Productivity increase valve and pipe assembly

An investigation of how to improve the manufacturing process in a large variant production environment

Master of Science Thesis

DAVID NYSTRÖM
PER SÖDERSTRÖM

Department of Signals and Systems
Division of Automatic Control, Automation and Mechatronics
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2009
Report No. EX072/2009

REPORT NO. XXXX/XXXX

Productivity increase valve and pipe assembly

An investigation of how to improve the manufacturing process
in a large variant production environment

DAVID O. NYSTRÖM
PER S. SÖDERSTRÖM

Department of Signals and Systems
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2009

Productivity increase valve and pipe assembly
An investigation of how to improve the manufacturing process in a large variant production environment

DAVID O. NYSTRÖM
PER S. SÖDERSTRÖM

Technical report no. XXX:XX
Department of Signals and Systems
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Tryckeri
Göteborg, Sweden 2009

Abstract

Increasing productivity is an ever present challenge in the manufacturing industry where demands on resource utilisation and reduced tied up capital are increasing constantly in order to match the competition and stay ahead as a world class truck manufacturer. The investigated part of the production is assembling one of the most complex fractions of the truck, with high variances in workload and in the end two different brands through the same work flow creating an unstable process hard to predict.

This project has been conducted using a structured way of first gathering, for the most part, primary data which is then used to analyse and develop a solution with the Volvo Production Systems as a base (the principles of Lean production adapted to Volvo Trucks). By improving the process stability with the tools 5S and standardized work an increase in productivity of 49 percent will be reached within a few months while the improvement within one to two years will be 107 percent. This is due to a reduction of all seven wastes, reduction in lead and a reduction of work in progress. The solution is based on an integration of 5S and standardized work, making the two tools work together in a profitable way compared to implementing them separately.

Acknowledgements

The authors of this Thesis would like to thank the following people without whom this project would not have been possible.

First and foremost we would like to thank Project manager Björn Andersson for his work in realising this project and the guidance provided throughout the work. Furthermore we would like to thank Manufacturing engineering manager Sergio Kunzel for giving us the opportunity to perform our Master's Thesis at Volvo Commercial Vehicles Australia, Wacol Plant.

We would also like to thank Shane Newnham and Scott Lowe together with the rest of the staff at Production engineering as well as the section leaders Franky De Bruyn and Dave Hassack for the time they have given us and the patience they have shown from the numerous discussions and questions we have had. We also have the utmost gratitude for the operators working in the valve and pipe area who have given us invaluable knowledge and feedback during this project.

Finally we would like to thank our supervisor Petter Falkman at Chalmers University of Technology for his guidance throughout this project.

Table of contents

List of figures

Abbreviations

CAP - Concept for Activating Performance
FFC - Future Factory Concept
GM - Global Manufacturing
IM - International Manufacturing
JIT - Just-in-time
MDC - Methods Design Concept
MPU - Method Performance Utilisation
MTM - Method Time Measurement
OMS - Operational Management System
PE - Production Engineering
TPS - Toyota Production System
VCVA - Volvo Commercial Vehicles Australia
VPS - Volvo Production System
VSM - Value Stream Mapping
WBS - Work Breakdown Structure
WIP - Work In Progress

1 Introduction

This chapter will describe the motivation behind why this project is carried out. A brief background is presented together with the purpose and objectives of the studies. Also described are areas not included in the report in order to maintain a manageable scope together with the organisation and the structure of the project group.

1.1 Background

Currently Volvo Truck Corporation is the second largest manufacturer of heavy-duty trucks in the world (Volvo, 2009a). Volvo is also a manufacturer of medium-heavy trucks and has a sales organisation that reaches out to more than 140 countries. The first Volvo truck was rolled out 1928 in Gothenburg, Sweden and in Australia the Wacol plant opened in 1972. When Volvo incorporated Mack Trucks in 2001 they strengthened the position as a world leader in truck manufacturing and the Wacol plant became a multi-brand factory with both brands within the range of production.

Increasing productivity is an ever present challenge in the manufacturing industry. Demands on resource utilisation and reduced tied up capital are increasing constantly in order to match the competitions and stay ahead as a world class manufacturer of trucks. With this as a basis the project “Productivity increase valve and pipe assembly” was initiated. This master’s thesis is investigating the valve and pipe area which is starting after the chassis have been painted and ends where the final assembly line take over. The final assembly line is separated into two where Volvo is assembled on one and Mack on the other. The underlying reason that focus is put on the valve and pipe assembly is that it has been identified as a particularly troublesome area when it comes to balancing and process stability, with workers constantly complaining about production disturbances and Takt time. .As a result the Wacol factory today is not producing enough trucks according to their target, eight trucks per day. When observing the actual area it looks like there is a lot of non value adding time and a non standardised way of working, i.e. it is an area that seems to have a great potential of improvements.

The Volvo Production System (VPS) is the Volvo system for Lean production. The original theories come from the Toyota Production System adapted to fit the Volvo organisation. VPS is something that this master’s thesis will work according to because it is a modern effective toolbox and stated as a requirement from the Wacol factory. VPS is described in more in detail in 2.1 - Volvo Production System.

