial Analysis

19 - Cycles per hour
6 - Wagons per kit
10 - Kits in total
1,92 - Seconds saved per component
1840 - Hours per year/shift
2 - Shifts
Cost per Manhour - Blue Collar worker including overtime

$$\left(\frac{19 \times 6 \times 10 \times 1{,}92 \times 1840 \times 2}{60 \times 60}\right) \times (\text{Y SEK/Hour})$$

Seconds — Minutes

$$= 2237 \times (\text{Cost Per Manhour})$$

Figure 34: Financial Analysis Equation

1840 x 2188.8 x 2 = 8,054,784 seconds saved in total per year from both shifts.

19 x 6 components/kit x 10 kits x 1.92 = 2188.8 secs saved per hour.

8,054,784/ (60 min per hour x 60 secs per minute) = 2237.44 hours saved per year.

2237.44 x Cost per Manhour saved per year.

7.3.2 Injury Rate Reduction

The second type of financial gain can be achieved from the monetary savings of reduced injuries and sick leave events from material handling ergonomic inefficiencies. As has been shown earlier in the improve phase, the tilt able function has reduced the total Lifting Index by a third of its initial value, thus indicating that the ergonomics of the main line have reached a more efficient standard as well as a less strenuous physical impact on the blue collar workers. Thus this type of financial gain will be more in the form of "indirect" money than that achieved from process and productivity improvement; nonetheless its economic value can be significant over the span of a year.

To attain more solid estimations on the potential fiscal value of injury reduction it will be necessary to evaluate the current losses per injury or sick leave linked by some means to material handling. Thus, the data currently available on the associated cost of such an incident from the Volvo financial records can be used in addition to a procedure for monitoring injury and sick leave events, which will be further discussed in the control phase.

In addition to direct injury costs from material handling another aspect of this financial analysis is by assessing the amount of external consultancy workforce being required due to the injuries or days of sick leave taken post-improvement and comparing this respective cost with that of material handling prior solution implementation.

7.3.3 Overall Cost-Benefit Analysis

The two aspects of financial returns described earlier in terms of both "direct" and "indirect" fiscal benefits, namely productivity improvement and reduced injury rate, should be held versus the cost of purchasing and implementing the tilt able cart function within material handling. Based on the current supplier negotiations for the design of tilt able carts, the price per unit is approximately 8,000 SEK. However, when buying in bulk the unit cost can decrease to 5,000 SEK. Considering the financial analysis conducted earlier, there are currently 10 kits for potential for improvement, each consisting of 6 large component pallets that can adopt the tilt able function. Considering the purchasing price per unit for bulk purchase at 5,000 SEK per unit, the total cost for the investment becomes:

10 kits x 6 pallets x 5,000 SEK per unit = 300,000 SEK cost of investment

However, this sunken cost is in the case of implementing the change for all the material handling kits used for production of heavy-duty engines. The financial gains considering only the productivity improvement indicate a Return On Investment (ROI) period of only 4.6 months, and beyond this span of time the productivity gains become purely profit by reducing working hours. Moreover, this ROI does not take into consideration the "indirect" aspect of financial returns due to reduced injury, which could even lead to a shorter ROI span and more potential for fiscal savings.

ROI period= 300,000 / 783,104 x 12= 4.6 Months

In the case of this project, the time span for financial analysis was taken as only one year. However, if the financial span for the investment is extended to more mid-to-long term periods then the sunken cost of initial investment becomes almost negligible in comparison to the financial gains that will be attained. For example, for a five-year cost-benefit analysis the savings reaches around 3,615,520 SEK. It is also important to realize that this financial analysis has only been based on the "direct" monetary gains from productivity improvements, not taking the "indirect" benefits into consideration, which are linked to lower injury rates and sick leave.

Over 5 years

5 x 2237.44 x Cost Per Manhour saved per year

(11,187.2 x Cost per Manhour saved per year) - 300,000 SEK sunken costs

7.4 Potential Scenarios for Financial Consideration

Due to the financial calculations provided earlier, two potential scenarios for future financial benefits emerge from the improved state of material handling operations. The first possibility is to achieve a higher capacity level within the production of HDE13 engines because of the higher productivity level found by reducing the time required for gathering the different component types. In this case the fiscal calculations will be based on the possibility to reduce the production cycle to below its current level of approximately 3 minutes and thus have the capability to produce more than 19 HDE13 engines per hour. The second emerging opportunity would be due to the lower costs from reduced man-hours by saving the 1.92 seconds found earlier per component gathered.

7.4.1 Increased Production Capacity

By reducing the time for gathering each component due to the tilt function used in the pilot project, the overall performance level has increased within the material handling at the kitting zones. The time necessary per cycle thus has the potential to be reduced from its current 3 minute mark to a lower value indicating a more rapid overall cycle time. If the production process can be balanced to keep up with the shorter material handling cycle without having significant bottlenecks to reduce its capability for improvement, then the production of more engines per hour will be feasible. The factors mentioned for potential increased capacity will thus be the basis for financial calculations of this future scenario over the span of one year.

Current cycle time: 60 mins/ 19 cycles = 3,16 minutes.
3,16 - (6 pallets/kit x 1,92 sec saved per component) = 3,0448 minutes per new cycle.
60/3,0448 = 19,70 engines produced per hour.
Thus, approximately one extra engine can be produced every 2 hours from the increased capacity.
Total hours worked per year= 1840 hours
2 shifts in total =3680 total hours per year.
More engines produced per year = 3680/2=1840 HDE13 engines
Potential for increased sales = 1840 HDE13 engines per year

7.4.2 Reduction of Man-hours

The lower cycle time reached from the saving of 1,92 seconds per component gathered could also lead to another scenario with fiscal benefits by reducing the man-hours needed within the kitting zones while still being able to maintain the same production cycle time. Thus the financial analysis in this case will be focused on determining how many workers can be reduced from the kitting zones. In the current state there are 20 workers in the kitting zones, each working 7,5 hours per day and there are both day and evening shifts. The calculations done earlier found that 2,237.44 hours can be saved in total per year. Each worker has 1840 man-hours per year each shift. Therefore, these values will be used to determine the potential reduction of blue-collar workers from the kitting zones.

(19 cycles x 6 picks x 10 kits x 1,92 secs saved per pick x 1840 hours/year x 2 shifts)/ (60 minutes/hour x 60 seconds/minute)= 2237.44 hours saved per year.

2237.44 / 1840 man-hours per worker for both shifts per year= 1.216 reduced workers in the kitting zones.

8. Control

The Control phase is the last part of the DMAIC cycle. In this phase after the improvements have been implemented it is important that the process is continuously monitored to ensure that the improvements in material handling are persistent in the future beyond the span of the project (George et al, 2005). Thus, the authors will bring forth the aspects that should be monitored by the stakeholders so that the improvement benefits can be maintained once the project results are handed-over. There will be two main focuses for the control phase that are a means for monitoring the new process performance standards in terms of productivity and ergonomics; as well as a means to document the injury rate over the coming years so that the "indirect" financial analysis from this perspective of the improvement can be determined.

8.1 Monitoring the Improvement

For the improvement to be sustained beyond the duration of the project there are some key points that should be taken into consideration. The first means for monitoring the improvement would be by recording the time reduction for gathering the components by using the light indicators in the main line as a basis for measurement. In the current material handling process the operators press a lit button for each of the different components picked which is used so that the right components are gathered for the requirements of heavy-duty engines. For monitoring the process performance the instances of pressing the button can be used to determine the reduction in time and variation for the components. Moreover, observations can be carried out in some instances to follow up on the improvements in material handling and maintain that the performance level remains at the improved standard.

The second key issue to take into consideration is that the tilt able cart for the pallets currently used for the project is a prototype and there is potential for a better-suited design according to the requirements of the material handling in this case. The tilt able cart used for this study tilts along its length but the future layout of the production would require the pallets to be tilted along their width. Therefore, the design specifications handed to the supplier should be conducted to create carts that can meet this requirement. In addition, this tilt function along the width of the pallet will lead to even more improved performance standards in terms of Mura, Muri and Ergonomics because the distance needed to reach the components will be reduced significantly by placing the pallets with their width towards the operator in the main line.

A third means of assessment and monitoring of the improvement in the future is by management organizing short meetings with the blue-collar workers to gain feedback on their point of view and their experience of working with the tilt able cart function in comparison to the current material handling process. This could also be done by means of surveys or questionnaires directed at those working in the production line.

8.2 Injury Rate Assessment

Upon project handover, the "indirect" monetary gains due to injury reduction can be achieved by keeping future records of injury instances or sick leave linked to material handling; as a basis for comparison to the injury rates prior to the improvement. By doing so, the cost due to each injury can be used to calculate the monetary gains achieved due to injury reduction. It would also be beneficial to keep track of the frequency when external recruitment agencies for temporary workforce are needed to replace an injured blue-collar employee within material handling. Even though this data will not be as solid as the financial analysis due to productivity improvement discussed earlier, keeping track of the mentioned criteria will be a useful way to estimate the fiscal gains linked to injury rate reduction in the future.