1.2 Purpose and objectives

By taking into account the factors above, several aspects that make the valve and pipe assembly process troublesome needs to be investigated. The chassis that are coming into the assembly area can be either Mack or Volvo making it hard to keep consistency and standardisation. In addition to this the vast number of different variations available for each truck adds to the problem of consistency. This makes it difficult to assess the time and workload needed for each chassis coming in. Therefore a thorough analysis of the current state of the process will be conducted and included in this thesis. Another important factor for the project is the reduction of work in progress (WIP). This as it not only increases the tied up capital but also takes up valuable factory floor space and increases the throughput time. This thesis will investigate how the WIP can be managed in a more efficient manner.

The main purpose of this thesis is therefore to *investigate how the valve and piping process can be changed, in accordance with the VPS framework, to increase productivity compared to the current situation.*

The objectives and the purpose that is stated above raises two questions that have been used as a basis for the investigative work and will also be answered by this thesis. They are as follows:

- Is it possible to change the production flow of the valve and piping process to increase process stability?
- How can the WIP be reduced within the area to reduce lead times thereby increase the productivity?

1.3 Delimitations

In order to be able to perform a thorough investigation and maintain the scope of the project the following delimitations have been made.

- The analysis will only focus on the internal production flow in the valve and piping process. Therefore no consideration will be taken with respect to material procurement and other supplier related issues.
- The valve and piping assembly process will be analysed without taking into account any changes required at the adjacent stations in the production flow. In this case the chassis paint located before the valve and pipe assembly as well as the Volvo and Mack mainlines located after the valve and pipe assembly.
- Potential issues and effects caused by changes in logistics and internal material handling will be investigated by the logistics department and not considered in this thesis.

- Human aspects, such as manning and workforce interaction, will be handled by the human resources department and not considered in the investigation. Neither will it cover any external factors.

1.4 Project organisation

This thesis is part of the project “Productivity increase valve and pipe assembly”. The work is supported by a project organisation, Figure 1, consisting of a Project manager appointed by Plant manager Mona Edström Frohm, a project team consisting of the authors of this report, a working group consisting of people from various departments such as Production Engineering (PE), Production and a reference group made up of the Assembly Network group. More specifically the persons involved are the following: Production engineering supervisor and Project manager Björn Andersson, Valve area section leader David Hassack, Production engineer Kevin Ward, Materials engineer Justin Murphy, Materials engineer David Curtis and Pipe area section leader Franky De Bruyn.

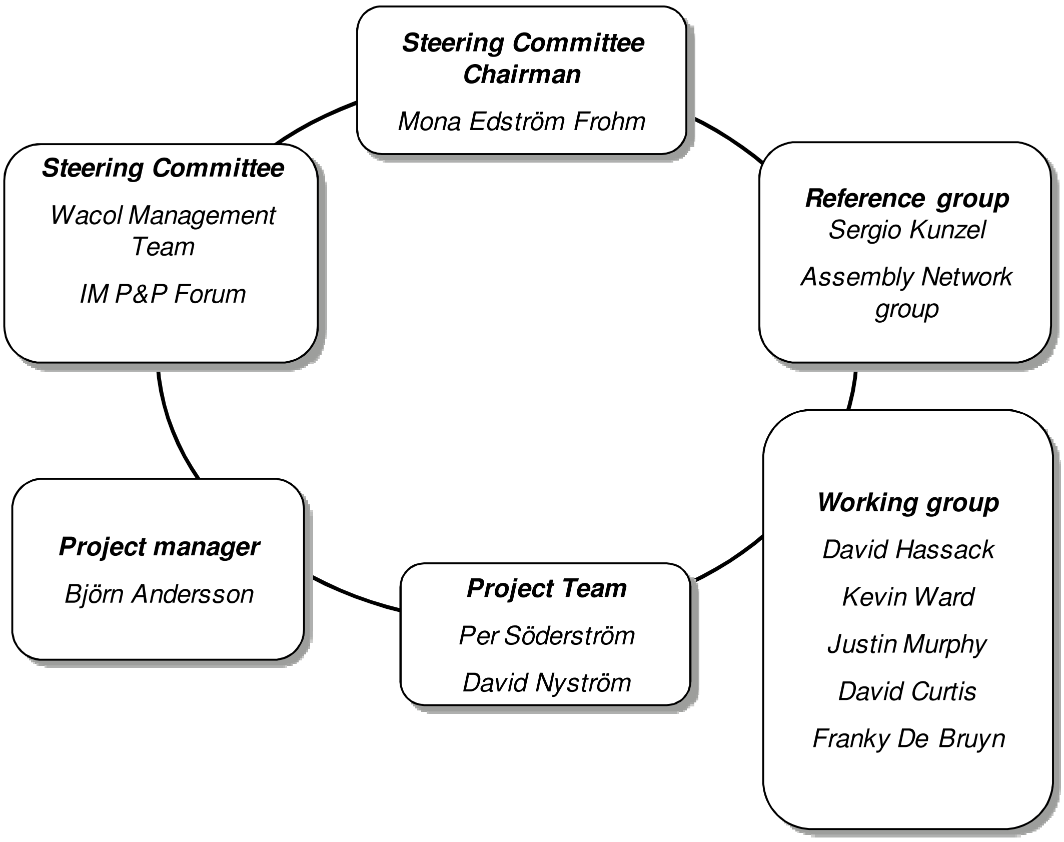


Figure 1: Project team organisation

Sweden. In addition support will be given by Volvo Global Manufacturing (GM) and Volvo International Manufacturing (IM), both of which are located at Lundby, Göteborg, Sweden. The IM P&P Forum is a central organisation within Volvo that manages projects and the Assembly Network Group is an engineering knowledge resource. Supervisor for the Master’s thesis is Petter Falkman, PhD Automation, Chalmers University of Technology, Sweden.

2 Theory

The following chapter presents the theoretical framework from which the continued work is based on. Since the general problem of this thesis is something that has been done many times before, a thorough literature study has been conducted in order to draw benefits from previous work. The ideas and concepts of the VPS are presented as it is the basis for all work carried out at Volvo.

2.1 Volvo Production System

VPS is developed from Lean production with The Volvo Way as the base which means the Volvo culture, goals and value judgements. VPS include several principles and tools for how to achieve these goals, see Figure 2. The following section will describe the history of VPS and the different areas that it consists of.

2.1.1 History

VPS is Volvos own interpretation of many of the concepts and methodologies found in the Toyota Production System (TPS), most commonly known by the somewhat abused term Lean Production. TPS started in the spring of 1950 when Eiji Toyoda visited Ford's Rogue plant in Detroit. When returning from his trip he concluded, together with Taiichi Ohno, that mass production would not work in Japan. It was Ohno who would implement the ideas of TPS over the course of 30 years and the results are evident today. (Pascal, 2007)

Volvos VPS implementation started in 2007 and builds on several earlier projects implemented previously. VPS has its foundation in three equally important parts, the *vision* which clearly defines what VPS wants to achieve, the *principles* that guides the work to achieve the vision and the *tools and techniques* that guides the work so that it follows the principles. The mission is as stated. (Volvo, 2009c)

"To implement a global Volvo Production System by creating an environment for continuous improvement"

The basic concepts will briefly be described in the next chapter and many of the tools and techniques will be covered in the coming chapters.

2.1.2 Basic concepts

The principles within VPS are illustrated in Figure 2 and show how the vision is supposed to be achieved. The root of the pyramid is that all work should be based on the Volvo way, which means that every employee should be involved and have the ability to improve the way he or she works. This is then followed by the principles of Teamwork, Process stability, Built-in quality, Just-in-time, Continuous improvements and Customer; many of these concepts will now be explained.

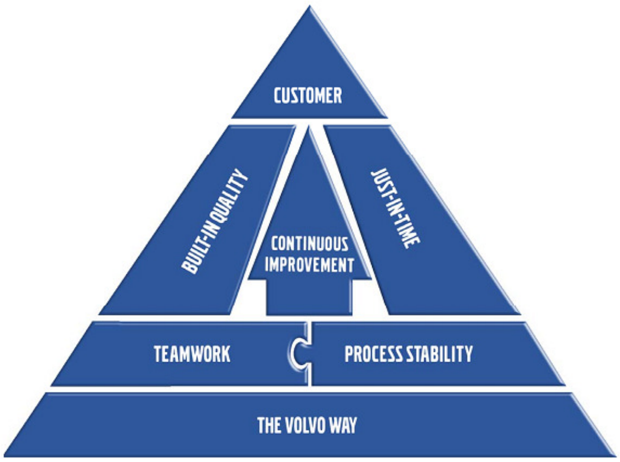


Figure 2: Principles within Volvo Production System (Volvo, 2009c)

2.1.3 Waste

Eliminating waste, or *muda* as it is translated to Japanese, is a key element in both a Lean manufacturing concept and the VPS framework. Waste is characterized by all activities in a production sequence that does not directly add value to the customer, or rather everything that the customer is not willing to pay for. In most operations within the manufacturing industry there are often several steps involved in an operation but only a few of these actually add value to the end product. However many of the steps that do not add value are still necessary in order to complete the task. The mission is therefore to minimize the time needed for these operations. The first question that should be asked is "*What does the customer want from this process?*" (Liker, 2004)

Waste can be divided into seven general categories and are described below. (Liker, 2004, Moore, 2007, Pascal, 2007)

1. **Over production:** Manufacturing products for which there exists no customer order, i.e. producing to a master schedule that relies on forecasts instead of actual orders. This will lead to problems with overstaffing, tied up capital through excess inventory and transportation costs from handling larger inventories.
2. **Unnecessary processes or over processing:** This waste is present when higher quality products than what the customer is asking for is produced. It can also be caused by bad product design or inefficient processing causing process times exceeding what is necessary.
3. **Waiting or delay:** Waiting waste occurs when a worker for instance has to wait for a machine to complete its work. It can also be the result of a high WIP, inventory shortages, unavailable tools or anything else that makes the operator have to wait for his next task. Delays causes lead time to increase, which is an important factor in a lean system.