8.3 Project Handover

The next stage beyond the pilot project would be to create an implementation plan for the tilt function solution identified. By taking the results found earlier during the project into consideration an action plan for implementing the solution should be carried out so that the findings for improvement are adopted. Considerations from the cost-benefit financial analysis can be used to determine the suitable pace of the action plan as well as the hindrances associated with taking a high paced implementation approach versus that of a gradual one.

9. Discussions

The following chapter will provide a discussion of the results obtained during the project as well as suggest future potential use for the findings within academia and in an industrial context.

9.1 Discussions and Future Recommendations

The project has been carried out in the form of a DMAIC cycle typically used for continuous improvement efforts within Six Sigma. However, in this case the goal of the project was to use the DMAIC cycle as a foundation for project structure and problem analysis towards creating an improved performance level. The perspective taken towards the material handling operations was threefold, namely in terms of time variation (Mura), ergonomic efficiency (Muri) and biomechanical lifting effects (Recommended Weight Limit and Lifting Index). The tools used in the define phase were effective when converging to a more specific problem focus. Moreover, the quality improvement tools used in the measure and analyze phase proved to be valuable for breaking down the problem at hand into several perspectives during the study.

The performance standards identified by the baseline state by using these tools were a key contributor towards finding a suitable solution to the problem at hand as well as to compare the improved state performance post-tilt function implementation from the pilot project. In some continuous improvement projects there is an inevitable balance that must be achieved in terms of trade-offs to be determined requiring sacrifices to be made on some process factors in order to achieve the final objective. However, in this case of material handling improvement a tradeoff was not necessary to achieve improved ergonomic efficiency and productivity while simultaneously being capable of achieving financial benefits for the organization. As has been shown from the comparison of the baseline state and the pilot project improvement carried out earlier, the more efficient ergonomics have reduced the physical stress on the blue collar workers and have provided the capability to carry out their work in a shorter time. In addition, the variation has decreased in the process leading to a higher performance level as shown in the pilot project results.

From an academic standpoint, the project goals described in the research questions have been met by carrying out the improvement project in the form of a continuous improvement DMAIC cycle. More specifically, the literature used to assess the problem was taken from both ergonomic and variation perspectives within material handling as well as the biomechanical equations for the physical ergonomic impact used to calculate the Recommended Weight Limit and Lifting Index. The findings from literature chosen for use in the thesis were aligned with the conditions of the production environment at Volvo Powertrain and most suitable for the focus areas of the project namely Lean, Six Sigma and ergonomics within material handling.

Reflecting upon the approach used during the project, the tilt function used in this case was a prototype that was tilted on the short side (Appendix 25) but the future of the production layout will most likely have pallets that are tilted on their broad side, therefore, the results of this study could have even led to a greater degree if improvement by reducing variation, improving ergonomics and process efficiency levels. The other production lines besides the HDE13 engines were not included in the focus of the improvement project; but it could potentially have also had a similar need for process improvement in their material handling operations. The findings of the pilot project carried out could also have been horizontally applied to other production lines within the Volvo Powertrain site, but the span of time given for carrying out a more thorough problem analysis including the other production lines was insufficient for this thesis work. The authors also identified the potential application of the solution for smaller pallets to achieve similar improvements but this investigation was unfortunately solely constrained towards material handling of components on larger pallet types. Thus, the authors recommend a future investigation of the smaller pallets within the kitting zones as an area for future potential improvement.

10. Conclusion

The conclusions from the project work will be explained in this chapter as well as how these findings can lead to future potential for development within industry. The lessons learned from carrying out the Masters thesis work will also be described.

10.1 Project Conclusions

The solution provided after problem analysis, which was partially implemented in the pilot project can be adapted to several areas within the production environment if a similar inefficiency exists in the future. Based on the results obtained the authors have found that this solution of a tilt function can be used in the material handling of diverse types of production environments beyond automotive if a similar problem exists. Moreover, the ergonomic improvement as well as that of productivity could also lead to financial benefits for organizations in different types of industries. Of course the solution is not a one size fits all type and should be customized depending on the type of components and raw materials within diverse production environments; however, the foundation of the improvement achieved through the solution will be fundamentally similar irrespective of the production environment or industry. The results of such an improvement could also most likely lead to scenarios similar to those described earlier with a tradeoff for future operations strategy to be made as to whether to increase the production capacity level or to reduce the cost associated with man-hours. The results of the pilot project using the tilt function did not compromise the quality of the components assessed during the study. However, it is important to take into consideration the type of components that are tilted in the production line because the material of some could be more sensitive than others.

The thesis work has proven that a few seconds of time losses can add up and lead to significant losses for an organization. In this case by adopting Mura, Muri and Ergonomic Efficiency the author have shed light on how a reduction in the impact of such seemingly insignificant losses and waste forms can improve the overall process performance drastically in the long run. Moreover, by adopting these three perspectives as a comparison of the current state performance versus that achieved through the pilot project; the authors have attained a concurrent improvement standard in each of them simultaneously.

10.2 Lessons Learned

While carrying out the DMAIC cycle several lessons were learned along this improvement project, which will be explained as a conclusion to this thesis work.

- *Base Decisions on Facts*

A reliable and accurate measurement method is crucial to ensure that the improvement effort is capable of having a solid foundation to compare the current state with that achieved post-solution adoption, in this case through the pilot project. Moreover, the tools used to measure this baseline state of performance must be capable of clearly mapping out the investigated process as well as its respective key process indicators (KPIs).

- *Tackle the Problem from Multiple Perspectives*

In order to determine the optimal solution towards a desired future improvement, a multi-perspective approach towards problem assessment is key. By taking such an approach the solution found will not be one-sided but rather could simultaneously improve several factors; which were in this case the Mura, Muri and Lifting Index standpoints used for studying process variation, productivity and ergonomic efficiency.

- *Understand People and Benefit from their Feedback*

The authors have learned that taking into consideration the point of views of project stakeholders as well as those directly effected by the outcome is important throughout the DMAIC cycle. Moreover, this is an essential means to determine whether or not the project focus is on the right track.

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11.2 Oral Sources

Jonas Håkansson, Internal Logistic Process and Technology Manager at Volvo Powertrain Skövde.

Hanna Karlsson, Pre-Production Engineer at Volvo Powertrain Skövde.

Kristian Larsson, Plant Logistic Engineer at Volvo Cars Gothenburg.

Henrik Eklund, Production Engineer at Volvo Powertrain Skövde

Magnus Jacobsson, Development Technician at Volvo Powertrain Skövde.

Kjell Edqvist, Financial Controller at Volvo Powertrain Skövde.

Niclas Carlsson, Production Engineer at Volvo Cars Skövde

Tim Andersson, Team Leader Zone 1 HDE13 at Volvo Powertrain Skövde.

Fredrik Karlsson, Team Leader Zone 3 HDE13 at Volvo Powertrain Skövde.

APPENDICES:

Appendix 1: Bracket Mura Measurement

Component	Layer	Area	Observer 1	Observer 2	Final Time
Bracket	1	A	2,5	2,36	2,43
Bracket	1	A	1,79	1,65	1,72
Bracket	1	A	2,05	1,95	2
Bracket	1	A	2,17	2,07	2,12
Bracket	1	A	2,24	2,14	2,19
Bracket	1	A	2,08	1,98	2,03
Bracket	1	A	1,95	1,85	1,9
Bracket	1	A	2,06	1,96	2,01
Bracket	2	A	2,01	2,17	2,09
Bracket	2	A	1,92	2,08	2
Bracket	2	A	2,02	2,18	2,1
Bracket	2	A	2,05	2,21	2,13
Bracket	2	A	2,11	2,05	2,08
Bracket	2	A	2,19	2,13	2,16
Bracket	2	A	2,34	2,28	2,31
Bracket	2	A	1,97	1,91	1,94
Bracket	3	A	3,68	3,44	3,56
Bracket	3	A	3,17	2,93	3,05
Bracket	3	A	3,17	2,93	3,05
Bracket	3	A	2,06	1,82	1,94
Bracket	3	A	2,06	1,82	1,94
Bracket	3	A	2,18	1,94	2,06
Bracket	3	A	2,29	1,95	2,12
Bracket	3	A	2,38	2,04	2,21
Bracket	4	A	2,66	2,32	2,49
Bracket	4	A	2,45	2,23	2,34
Bracket	4	A	2,53	2,31	2,42
Bracket	4	A	2,33	2,11	2,22
Bracket	4	A	2,42	2,2	2,31
Bracket	4	A	2,62	2,4	2,51
Bracket	4	A	2,7	2,48	2,59
Bracket	4	A	3,08	2,86	2,97