4. **Unnecessary transport:** Inefficient factory layouts where work pieces have to be moved far distances is the main contributing factor to this waste. Another aspect is a large WIP count where significant time is needed to manage inventories and finished product stocks.
5. **Excess inventory:** This is present when there is an excess of incoming raw material, WIP or large quantities of finished goods. It occurs when the production flow is not synchronized with a common Takt time. Results in higher costs due to transportation, damage goods and inventory keeping. Large inventories or buffers also hide other problems that might be present in a production system as material is withdrawn from buffers while some other part of the production process is struggling.
6. **Unnecessary movement:** This relates to both human and machine movement. Human motions including twisting, looking for, reaching for, stacking, and walking is considered a waste. This also relates to quality issues when workers have to reach and strain themselves in order to complete their task. Machine movement waste is also a factor for instance when two welding spots are placed further away from each other than necessary.
7. **Defects or correction:** Products ending up defect or needing correction generates waste. Time and effort is needed for inspection and corrective measures as well as the material consumption when repairing or scrapping a part.

Of these seven wastes above the first, over production, is the most critical one. This is because it contributes to most of the other wastes as these are present within the production system. Therefore for each over produced item, all the other wastes add to the total waste automatically.

2.1.4 VSM

Value stream mapping (VSM) is a tool used to visually represent a business process or a product family, identifying opportunities for waste elimination. First, value is defined from the customer's point of view. After this the value stream is mapped backwards throughout the different steps of the process that the product family flows through until you reach the defined supplier (Duggan, 2002). Information is recorded regarding cycle times, type of material flow, buffer sizes and the number of operators at each stage to name a few things. It is however not only the product that is taken into account and represented, the information flow is an important part of the process and is also graphically displayed. When completed the map will visually show the current state of the process when the VSM was created, a snapshot. From the current state map improvement opportunities are identified and a future state map is drawn where improvements have been made to the problem areas (Mascitelli, 2006). The final step is to set in place an action plan for how to reach the future state from the current state. An example of a VSM can be seen in Figure 3.

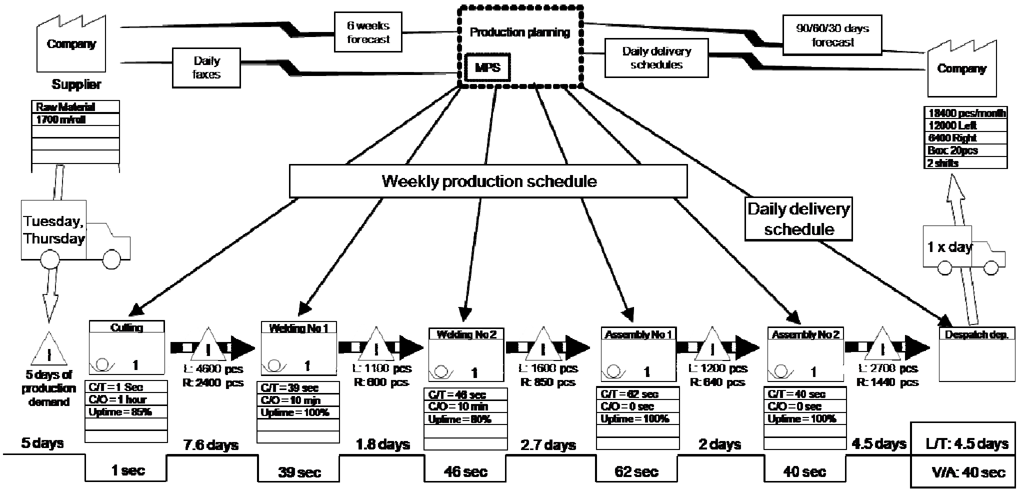


Figure 3: Example of a VSM (Volvo, 2008)

The VSM can be created on several different levels of detail. It can for instance be used to map the entire plant using the end products as the unit to be mapped, with the end customer and supplier at the ends of the VSM. However it can also be used to map the value stream of internal process flows within the factory such as materials flow or between segments of the production. In this case the customer will for instance be represented by the subsequent station in the production flow and the supplier will be the previous station.

One of the benefits of the VSM is that it is very easy to understand, thus enabling everyone working in the process to be involved in the development of the future state. It is also easy to show where the problem areas are in an uncomplicated and clear way. Many of the improvements that are usually implemented after the action plan has been set in place will be further described later in this chapter.

2.1.5 Stability

Stability is one of the cornerstones to the implementation of lean processes. A common misconception is that Lean manufacturing is about producing only when the customer has placed an order. This will create unevenness and large fluctuations in the workload as customer demands are seldom predictable. In that kind of environment it is impossible to reap the benefits of lean tools since they rely on stable processes so that inventory management and one piece flow can function (Liker, 2004). In order to create stability, levelled production and 5S are used together with standardised work. Levelled production and 5S will be described in this chapter whereas standardised work is described in section 2.1.6 - Standardised work.

Finally the most important factor to create stability according to Moore (2007) is management stability. In many cases companies are constantly changing management positions which create discontinuity in the improvement work and information is lost along the way.

Levelled production

In order to create stability levelled production must be put in place. Having a production system with constant starts and stops creating both over- and underutilisation is something that works against quality, standardisation of work and productivity. The idea behind levelling production, or *heijunka* as it is called in Japanese, is to even out both the production schedule and the product mix. Instead of producing exactly what the customer need, the orders are looked at over a period of time. The different order variations are then broken down into an even schedule where the same product mix and quantity is produced every day. (Liker, 2004)

Four benefits can be identified when levelling and evening out the product mix:

1. Flexibility to make what the customer wants when he wants it, meaning reduced inventory and finished goods stock.
2. Reduced risk of unsold goods, if the mix is evenly spread the risk of ending up with unsold goods due to for instance order cancellations is reduced.
3. Balanced use of labour and machines, by levelling the product mix elasticity is created in the system. Even though some items may require more time to produce, it is acceptable as long as it is not followed by another item that requires more time. Production levelling enables schedules to be planned to accommodate this unevenness.
4. Smoothed demand on the upstream processes and the suppliers, since the levelled production is predictable upstream processes together with suppliers will have a constant stream of either products or orders.

To further help the implementation of levelled production the concepts of Takt time, cycle time and balancing are important. These will now briefly be explained.

Takt time

Takt time is what synchronizes the entire production flow; it is the rhythm of the plant. The Takt time is a function of the customer demand and the available working time. Imagine for instance that the customer demand is eight products a day and the available working time is eight hours. That means that the Takt time, the pace at which products move forward in the flow, will be one hour. Most assembly lines are constructed and designed for a minimum Takt time but in actuality operate at a slower pace and changes are only made when significant changes in the market occur. (Baudin, 2002)

Cycle time and balancing

Once the Takt time has been established the time it takes to conduct each operation needs to be recorded or estimated, this is called the cycle time. The cycle time can never extend the Takt time since the operator needs to be able to finish the work before the work piece moves further upstream. In most cases the aim is to keep the cycle time per operator at about 80 percent of the Takt time to give room for variations that occurs in the cycle time. The task of balancing is therefore to spread the different operations at a particular station in such a way that all the operators have a somewhat evenly spread workload (at least below Takt time), whilst still keeping movement and other wastes to a minimum. (Volvo, 2009c)

5S

The 5S methodology is a tool which has had an increased rate of implementation among companies around the world. It is no longer isolated to the manufacturing processes but is being increasingly present also in the administrative departments and office environments. The main objective of the 5S tool is to make employees change their habits in order to be able to withhold an ordered workplace. This is made possible through education and encouragement. Many of the concepts could be considered common sense, but investigations indicate that maintaining a clean and ordered working place is not something that is properly executed in companies. (Santos et al., 2006)

5S is based around five so called *pillars* and each of them will be described briefly. Each of the pillars have the prerequisite of the one before so in order to implement pillar three you have to have completed one and two and so on.

1. **Sort** (Seiri): The first pillar is based on sorting out the things that are unnecessary to complete the work at hand. The work place can easily get overrun with parts, scrap material, tool cabinets and chairs just to name a few things. This leads to obstructions in material handling as well as increased lead times.
2. **Set in order** (Seiton): When the sorting has been taken care of it is time to start the organisation of the workplace and set everything in order. How machines and tools should be placed to minimize movement waste. An important factor here is the implementation of colour coding and visual aids. This will increase ease of perception and the ability to find what you are looking for faster, as this progresses *Poka-yokes* described in section 2.1.8 - Poka-yoke will automatically be created.
3. **Shine** (Seiso): When the first two pillars have been implemented it should in most cases have freed up a lot of floor space, making it easier to keep clean. This is what constitutes the third pillar, keeping the workplace clean. Cleaning stations should be set up where everything is available in order to keep the workplace clean. Responsibilities and cleaning schedules should also be put in place to enable mutual responsibility within the group.

4. **Standardise** (Seiketsu): By now the workplace is well organized and clean, since the first three steps have been completed. To keep this new state it is important to standardise the process by which we are working, otherwise it soon tends to fall apart or degrade.
5. **Sustain** (Shitsuke): The last and final step is to ensure that the 5S methodology becomes the standard by which the company is working. This is enabled by education and communication.

In many cases 5S is seen as a prerequisite for other improvement work to commence. If you do not have a clean workplace that is in control you cannot make any other improvements. This does not mean that it is impossible to make changes before 5S is fulfilled but should serve as a reminder that it is an important factor to consider.