Component	Layer	Area	Observer 1	Observer 2	Final Time
Bracket	1	B	2,94	2,82	2,88
Bracket	1	B	3,08	3	3,04
Bracket	1	B	2,73	2,83	2,78
Bracket	1	B	3,01	2,87	2,94
Bracket	1	B	3,36	3,22	3,29
Bracket	1	B	3,26	3,12	3,19
Bracket	1	B	3,46	3,32	3,39
Bracket	1	B	3,47	3,65	3,56
Bracket	2	B	3,11	3,01	3,06
Bracket	2	B	2,39	2,55	2,47
Bracket	2	B	2,21	2,37	2,29
Bracket	2	B	3,36	3,52	3,44
Bracket	2	B	3,04	3,2	3,12
Bracket	2	B	3,15	3,31	3,23
Bracket	2	B	3,01	3,17	3,09
Bracket	2	B	3,93	4,09	4,01
Bracket	3	B	2,54	2,48	2,51
Bracket	3	B	2,74	2,68	2,71
Bracket	3	B	2,75	2,69	2,72
Bracket	3	B	2,69	2,63	2,66
Bracket	3	B	3,62	3,56	3,59
Bracket	3	B	4,12	3,88	4
Bracket	3	B	3,68	3,44	3,56
Bracket	3	B	4,62	4,38	4,5
Bracket	4	B	3,19	2,85	3,02
Bracket	4	B	3,93	3,59	3,76
Bracket	4	B	3,68	3,34	3,51
Bracket	4	B	3,85	3,51	3,68
Bracket	4	B	3,99	3,65	3,82
Bracket	4	B	4,08	3,74	3,91
Bracket	4	B	4,06	3,72	3,89
Bracket	4	B	3,86	3,52	3,69

Appendix 2: Filter Mura Measurement

Component	Layer	Area	Observer 1	Observer 2	Final Time
Filter	1	A	1,76	1,62	1,69
Filter	1	A	1,7	1,56	1,63
Filter	1	A	2,23	2,09	2,16
Filter	1	A	1,7	1,8	1,75
Filter	1	A	1,63	1,73	1,68
Filter	1	A	1,67	1,77	1,72
Filter	1	A	1,47	1,57	1,52
Filter	1	A	1,58	1,68	1,63
Filter	1	A	1,34	1,44	1,39
Filter	1	A	1,55	1,65	1,6
Filter	1	A	1,67	1,77	1,72
Filter	1	A	1,47	1,57	1,52
Filter	1	A	1,49	1,67	1,58
Filter	1	A	1,59	1,77	1,68
Filter	1	A	1,64	1,82	1,73
Filter	1	A	1,73	1,91	1,82
Filter	1	A	1,75	1,93	1,84
Filter	1	A	1,42	1,6	1,51
Filter	1	A	1,45	1,63	1,54
Filter	1	A	1,47	1,65	1,56
Filter	2	A	2,86	2,74	2,8
Filter	2	A	2,62	2,5	2,56
Filter	2	A	2,77	2,65	2,71
Filter	2	A	2,16	2,04	2,1
Filter	2	A	2,12	2	2,06
Filter	2	A	2,09	1,97	2,03
Filter	2	A	2,16	2,04	2,1
Filter	2	A	2,38	2,26	2,32
Filter	2	A	2,25	2,13	2,19
Filter	2	A	2,31	2,19	2,25
Filter	2	A	2,28	2,16	2,22
Filter	2	A	2,37	2,25	2,31
Filter	2	A	2,27	2,15	2,21
Filter	2	A	2,56	2,44	2,5
Filter	2	A	2,69	2,55	2,62
Filter	2	A	2,73	2,59	2,66
Filter	2	A	2,62	2,48	2,55
Filter	2	A	2,72	2,58	2,65
Filter	2	A	2,69	2,55	2,62
Filter	2	A	2,73	2,59	2,66

Component	Layer	Area	Observer 1	Observer 2	Final Time
Filter	1	B	2,24	2,46	2,35
Filter	1	B	1,73	1,95	1,84
Filter	1	B	2,23	2,45	2,34
Filter	1	B	2,43	2,65	2,54
Filter	1	B	2,65	2,49	2,57
Filter	1	B	2,71	2,55	2,63
Filter	1	B	3,09	2,93	3,01
Filter	1	B	3,2	3,04	3,12
Filter	1	B	4,14	3,98	4,06
Filter	1	B	5,38	5,22	5,3
Filter	1	B	5,5	5,34	5,42
Filter	1	B	4,8	4,64	4,72
Filter	1	B	4,72	4,52	4,62
Filter	1	B	4,76	4,56	4,66
Filter	1	B	5	4,8	4,9
Filter	1	B	5,19	4,99	5,09
Filter	1	B	5,89	5,69	5,79
Filter	1	B	5,51	5,31	5,41
Filter	1	B	5,39	5,19	5,29
Filter	1	B	5,72	5,52	5,62
Filter	2	B	2,69	2,87	2,78
Filter	2	B	2,98	3,16	3,07
Filter	2	B	2,78	2,96	2,87
Filter	2	B	3,07	3,25	3,16
Filter	2	B	3,75	3,93	3,84
Filter	2	B	3,13	3,31	3,22
Filter	2	B	4,07	4,25	4,16
Filter	2	B	3,83	3,97	3,9
Filter	2	B	5,65	5,79	5,72
Filter	2	B	4,55	4,69	4,62
Filter	2	B	4,19	4,33	4,26
Filter	2	B	4,57	4,71	4,64
Filter	2	B	5,05	5,19	5,12
Filter	2	B	5,32	5,46	5,39
Filter	2	B	5,49	5,63	5,56
Filter	2	B	5,78	6	5,89
Filter	2	B	5,56	5,78	5,67
Filter	2	B	5,91	6,13	6,02
Filter	2	B	5,87	6,09	5,98
Filter	2	B	6,11	6,33	6,22

Appendix 3: Separator Mura Measurement

Component	Layer	Area	Observer 1	Observer 2	Final Time
Separator	1	A	2,88	2,7	2,79
Separator	1	A	2,9	2,72	2,81
Separator	1	A	3,02	2,84	2,93
Separator	1	A	3,06	2,88	2,97
Separator	2	A	3,21	3,05	3,13
Separator	2	A	3,29	3,13	3,21
Separator	2	A	3,31	3,15	3,23
Separator	2	A	3,39	3,23	3,31
Separator	3	A	3,23	3,39	3,31
Separator	3	A	3,3	3,46	3,38
Separator	3	A	3,54	3,7	3,62
Separator	3	A	3,7	3,86	3,78
Separator	1	B	3,48	3,3	3,39
Separator	1	B	3,53	3,35	3,44
Separator	1	B	3,84	3,66	3,75
Separator	1	B	4,37	4,19	4,28
Separator	2	B	3,7	3,54	3,62
Separator	2	B	3,83	3,67	3,75
Separator	2	B	4	3,84	3,92
Separator	2	B	4,21	4,05	4,13
Separator	3	B	3,82	3,98	3,9
Separator	3	B	3,95	4,11	4,03
Separator	3	B	4,24	4,4	4,32
Separator	3	B	4,57	4,73	4,65

Component	Layer	Area	Observer 1	Observer 2	Final Time
Separator	1	C	2,57	2,81	2,69
Separator	1	C	2,7	2,94	2,82
Separator	1	C	2,96	3,2	3,08
Separator	1	C	3,26	3,5	3,38
Separator	2	C	3,27	3,49	3,38
Separator	2	C	3,4	3,62	3,51
Separator	2	C	3,51	3,73	3,62
Separator	2	C	3,58	3,8	3,69
Separator	3	C	3,38	3,62	3,5
Separator	3	C	3,82	4,06	3,94
Separator	3	C	3,85	4,09	3,97
Separator	3	C	3,88	4,12	4
Separator	1	D	3,65	3,89	3,77
Separator	1	D	3,78	4,02	3,9
Separator	1	D	4,1	4,34	4,22
Separator	1	D	4,29	4,53	4,41
Separator	2	D	3,7	3,92	3,81
Separator	2	D	3,9	4,12	4,01
Separator	2	D	4,64	4,86	4,75
Separator	2	D	5	5,22	5,11
Separator	3	D	4,29	4,53	4,41
Separator	3	D	4,69	4,93	4,81
Separator	3	D	4,7	4,94	4,82
Separator	3	D	4,75	4,99	4,87

Appendix 4: Duct Mura Measurement

Component	Layer	Observer 1	Observer 2	Final Time
Duct	1	2,11	2,35	2,23
Duct	1	2,44	2,68	2,56
Duct	1	2,29	2,53	2,41
Duct	2	3,22	3,46	3,34
Duct	2	3,47	3,69	3,58
Duct	2	3,75	3,97	3,86
Duct	3	3,92	4,14	4,03
Duct	3	4,1	4,32	4,21
Duct	3	4,2	4,44	4,32
Duct	4	5,23	5,47	5,35
Duct	4	5,72	5,96	5,84
Duct	4	5,53	5,77	5,65
Duct	5	5,96	6,2	6,08
Duct	5	5,64	5,88	5,76
Duct	5	5,47	5,71	5,59
Duct	6	6,92	7,16	7,04
Duct	6	6,98	7,2	7,09
Duct	6	6,48	6,7	6,59
Duct	7	7,12	7,34	7,23
Duct	7	6,21	6,43	6,32
Duct	7	6,41	6,65	6,53
Duct	8	6,64	6,88	6,76
Duct	8	6,91	7,15	7,03
Duct	8	7,09	7,33	7,21