2.1.6 Standardised work

Standardisation is a necessity for continuous improvement and quality. Before continuous improvement can be applied to a process it has to be standardised and stabilized. Otherwise the improvements that are implemented will only appear as random increases in the productivity and not made clear due to the constant ups and downs of an unstable process. Standardisation is a way of describing the safest, easiest, and most effective way of doing the job that is currently known. Figure 4 tries to illustrate the importance of standardisation in relation to continuous improvement. Instead of making drastic changes improvements should be implemented in small increments and standardised at every level provided they had a positive effect. This will create a lasting improvement and a stable process. (Liker, 2004)

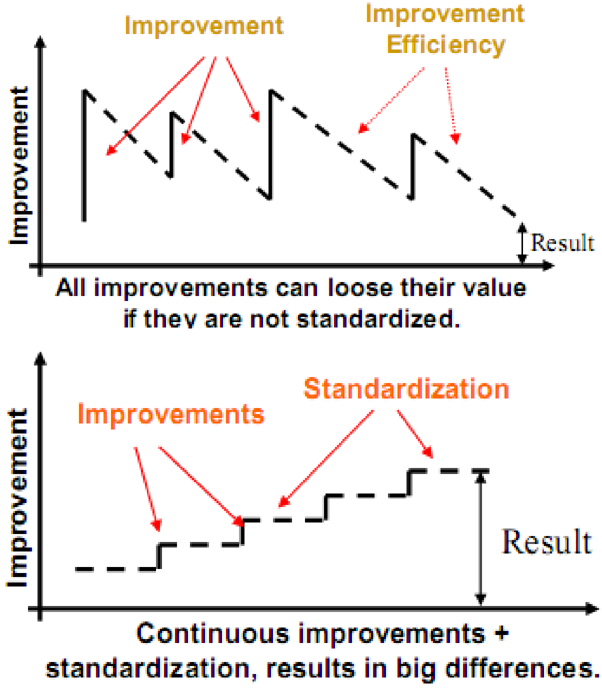


Figure 4: Differences between improvements with and without standardisation (Volvo, 2009c)

As implied by the statements above standardisation brings several positive effects with its implementation. Pascal (2007) mentions seven benefits that come from standardised work.

1. **Process stability:** Stability means that we have a predictable output that will conform to set standards in terms of quality, cost, lead time, and safety just to name a few.
2. **Clear stop and start points for each process:** This enables a quick overview on how the overall production is moving along since it makes it easy to see of certain processes are falling behind or if they are moving ahead to quick.
3. **Organizational learning:** Standardised work leads to widespread knowledge within the company. This in turn alleviates the difficulty of replacing workers with specialist knowledge since a standardised process has clear instructions that any new worker should be able to follow.
4. **Audit and problem solving:** Standardised work makes it possible to map out the current condition and identify the problems.
5. **Employee involvement and poka-yoke:** Since the process is standardised the room for error is reduced. Moreover, workers involved in the process are themselves able to come up with improvement suggestions.
6. **Continuous improvement:** Standardised work is the foundation from which continuous improvement can be built upon as described earlier.
7. **Training:** Standardised work provides a platform where the training of employees is made easier. This in turn makes adaptation to shifting demand and production changes quicker and the response time is lowered.

2.1.7 Just-in-time

Just-in-time (JIT) means producing the right amount of items at the right time, anything else is waste. JIT is not just a word however; it is a concept and a set of tools and techniques that can be used to create items in small quantities, resulting in shorter lead times in line with customer demand. When implemented correctly JIT allows for, as mentioned, delivery of the right items at the right time and in the right quantity as further concluded by Matson and Matson (2007). Four rules are mentioned in Pascal (2007) that JIT production should follow:

1. Don't produce something unless the customer has ordered it.
2. Level demand so that work may proceed smoothly throughout the plant.
3. Link all processes to customer demand through simple visual tools (called kanbans).
4. Maximize the flexibility of people and machinery.

The power of JIT is best explained with a short example taken from Pascal (2007). By applying Little's law, Equation 1, which is a fundamental equation that is applicable in both manufacturing and service industries, a good ground for implementing JIT can be understood.

$$\text{Cycle time} = \frac{\text{Work in progress}}{\text{Throughput}} \Rightarrow \text{Throughput} = \frac{\text{Work in progress}}{\text{Cycle time}} \qquad \text{(Equation 1)}$$

Where the *throughput* is the average output from the process per unit time. The *cycle time* is the average time it takes for a part from the point it enters the specific station or working area until it is passed on to the next operation. *Work in progress* is the total number of working pieces that exists between the starting point and the ending point.

A number of implications can be drawn from the example above. First of all if the capacity of the area is fixed there is a proportional relation between cycle time and WIP. Second, if WIP is increased throughput will increase as is the case in mass production. On the other hand if cycle time is reduced throughput is increased, in line with lean principles. Third, if we have no WIP there will be no throughput, meaning buffers are a necessity.

A framework for analysing the implementation of JIT is presented in Matsui (2007) where nine measurement scales are used together with a combined super-scale to enable different companies to evaluate the requirements of JIT and role of JIT systems. This can then be used to compare different companies and how far they have reached in their JIT implementation.

In order to be able to implement JIT materials handling and processes many of the lean tools needs to be utilised. Levelled production and standardised work as described before lays the foundation, quality control measures, described later, ensures errors are not passed on and lastly the methods of kitting and kanban materials handling together with continuous flow and pull production will be described in the following section.