Appendix 5: Brackets Muri Waste Measurement Part 1

VOLVO | **Muri Ergonomic Waste Measurement** | VPS

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Edit Mode

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Volume 1 per shift

	Movements on the job	Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
	Manual labour process	15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
1	1st layer area A	1						1															
2	1st layer area A	1						1															
3	1st layer area A	1						1															
4	1st layer area A	1						1															
5	1st layer area A	1						1															
6	1st layer area A	1						1															
7	1st layer area A	1						1					1										
8	1st layer area A	1						1					1										
9	1st layer area B	1						1					1										
10	1st layer area B		1						1														
11	1st layer area B	1						1					1										
12	1st layer area B		1						1														
13	1st layer area B		1						1														
14	1st layer area B		1						1														
15	1st layer area B		1						1														
16	1st layer area B		1						1														
17	2nd layer area A	1						1															
18	2nd layer area A	1						1															
19	2nd layer area A	1						1															
20	2nd layer area A	1						1															
21	2nd layer area A	1						1															
22	2nd layer area A	1						1															
23	2nd layer area A	1						1															
24	2nd layer area A	1							1														
25	2nd layer area B		1						1														
26	2nd layer area B		1						1														
27	2nd layer area B		1						1														
28	2nd layer area B	1							1				1		1								
29	2nd layer area B	1							1				1		1								
30	2nd layer area B	1							1				1		1								
31	2nd layer area B	1							1				1		1								
32	2nd layer area B		1						1														
33	3rd layer area A		1					1															
34	3rd layer area A		1					1															
35	3rd layer area A		1					1															
36	3rd layer area A		1					1															
37	3rd layer area A		1					1															
38	3rd layer area A		1						1														
39	3rd layer area A		1						1														
40	3rd layer area A	1							1				1		1								
41	3rd layer area B		1						1														
42	3rd layer area B		1						1														
43	3rd layer area B		1						1														
44	3rd layer area B		1						1														
45	3rd layer area B		1						1				1		1								
46	3rd layer area B		1						1														
47	3rd layer area B		1						1														
48	3rd layer area B		1						1														
49	4th layer area A		1						1														
50	4th layer area A		1						1														
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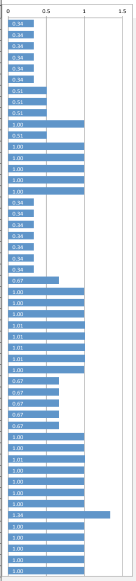

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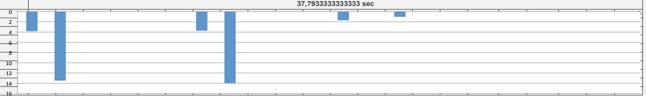

Appendix 6: Brackets Muri Waste Measurement Part 2

VOLVO **Muri Ergonomic Waste Measurement** VPS 16

Edit Mode

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Document ID: Bracket	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:

Volume 1 per shift

Movements on the job / Manual labour process		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
1	4th layer area A		1						1														
2	4th layer area A		1						1														
3	4th layer area A		1						1														
4	4th layer area A		1						1														
5	4th layer area A		1						1														
6	4th layer area A		1						1														
7	4th layer area B		1						1														
8	4th layer area B		1						1														
9	4th layer area B		1						1														
10	4th layer area B		1						1														
11	4th layer area B		1						1														
12	4th layer area B		1						1				1		1								
13	4th layer area B		1						1				1		1								
14	4th layer area B		1						1				1		1								
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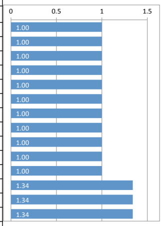

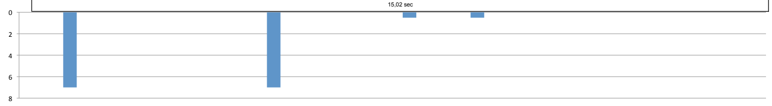

Appendix 7: Filter Muri Waste Measurement Part 1

VOLVO **Muri Ergonomic Waste Measurement** VPS

16

Edit Mode

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Document ID: Oil Filter	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:
	Volume 1 per shift						

N°	Movements on the job / Manual labour process	Flexion angle of the waist 15°-30°	Flexion angle of the waist >30°	Height of the working arm 60°-90°	Height of the working arm > 90°	Working range 45° - 90°	Working range > 90°	Distance of reach Inches (20-30cm)	Distance of reach > 74 Inches (30cm)	Transport 5-10 lbs (3-5Kg)	Transport >10 lbs (>5Kg)	Transport Max	Walk 5-9 steps	Walk >10 steps	Rotation angle of the waist 15°-45°	Rotation angle of the waist >45°	Flexion,stretching angle of the knee 30°-60°	Flexion,stretching angle of the knee > 60°	Forarm rotation	Flexion, extension of the wrist -20°-30°	Pushing using 2 fingers or more >5 lbs (> 3daN)	Pushing using one hand >5 lbs (> 3daN)	Pushing using one finger >3.3 lbs (>1,5daN)
	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
1	1st layer area A	1						1															
2	1st layer area A	1						1															
3	1st layer area A	1							1														
4	1st layer area A	1							1														
5	1st layer area A	1							1														
6	1st layer area A	1							1														
7	1st layer area A	1							1														
8	1st layer area A	1						1					1		1								
9	1st layer area A	1						1					1		1								
10	1st layer area A	1							1				1										
11	1st layer area A	1							1				1		1								
12	1st layer area A	1							1				1		1								
13	1st layer area A	1						1															
14	1st layer area A	1						1															
15	1st layer area A	1						1															
16	1st layer area A	1						1															
17	1st layer area A	1						1															
18	1st layer area A	1						1															
19	1st layer area A	1						1															
20	1st layer area A	1						1					1		1								
21	1st layer area B		1						1				1		1								
22	1st layer area B	1							1				1			1							
23	1st layer area B		1						1				1		1								
24	1st layer area B		1						1				1		1								
25	1st layer area B		1						1				1										
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27	1st layer area B		1						1				1		1								
28	1st layer area B		1						1				1		1								
29	1st layer area B		1						1				1		1								
30	1st layer area B	1							1				1			1							
31	1st layer area B		1						1				1		1								
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38	1st layer area B		1						1				1		1								
39	1st layer area B		1						1				1		1								
40	1st layer area B		1						1				1		1								
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42	2nd layer area A	1							1														
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45	2nd layer area A	1							1														
46	2nd layer area A	1							1														
47	2nd layer area A	1							1														
48	2nd layer area A	1							1														
49	2nd layer area A	1							1														
50	2nd layer area A	1							1														
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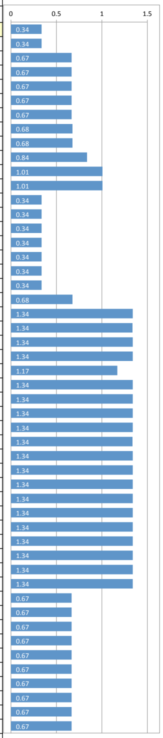

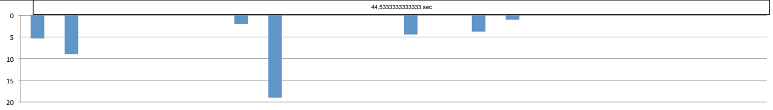

Appendix 8: Filter Muri Waste Measurement Part 2

VOLVO **Muri Ergonomic Waste Measurement** VPS

16

Edit Mode

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Document ID: Oil Filter	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:
	Volume 1 per shift						

Movements on the job / Manual labour process		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
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3	2nd layer area A	1							1														
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5	2nd layer area A		1						1														
6	2nd layer area A		1						1														
7	2nd layer area A		1						1														
8	2nd layer area A		1						1														
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22	2nd layer area B		1						1				1		1								
23	2nd layer area B		1						1				1		1								
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30	2nd layer area B		1						1				1		1								
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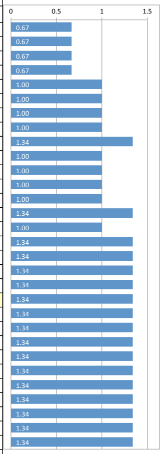

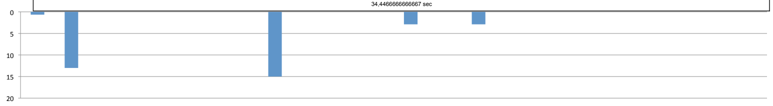

Appendix 9: Separator Muri Waste Measurement

Muri Ergonomic Waste Measurement

16

Document ID:	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:
Separator					18/04/15	Patrik & Majeed	

Volume 1 per shift

Edit Mode

Delete all input data?