Continuous flow

To enable the implementation of JIT the concepts of continuous flow and pull production is useful if not a prerequisite. The main idea of a continuous flow is to streamline the process from the raw material coming in to the finished products going out. This will lead to the best quality, and shortest delivery time (Liker, 2004). It is also often the case that continuous flow has the effect that other lean tools need to be implemented and used. A highly used example is that of “the Japanese sea” as seen in Figure 5. With a large inventory, illustrated by a high sea level, many problems can be mitigated or hidden. When a continuous flow is implemented with reduced inventory, as illustrated by lowering the sea level, it exposes other problems that are present in the production system.

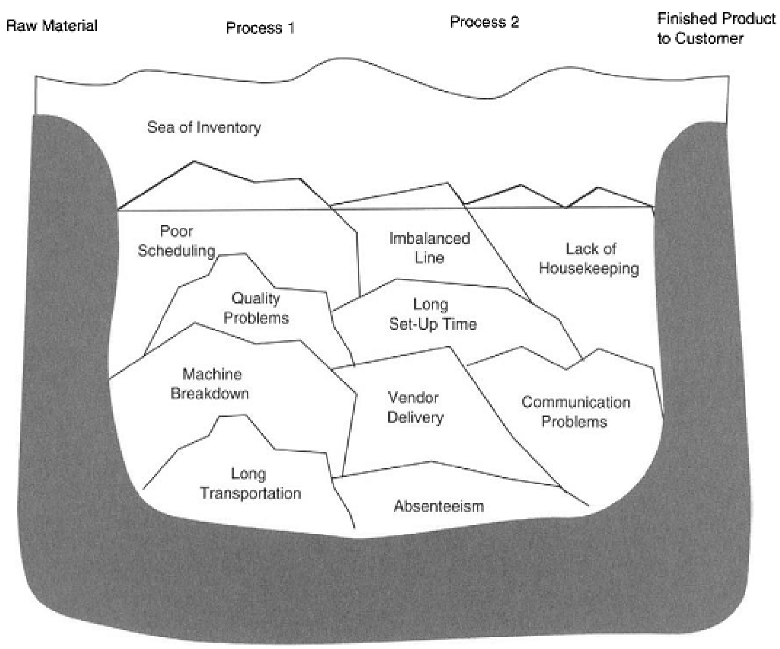


Figure 5: Sea of inventory hides the underlying problems in the process (Moore, 2007)

Continuous flow also helps in increasing prioritization in maintenance and repairs as a disturbance somewhere in the flow is directly affecting every other operation due to the one piece flow. Focus can then quickly be shifted to the problem area and remedied faster than with a traditional set up where problem areas might be hard to detect.

Pull production

To further build on the continuous flow concept, pull production can be used in order to reduce the risk of overproduction. Instead of the traditional mass production approach where production is carried out according to a set schedule a pull system only produces what the customer has ordered. In the most extreme case using a continuous one piece flow as described above a pull system taking in a customer order would produce only one product with no inventory what so ever, constituting the most lean system imaginable. This is also the ideal state of a JIT implementation. However resources and materials flow can't be expected to operate every single time instance making a certain degree of inventory a necessity for maintaining a stable output (Liker, 2004). An illustration of a pull system is shown in Figure 6.

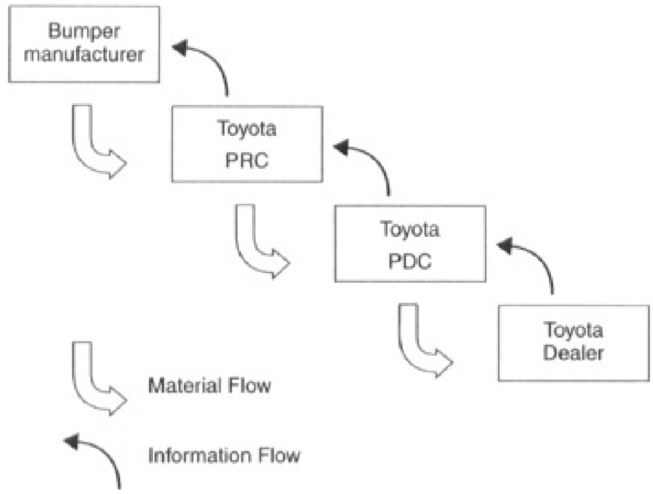


Figure 6: Pull production where the chain of events is initiated at the dealer (Pascal, 2007)

Kanban

A Kanban is in its original form a card that is used to implement JIT production. A Kanban is an authorization to produce or withdraw items and can also contain information such as where the item should be placed or who the customer is. Kanban's have since evolved and can take many forms, whether it is a vinyl card or an electrical signal or some other form of information passing. (Pascal, 2007)

The basic idea is that once material is used or consumed in the process a Kanban signal is sent to the warehouse or logistics department informing them of what particular part needs replenishment. This approach has several advantages over traditional scheduling and materials planning. First of all the resources previously attached to these tasks can be freed up and instead used for problem solving and process improvement. Second an implementation of a Kanban system has several other positive effects such as reduced inventory, reduced risk of over production, places the control at the operations level, improves flow, improves responsiveness to change in demand, minimizes the risk of inventory obsolescence and finally it creates visual scheduling and management of the process. (Gross and McInnis, 2003)

Figure 7 shows the basic idea behind a move Kanban system. When the pallet is empty or when the first item has been picked the Kanban card is released (Step 1). The card is moved to the supplying unit (Step 2) which is now authorized to supply a new pallet to the consuming unit (Step 3). The card is attached to the pallet before delivery to the consuming unit.