Undo last entry_

Movements on the job		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
Manual labour process		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
1	1st layer Area A																						
2	1st layer Area A																						
3	1st layer Area A																						
4	1st layer Area A																						
5	1st layer Area B																						
6	1st layer Area B																						
7	1st layer Area B												1										
8	1st layer Area B												1										
9	1st layer Area C	1						1															
10	1st layer Area C	1						1															
11	1st layer Area C	1						1															
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18	2nd layer Area A	1						1															
19	2nd layer Area A	1						1															
20	2nd layer Area A	1						1															
21	2nd layer Area B	1						1															
22	2nd layer Area B	1						1															
23	2nd layer Area B	1						1					1										
24	2nd layer Area B	1						1					1										
25	2nd layer Area C	1							1														
26	2nd layer Area C	1							1														
27	2nd layer Area C	1							1						1								
28	2nd layer Area C	1							1						1								
29	2nd layer Area D	1							1														
30	2nd layer Area D	1							1														
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32	2nd layer Area D	1							1				1		1								
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34	3rd layer Area A	1							1						1								
35	3rd layer Area A	1							1						1								
36	3rd layer Area A	1							1						1								
37	3rd layer Area B	1							1						1								
38	3rd layer Area B	1							1						1								
39	3rd layer Area B	1							1				1		1								
40	3rd layer Area B	1							1				1		1								
41	3rd layer Area C		1						1							1							
42	3rd layer Area C		1						1							1							
43	3rd layer Area C		1						1							1							
44	3rd layer Area C		1						1							1							
45	3rd layer Area D		1						1							1							
46	3rd layer Area D		1						1							1							
47	3rd layer Area D		1						1				1			1							
48	3rd layer Area D		1						1				1			1							
49																							
50																							
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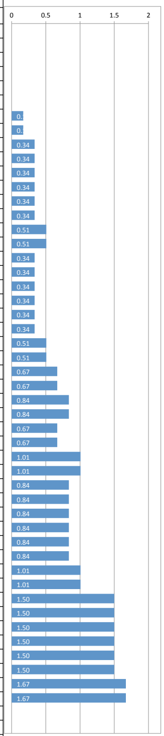

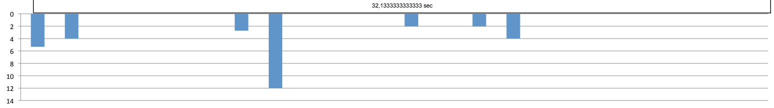

Appendix 10: Duct Muri Waste Measurement

VOLVO | **Muri Ergonomic Waste Measurement** | VPS

16

Edit Mode

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Document ID: Coolant Duct	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by: Majeed & Patrik	Approved by:

Volume 1 per shift

N°	Movements on the job / Manual labour process	Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
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2	1st layer	1							1														
3	1st layer	1							1														
4	2nd layer	1							1														
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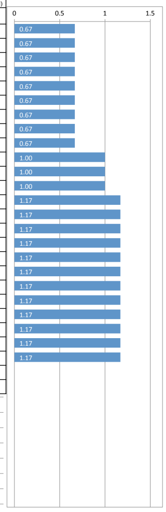
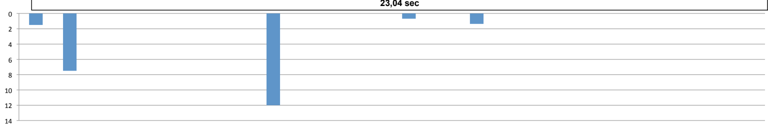
23	8th Layer		1						1				1										
24	8th Layer		1						1						1								
	Time Summary	1,5	7,5	0	0	0	0	0	12	0	0	0	0,68	0	1,36	0	0	0	0	0	0	0	0
		23,04 sec																					





Appendix 11: Project Charter

Project Title:

"Utilizing Lean Six Sigma to Improve Material Handling Operations in the Production of Heavy Duty Engines at Volvo Powertrain"

Company (Organization)	Volvo Group Trucks Operations / Volvo Powertrain	**Unit/Department:**	Production and Material Handling Operations
Executive	Lars Medbo	**Senior Deployment Champion**	Jonas Håkansson
Deployment Champion	Hanna Karlsson	**Project Champion**	Majeed Assaf Patrik Jukic
Master Black Belt	Peter Hammersberg	**Finance Champion**	Kjell Edqvist
Responsible Black Belt	Majeed Assaf Patrik Jukic	**E-mail**	assaf@student.chalmers.se jukicp@student.chalmers.se
Sponsor & process owner	Jonas Håkansson	**Site or location**	Skövde, Sweden
Project Start Date	21/1-2015	**Project completion Date**	15/5-2015
Expected impact level	Improvement of Material Handling Operations in the Production of Heavy-duty Engines.	**Expected financial impact (savings/revenues)**	Between 700 KSEK and 3,600 KSEK

Element	**Description**	**Charter**
Project Summary	A short description of the project	Analyze the process of internal material handling to identify areas where there is potential for improvement. Provide a solution to the identified inefficiencies from a productivity and ergonomic perspective.

Benefit to customers	Define internal and external customers (most critical) and their requirements	The KPI of the internal material handling operations is to improve the productivity of the main material handling line of the HDE13 heavy-duty engines. This will lead to savings in production time by having a more effective material handling process. The human factors and ergonomics improvement will also create a more stable and safe work environment for the workers involved in the material handling of the components in the main line.		
Benefit to the business	Describe the expected improvement in business performance	Volvo Powertrain will be able to reduce the needed man-hours due to the improvement in production and material handling and thus lead to financial gains for the company. The ergonomic and human factors improvements will provide a safer and less stressful working procedure/environment, which in turn reduces the costs associated with injuries on the job.		
Project Delimitations	What will be excluded from the project	External suppliers along the supply chain are outside the scope of this study. Improvement of other production processes and material handling for other products will also not be part of the project, but rather only on the main line of HDE13 heavy-duty engines.		
Required Support	Support in terms of resources (Human and Financial) required for the project	Support needed from project champions for guidance and direction during the DMAIC improvement cycle. Support needed from those directly working with or involved in the production line. Support needed from Lean waste experts in order to gain insights about past process performance and improvement.		
Measure to improve	Define the baselines, your realistic goals for the project and the best case targets for improvement.	**Actual value**	**Realistic goal by project end date**	
Specific Goals	Define the baselines, your realistic goals for the project and the best case targets for improvement.	No solid Measurement System currently exists	1000 KSEK	**Best case goal:** **3,600 KSEK**

Team members	Names of the participants in the project (area of competence)	Majeed Assaf Patrik Jukic
Others Involved	List technical experts who will be part of the team	Jonas Håkansson, Hanna Karlsson, Henrik Eklund, Kristian Lilja, Kjell Edqvist, Niclas Carlsson, Magnus Jacobsson.

DEFINE phase completion date	22/2	**MEASURE phase completion date**	24/3
ANALYZE phase completion date	16/4	**IMPROVE phase completion date**	28/4
CONTROL phase completion date	4/5	**PROJECT results presentation date**	15/5

Appendix 12: Interview Questions

1. What are the problems in the material handling operations?
2. Which parts of the production process are most problematic?
3. What measurement methods have been used in the past for productivity?
4. Have previous improvement projects been carried out in the production line? How?
5. What are some approaches previously taken for improvement?
6. Who was responsible for carrying out past improvement projects in the process?
7. Have lean manufacturing methodologies been used in the past? How?
8. Is there any current estimation of different lean wastes in the material handling operations?
9. Why are the products placed on large pallets more problematic than others?
10. What do the project stakeholders expect as an outcome of the project?
11. What were some of the unexpected challenges faced during continuous improvement projects in the past?
12. What are the desired results in terms of a pilot project towards the end of the DMAIC cycle?

Appendix 13: Internal Material Handling

Component Name	Collars	Size	Weight	Number per pallet	Yearly freq.	Zone	Lifting tool?	Pallet position	Wagon
Separator	3	S2	2,285	16x3=48	26497	3	No	Broad side	Wheels
[redacted]	3	S2	2,285	16x3=48	18552	3	No	Broad side	Wheels
[redacted]	3	S2	2,284	16x3=48	2595	3	No	Broad side	Wheels
[redacted]	Carton	L2	5,7		35341	3	No		Fixed
[redacted]	Carton	L2	8,1		4352	3	No		Fixed
[redacted]	Blue Packaging	L2	6,911		23347	3	No		Fixed
[redacted]	Carton	L2	2,784		39318	3	No		Fixed
[redacted]	3	S1	1,62	12x3=36	15974	2	No	Broad side	Wheels
[redacted]	3	M2	5	8x3=24	4047	2	No	Broad side	Wheels
[redacted]	3	M2	5	8x3=24	1525	2	No	Broad side	Wheels
[redacted]	3	M2	5	8x3=24	966	2	No	Broad side	Wheels
[redacted]	3	M2	9,999	8x3=24	581	2	No	Broad side	Wheels
[redacted]	3	M2	5	8x3=24	408	2	No	Broad side	Wheels
[redacted]	3	M2	5	8x3=24	95	2	No	Short side	Wheels
[redacted]	Blue Packaging	L2	13,9		16942	1	Yes	Broad side	Fixed
[redacted]	1	L2	9		42410	1	Yes?	Short side	Fixed
[redacted]	2	M1	2,6	29x3=87	55469	1	No	Short side	Fixed
[redacted]	2	M1	2,6	32x4=128	50152	1	No	Short side	Fixed
[redacted]	2	L2	15,046	24?	2473	1	Yes	Short side	Fixed
[redacted]	2	M2	5,104	36x3=108	24573	1	No	Short side	Fixed
Bracket	2	M2	5,2	16x4=64	58852	1	No	Short side	Fixed
[redacted]	2	M2	4,63	36x3=108	39693	1	No	Short side	Fixed
Filter	3	M1	1,205	80x2=160	131882	1	No	Short side	Fixed
[redacted]	3	M1	1,136	80x2=160	65941	1	No	Short side	Fixed
[redacted]	3	M1	1,222	80x2=160	9680	1	No	Short side	Fixed
[redacted]	3	M1	1,161	80x2=160	4840	1	No	Short side	Fixed
[redacted]	2	M2	4,682	100	18407	1	No	Short side	Wheels **
[redacted]	2	M2	6,6	80	39693	1	No	Short side	Wheels **
[redacted]	Blue Packaging	L2	8,714		19920	1	Yes	Broad side	Fixed
Duct	3	L2	7,919	4x6=24	5523	1	Yes	Short side	Fixed

* = Not included in study
**Switch with the trash bins
S = Small Component
M = Medium Component
L = Large Component

1 = One hand for grip
2 = Two hands for grip

Appendix 14: Bracket Mura Measurements Pilot

Component	Layer	Area	Observer 1	Observer 2	Final Time
Bracket	1	A	0,92	0,78	0,85
Bracket	1	A	0,86	0,72	0,79
Bracket	1	A	0,97	0,87	0,92
Bracket	1	A	1,06	0,96	1,01
Bracket	1	A	1,1	1	1,05
Bracket	1	A	1	0,9	0,95
Bracket	1	A	1,13	1,03	1,08
Bracket	1	A	0,97	0,87	0,92
Bracket	2	A	1	1,16	1,08
Bracket	2	A	1,2	1,36	1,28
Bracket	2	A	1,74	1,9	1,82
Bracket	2	A	1,67	1,83	1,75
Bracket	2	A	1,66	1,6	1,63
Bracket	2	A	1,12	1,06	1,09
Bracket	2	A	1,26	1,2	1,23
Bracket	2	A	1,92	1,86	1,89
Bracket	3	A	1,74	1,5	1,62
Bracket	3	A	1,84	1,6	1,72
Bracket	3	A	2,01	1,77	1,89
Bracket	3	A	1,34	1,1	1,22
Bracket	3	A	1,71	1,47	1,59
Bracket	3	A	1,93	1,69	1,81
Bracket	3	A	1,86	1,52	1,69
Bracket	3	A	2,08	1,74	1,91
Bracket	4	A	1,74	1,4	1,57
Bracket	4	A	1,8	1,58	1,69
Bracket	4	A	1,86	1,64	1,75
Bracket	4	A	1,69	1,47	1,58
Bracket	4	A	1,39	1,17	1,28
Bracket	4	A	1,46	1,24	1,35
Bracket	4	A	1,64	1,42	1,53
Bracket	4	A	1,5	1,28	1,39

Component	Layer	Area	Observer 1	Observer 2	Final Time
Bracket	1	B	1,25	1,15	1,2
Bracket	1	B	1,24	1,14	1,19
Bracket	1	B	1,38	1,28	1,33
Bracket	1	B	1,62	1,52	1,57
Bracket	1	B	1,74	1,64	1,69
Bracket	1	B	1,86	1,76	1,81
Bracket	1	B	1,83	1,73	1,78
Bracket	1	B	1,8	1,7	1,75
Bracket	2	B	2	1,9	1,95
Bracket	2	B	1,94	2,1	2,02
Bracket	2	B	1,65	1,81	1,73
Bracket	2	B	1,72	1,88	1,8
Bracket	2	B	1,39	1,55	1,47
Bracket	2	B	1,27	1,43	1,35
Bracket	2	B	1,2	1,36	1,28
Bracket	2	B	1,33	1,49	1,41
Bracket	3	B	1,95	1,89	1,92
Bracket	3	B	1,68	1,62	1,65
Bracket	3	B	1,75	1,69	1,72
Bracket	3	B	1,25	1,19	1,22
Bracket	3	B	1,12	1,06	1,09
Bracket	3	B	1,17	0,93	1,05
Bracket	3	B	1,65	1,41	1,53
Bracket	3	B	1,37	1,13	1,25
Bracket	4	B	1,99	1,65	1,82
Bracket	4	B	2,08	1,74	1,91
Bracket	4	B	1,96	1,62	1,79
Bracket	4	B	2,25	1,91	2,08
Bracket	4	B	2,38	2,04	2,21
Bracket	4	B	1,95	1,61	1,78
Bracket	4	B	2,48	2,14	2,31
Bracket	4	B	2,12	1,78	1,95

Appendix 15: Filter Mura Measurements Pilot

Component	Layer	Area	Observer 1	Observer 2	Final Time
Filter	1	A	1,08	0,98	1,01
Filter	1	A	1,12	0,98	1,05
Filter	1	A	1,22	1,08	1,15
Filter	1	A	1,16	1,02	1,09
Filter	1	A	1,29	1,15	1,22
Filter	1	A	1,48	1,34	1,41
Filter	1	A	1,57	1,43	1,5
Filter	1	A	1,6	1,46	1,53
Filter	1	A	1,2	1,3	1,25
Filter	1	A	1,23	1,33	1,28
Filter	1	A	1,44	1,54	1,49
Filter	1	A	1,57	1,67	1,62
Filter	1	A	1,04	1,14	1,09
Filter	1	A	1,11	1,21	1,16
Filter	1	A	1,56	1,66	1,61
Filter	1	A	1,45	1,55	1,5
Filter	1	A	1,34	1,48	1,43
Filter	1	A	1,47	1,65	1,56
Filter	1	A	1,35	1,53	1,44
Filter	1	A	1,47	1,65	1,56
Filter	2	A	1,63	1,81	1,72
Filter	2	A	1,74	1,92	1,83
Filter	2	A	1,6	1,78	1,69
Filter	2	A	1,86	2,04	1,95
Filter	2	A	1,43	1,61	1,52
Filter	2	A	1,56	1,74	1,65
Filter	2	A	1,5	1,68	1,59
Filter	2	A	1,79	1,93	1,88
Filter	2	A	1,68	1,82	1,75
Filter	2	A	1,76	1,9	1,83
Filter	2	A	1,84	1,98	1,91
Filter	2	A	1,9	2,04	1,97
Filter	2	A	1,59	1,73	1,66
Filter	2	A	1,34	1,48	1,41
Filter	2	A	1,52	1,66	1,59
Filter	2	A	1,44	1,3	1,37
Filter	2	A	1,82	1,68	1,75
Filter	2	A	1,69	1,55	1,62
Filter	2	A	1,78	1,64	1,71
Filter	2	A	1,54	1,4	1,47

Component	Layer	Area	Observer 1	Observer 2	Final Time
Filter	1	B	1,73	1,57	1,65
Filter	1	B	1,8	1,64	1,72
Filter	1	B	1,83	1,67	1,75
Filter	1	B	1,54	1,38	1,46
Filter	1	B	2,2	2,04	2,12
Filter	1	B	1,72	1,52	1,62
Filter	1	B	1,66	1,46	1,56
Filter	1	B	1,72	1,52	1,62
Filter	1	B	1,69	1,49	1,59
Filter	1	B	1,63	1,43	1,53
Filter	1	B	1,88	1,68	1,78
Filter	1	B	1,95	1,75	1,85
Filter	1	B	1,82	1,62	1,72
Filter	1	B	1,85	1,65	1,75
Filter	1	B	2,01	1,81	1,91
Filter	1	B	1,92	1,72	1,82
Filter	1	B	2,08	1,88	1,98
Filter	1	B	1,82	1,62	1,72
Filter	1	B	1,86	1,66	1,76
Filter	1	B	2,05	1,85	1,95
Filter	2	B	1,72	1,9	1,81
Filter	2	B	1,66	1,84	1,75
Filter	2	B	1,69	1,87	1,78
Filter	2	B	1,72	1,9	1,81
Filter	2	B	1,7	1,88	1,79
Filter	2	B	1,66	1,84	1,75
Filter	2	B	1,73	1,91	1,82
Filter	2	B	1,93	2,07	2
Filter	2	B	2,02	2,16	2,09
Filter	2	B	2,18	2,32	2,25
Filter	2	B	2,24	2,38	2,31
Filter	2	B	2,14	2,28	2,21
Filter	2	B	2,31	2,45	2,38
Filter	2	B	2,34	2,48	2,41
Filter	2	B	2,38	2,52	2,45
Filter	2	B	2,38	2,6	2,49
Filter	2	B	2,4	2,62	2,51
Filter	2	B	2,28	2,5	2,39
Filter	2	B	1,97	2,19	2,08
Filter	2	B	2,36	2,58	2,47

Appendix 16: Separator Mura Measurements Pilot

Component	Layer	Area	Observer 1	Observer 2	Final Time
Separator	1	A	2	1,82	1,91
Separator	1	A	1,81	1,63	1,72
Separator	1	A	1,82	1,64	1,73
Separator	1	A	1,91	1,73	1,82
Separator	1	B	1,71	1,53	1,62
Separator	1	B	1,75	1,57	1,66
Separator	1	B	2,03	1,85	1,94
Separator	1	B	1,84	1,66	1,75
Separator	1	C	1,63	1,87	1,75
Separator	1	C	1,69	1,93	1,81
Separator	1	C	1,81	2,05	1,93
Separator	1	C	1,92	2,16	2,04
Separator	1	D	1,57	1,81	1,69
Separator	1	D	1,82	2,06	1,94
Separator	1	D	1,96	2,2	2,08
Separator	1	D	1,71	1,95	1,83
Separator	2	A	1,62	1,46	1,54
Separator	2	A	1,76	1,6	1,68
Separator	2	A	1,81	1,65	1,73
Separator	2	A	2	1,84	1,92
Separator	2	B	1,97	1,81	1,89
Separator	2	B	1,74	1,58	1,66
Separator	2	B	1,86	1,7	1,78
Separator	2	B	1,91	1,75	1,83

Component	Layer	Area	Observer 1	Observer 2	Final Time
Separator	2	C	1,8	2,02	1,91
Separator	2	C	1,56	1,78	1,67
Separator	2	C	1,78	2	1,89
Separator	2	C	1,8	2,02	1,91
Separator	2	D	1,48	1,7	1,59
Separator	2	D	1,76	1,98	1,87
Separator	2	D	1,87	2,09	1,98
Separator	2	D	1,94	2,16	2,05
Separator	3	A	1,44	1,6	1,52
Separator	3	A	1,51	1,67	1,59
Separator	3	A	1,63	1,79	1,71
Separator	3	A	1,77	1,93	1,85
Separator	3	B	2,04	2,2	2,12
Separator	3	B	1,75	1,91	1,83
Separator	3	B	1,67	1,83	1,75
Separator	3	B	1,84	2	1,92
Separator	3	C	1,77	2,01	1,89
Separator	3	C	1,47	1,71	1,59
Separator	3	C	1,98	2,22	2,1
Separator	3	C	2,13	2,37	2,25
Separator	3	D	2,29	2,53	2,41
Separator	3	D	1,88	2,12	2
Separator	3	D	1,91	2,15	2,03
Separator	3	D	2,29	2,53	2,41

Appendix 17: Duct Mura Measurements Pilot

Component	Layer	Area	Observer 1	Observer 2	Final Time
Duct	1	N/A	1,8	2,02	1,91
Duct	1	N/A	1,74	1,96	1,85
Duct	1	N/A	1,83	2,05	1,94
Duct	2	N/A	1,95	2,17	2,06
Duct	2	N/A	1,67	1,89	1,78
Duct	2	N/A	2,1	2,32	2,21
Duct	3	N/A	2,26	2,48	2,37
Duct	3	N/A	2,01	2,23	2,12
Duct	3	N/A	2,19	2,35	2,27
Duct	4	N/A	2,38	2,54	2,46
Duct	4	N/A	2,59	2,75	2,67
Duct	4	N/A	2,53	2,69	2,61
Duct	5	N/A	2,73	2,89	2,81
Duct	5	N/A	2,64	2,8	2,72
Duct	5	N/A	2,54	2,7	2,62
Duct	6	N/A	2,89	3,05	2,97
Duct	6	N/A	2,9	3,14	3,02
Duct	6	N/A	2,77	3,01	2,89
Duct	7	N/A	3,13	3,37	3,25
Duct	7	N/A	2,99	3,23	3,11
Duct	7	N/A	3,26	3,5	3,38
Duct	8	N/A	3,39	3,63	3,51
Duct	8	N/A	3,35	3,59	3,47
Duct	8	N/A	3,47	3,71	3,59

Appendix 18: Bracket Muri Measurements Pilot

VOLVO

Muri Ergonomic Waste Pilot Measurement

16

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Document ID: Bracket	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:

Volume 1 per shift

Movements on the job / Manual labour process		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	50-75 Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
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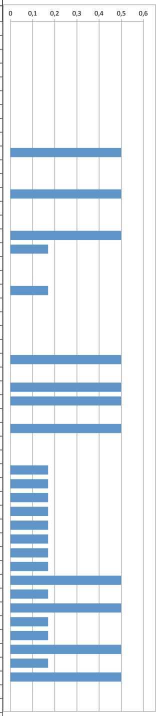
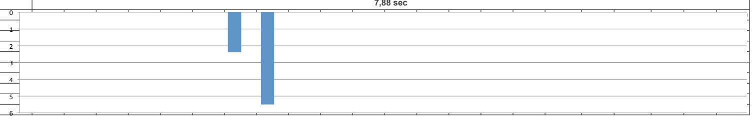


25



Appendix 19: Bracket Muri Measurements Pilot Part 2

VOLVO

Muri Ergonomic Waste Measurement

16

Document ID: Bracket	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:
	Volume 1 per shift						

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Movements on the job		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
Manual labour process		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
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12	4th layer area B																						
13	4th layer area B								1														
14	4th layer area B																						
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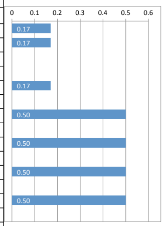
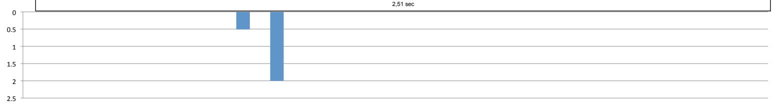
		2,51 sec																					





Appendix 20: Filter Muri Measurements Pilot

VOLVO **Muri Ergonomic Waste Pilot Measurement** VPS 16

Document ID: Filter	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:
	Volume 1 per shift						

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Movements on the job		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
Manual labour process		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	30-73 Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
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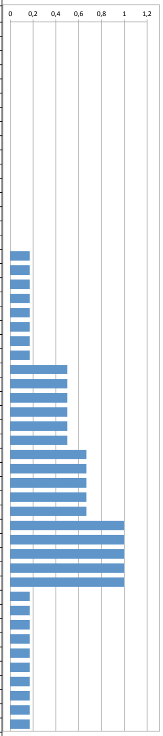
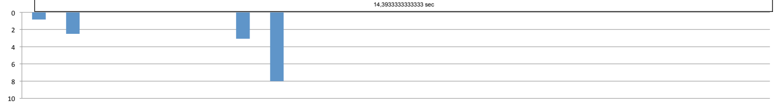
39	1st layer area B		1						1														
40	1st layer area B		1						1														
41	2nd layer area A							1															
42	2nd layer area A							1															
43	2nd layer area A							1															
44	2nd layer area A							1															
45	2nd layer area A							1															
46	2nd layer area A							1															
47	2nd layer area A							1															
48	2nd layer area A							1															
49	2nd layer area A							1															
50	2nd layer area A							1															
	Time Summary	0,8333333	2,5	0	0	0	0	3,06	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		14,3933333333333 sec																					





Appendix 21: Filter Muri Measurements Pilot Part 2

VOLVO **Muri Ergonomic Waste Pilot Measurement** VPS

16

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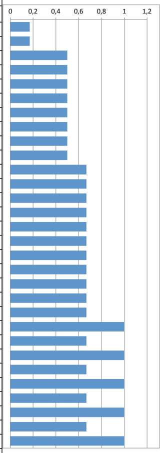
Undo last entry

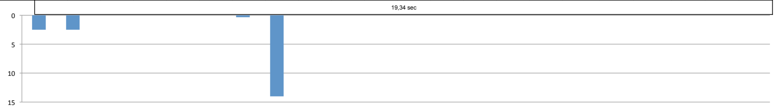
Document ID: Filter	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:

Volume 1 per shift

	Movements on the job	Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
	Manual labour process	15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
1	2nd layer area A							1															
2	2nd layer area A							1															
3	2nd layer area A								1														
4	2nd layer area A								1														
5	2nd layer area A								1														
6	2nd layer area A								1														
7	2nd layer area A								1														
8	2nd layer area A								1														
9	2nd layer area A								1														
10	2nd layer area A								1														
11	2nd layer area B	1							1														
12	2nd layer area B	1							1														
13	2nd layer area B	1							1														
14	2nd layer area B	1							1														
15	2nd layer area B	1							1														
16	2nd layer area B	1							1														
17	2nd layer area B	1							1														
18	2nd layer area B	1							1														
19	2nd layer area B	1							1														
20	2nd layer area B	1							1														
21	2nd layer area B	1							1														
22	2nd layer area B		1						1														
23	2nd layer area B	1							1														
24	2nd layer area B		1						1														
25	2nd layer area B	1							1														
26	2nd layer area B		1						1														
27	2nd layer area B	1							1														
28	2nd layer area B		1						1														
29	2nd layer area B	1							1														
30	2nd layer area B		1						1														
	Time Summary	2,5	2,5	0	0	0	0	0,34	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0

19,34 sec





Appendix 22: Separator Muri Measurements Pilot

VOLVO — **Muri - Ergonomics analyze** — VPS

16

☐ Edit Mode

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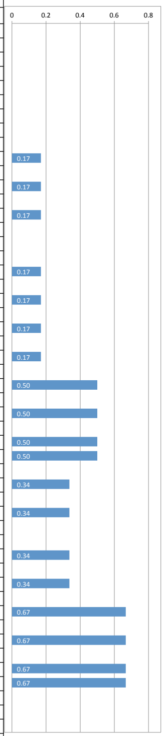
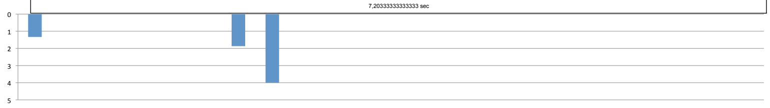
Document ID:	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by:	Approved by:
Separator					18/04/15	Patrik & Majeed	

Volume 1 per shift

	Movements on the job																						
		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
	Manual labour process	15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	Seconds	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	1,00	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17	0,50	0,17
1	1st layer Area A																						
2	1st layer Area A																						
3	1st layer Area A																						
4	1st layer Area A																						
5	1st layer Area B																						
6	1st layer Area B																						
7	1st layer Area B																						
8	1st layer Area B																						
9	1st layer Area C																						
10	1st layer Area C							1															
11	1st layer Area C																						
12	1st layer Area C							1															
13	1st layer Area D																						
14	1st layer Area D							1															
15	1st layer Area D																						
16	1st layer Area D																						
17	2nd layer Area A																						
18	2nd layer Area A							1															
19	2nd layer Area A																						
20	2nd layer Area A							1															
21	2nd layer Area B																						
22	2nd layer Area B							1															
23	2nd layer Area B																						
24	2nd layer Area B							1															
25	2nd layer Area C																						
26	2nd layer Area C								1														
27	2nd layer Area C																						
28	2nd layer Area C								1														
29	2nd layer Area D																						
30	2nd layer Area D								1														
31	2nd layer Area D								1														
32	2nd layer Area D																						
33	3rd layer Area A	1						1															
34	3rd layer Area A																						
35	3rd layer Area A	1						1															
36	3rd layer Area A																						
37	3rd layer Area B																						
38	3rd layer Area B	1						1															
39	3rd layer Area B																						
40	3rd layer Area B	1						1															
41	3rd layer Area C																						
42	3rd layer Area C	1							1														
43	3rd layer Area C																						
44	3rd layer Area C	1							1														
45	3rd layer Area D																						
46	3rd layer Area D	1							1														
47	3rd layer Area D	1							1														
48	3rd layer Area D																						
49																							
50																							
	Time Summary	1,3333333	0	0	0	0	0	1,87	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0

7,20333333333333 sec





Appendix 23: Duct Muri Measurements Pilot

VOLVO **Muri Ergonomic Waste Pilot Measurement** 16

Document ID: Duct	Edition:	Line:	Station name:	Variant:	Issue Date:	Issued by: Majeed & Patrik	Approved by:

Volume 1 per shift

Edit Mode

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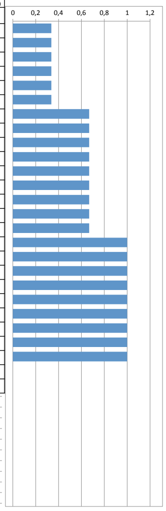
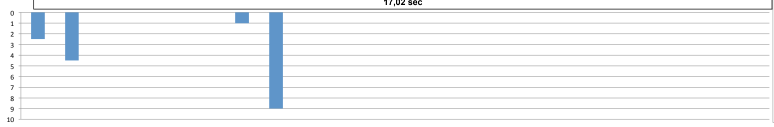
Movements on the job / Manual labour process		Flexion angle of the waist		Height of the working arm		Working range		Distance of reach		Transport			Walk		Rotation angle of the waist		Flexion,stretching angle of the knee		Forarm rotation	Flexion, extension of the wrist	Pushing using 2 fingers or more	Pushing using one hand	Pushing using one finger
		15°-30°	>30°	60°-90°	> 90°	45° - 90°	> 90°	Inches (20-30cm)	> 74 Inches (30cm)	5-10 lbs (3-5Kg)	>10 lbs (>5Kg)	Max	5-9 steps	>10 steps	15°-45°	>45°	30°-60°	> 60°		-20°-30°	>5 lbs (> 3daN)	>5 lbs (> 3daN)	>3.3 lbs (>1,5daN)
N°	**Seconds**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**	**0,50**	**1,00**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**	**0,50**	**0,17**
1	1st layer	1						1															
2	1st layer	1						1															
3	1st layer	1						1															
4	2nd layer	1						1															
5	2nd layer	1						1															
6	2nd layer	1						1															
7	3rd Layer	1							1														
8	3rd Layer	1							1														
9	3rd Layer	1							1														
10	4th Layer	1							1														
11	4th Layer	1							1														
12	4th Layer	1							1														
13	5th Layer	1							1														
14	5th Layer	1							1														
15	5th Layer	1							1														
16	6th Layer		1						1														
17	6th Layer		1						1														
18	6th Layer		1						1														
19	7th Layer		1						1														
20	7th Layer		1						1														
21	7th Layer		1						1														
22	8th Layer		1						1														
23	8th Layer		1						1														
24	8th Layer		1						1														
	Time Summary	**2,5**	**4,5**	**0**	**0**	**0**	**0**	**1,02**	**9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
		17,02 sec																					





Appendix 24: Mura Improvement Calculations

Bracket	Brackets per part	Current	Pilot	Improvement	Savings per part	Total Savings
Layer 1 Area A	8	2,05	0,95	1,1	8,8	80,64
Layer 2 Area A	8	2,1	1,47	0,63	5,04	
Layer 3 Area A	8	2,49	1,68	0,81	6,48	
Layer 4 Area A	8	2,48	1,52	0,96	7,68	
Layer 1 Area B	8	3,13	1,54	1,59	12,72	
Layer 2 Area B	8	3,09	1,63	1,46	11,68	
Layer 3 Area B	8	3,28	1,43	1,85	14,8	
Layer 4 Area B	8	3,66	1,98	1,68	13,44	
Filter	**Filters per part**	**Current**	**Pilot**	**Improvement**	**Savings per part**	**Total Savings**
Layer 1 Area A	20	1,66	1,35	0,31	6,2	116,6
Layer 2 Area A	20	2,41	1,69	0,72	14,4	
Layer 1 Area B	20	4,06	1,74	2,32	46,4	
Layer 2 Area B	20	4,61	2,13	2,48	49,6	
Separator	**Separators per part**	**Current**	**Pilot**	**Improvement**	**Savings per part**	**Total Savings**
Layer 1 Area A	4	2,88	1,8	1,08	4,32	90,84
Layer 2 Area A	4	3,22	1,72	1,5	6	
Layer 3 Area A	4	3,52	1,67	1,85	7,4	
Layer 1 Area B	4	3,71	1,74	1,97	7,88	
Layer 2 Area B	4	3,85	1,79	2,06	8,24	
Layer 3 Area B	4	4,22	1,91	2,31	9,24	
Layer 1 Area C	4	2,99	1,88	1,11	4,44	
Layer 1 Area C	4	3,55	1,85	1,7	6,8	
Layer 1 Area C	4	3,85	1,96	1,89	7,56	
Layer 1 Area D	4	4,07	1,89	2,18	8,72	
Layer 1 Area D	4	4,42	1,87	2,55	10,2	
Layer 1 Area D	4	4,72	2,21	2,51	10,04	
Duct	**Ducts per part**	**Current**	**Pilot**	**Improvement**	**Savings per part**	**Total Savings**
Layer 1	3	2,4	1,9	0,5	1,5	63
Layer 2	3	3,59	2,02	1,57	4,71	
Layer 3	3	4,19	2,25	1,94	5,82	
Layer 4	3	5,61	2,58	3,03	9,09	
Layer 5	3	5,81	2,72	3,09	9,27	
Layer 6	3	6,91	2,96	3,95	11,85	
Layer 7	3	6,69	3,25	3,44	10,32	
Layer 8	3	7	3,52	3,48	10,44	
Mean Improvement per component		1,92				

Appendix 25: Lifting Index Current Vs. Pilot Calculations

	LI RATIO CURRENT	LI RATIO PILOT	IMPROVEMENT	LI RATIO CURRENT	LI RATIO PILOT	IMPROVEMENT
	Bracket	Bracket		Filter	Filter	
	0,4	0,15	0,25	0,09	0,05	0,04
	0,57	0,45	0,12	0,17	0,11	0,06
	0,76	0,51	0,25	0,2	0,12	0,08
	0,73	0,28	0,45	0,16	0,09	0,07
	1,04	0,84	0,2	0,32	0,2	0,12
	1,4	0,95	0,45	0,36	0,23	0,13
	1,13	0,46	0,67	0,24	0,14	0,1
	1,61	1,34	0,27	0,49	0,32	0,17
	2,16	1,52	0,64	0,55	0,36	0,19
TOTAL	**9,8**	**6,5**	**3,3**	**2,58**	**1,62**	**0,96**
	LI RATIO CURRENT	LI RATIO PILOT	IMPROVEMENT	LI RATIO CURRENT	LI RATIO PILOT	IMPROVEMENT
	Separator	Separator		Duct	Duct	
	0,16	0,09	0,07	0,57	0,3	0,27
	0,33	0,2	0,13	1,14	0,7	0,44
	0,37	0,23	0,14	1,29	0,8	0,49
	0,3	0,16	0,14	1,04	0,57	0,47
	0,6	0,38	0,22	2,08	1,32	0,76
	0,68	0,43	0,25	2,36	1,49	0,87
	0,46	0,26	0,2	1,6	0,91	0,69
	0,93	0,61	0,32	3,22	2,11	1,11
	1,05	0,69	0,36	3,64	2,39	1,25
TOTAL	**4,88**	**3,05**	**1,83**	**16,94**	**10,59**	**6,35**
TOTAL LI RATIO CURRENT		**34,2**				
TOTAL LI RATIO PILOT		**21,76**				
TOTAL IMPROVEMENT (%)		**36,4**				

Appendix 25: Pilot Project Prototype Wagon