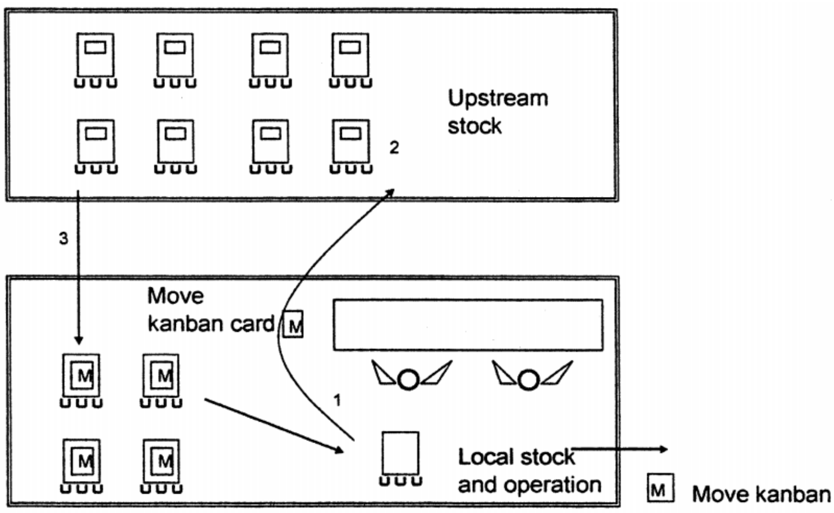


Figure 7: A three step Kanban system used to coordinate logistics (Jonsson and Mattsson, 2008)

Kitting

Kitting is another strategy of materials handling and is commonly used in a high variation low-volume manufacturing process. The idea behind kitting is that all the material needed to complete a certain operation is made available beforehand. The parts are usually supplied in either racks or specially constructed trolleys where the material is organised. The underlying reason being that in a high variation manufacturing process all the parts needed to cover the entire model spectrum would take up too much space and make replenishment almost impossible. It is often the case that small materials such as nuts and bolts are restocked using normal replenishment procedures whilst the actual parts are kitted. (Lane, 2007)

Kitting also contributes to reduced movement waste as the operator gets everything he needs directly or at least in close vicinity to his working area instead of wandering around looking for material. Furthermore kitting comes with a built in error prevention, Poka-yoke explained later, since the operator gets exactly the parts he needs for his operation. If something is missing or parts are left over when the task is finished it directly gives provides feedback that something is wrong.

2.1.8 Built in quality control

Built in quality control, or *jidoka*, is a philosophy that constitutes one of the cornerstones of the VPS model. It is based on the idea that the best quality comes from manufacturing the right things the first time. Without a low defect ratio other tools like JIT stops functioning correctly and line stoppages will occur frequently both disturbing the flow and the process stability. Resupply systems using Kanban and Kitting will collapse if defective items are delivered. (Pascal, 2007)

The most important aspect is that no error should be passed forward in the production chain. Instead the every operator has the ability to stop the process as soon as a fault is detected. The quote “Stop production so that production never has to stop” is well known and describes built in quality control in a good way. By delegating responsibility of quality to the operator they will feel that they are needed and that in turn will make them perform their job better. This also means that traditional quality control people such as supervisors can be reallocated to instead fix the problems that occur. Several methods to exist to achieve built in quality, two of the most well known are Poka-yoke and visual control.

Poka-yoke

Poka-yoke is as many other terms in the lean concept inherited from the Japanese language. *Poka* means inadvertent error and *yoke* means prevention. Poka-yokes should be simple and inexpensive countermeasure that prevents errors from occurring or stops the process once a fault has been detected. The main idea behind Poka-yokes is that no faults should be passed on to the next stage in the process which will eventually lead to defect products. Errors and faults are inevitable as machines and people can never perform a perfect job in all situations. The sooner the fault can be detected the less risk it is that it escalates through the production flow eventually causing a defect. Therefore in the manufacturing industry Poka-yokes are installed in different areas to prevent these things from happening thus aiding the concepts of JIT and stable processes. (Santos et al., 2006)

Three forms of Poka-yokes are mentioned in (Volvo, 2009c). First is a Poka-yoke that enables control, which means that errors and defects cannot pass on to the next stage in the process. Second are Poka-yokes that execute shutdowns, when an error or defect is noticed the process is stopped. Third and last is the warning Poka-yoke that signals to the operator that an error or defect has occurred or is about to occur.

Visual control

Visual control is closely linked to the ideas of 5S and is any communication method that tells the worker quickly and efficiently how the process is performing or how a certain job should be performed. Many examples can be found in real life applications, traffic lights for instance is a visual control system that controls the traffic flow and hopefully makes the drivers aware when they are deviating from the standard. (Liker, 2004)

Some of the most commonly found visual control systems in assembly plants is the Kanban system of procuring material, described in section 2.1.7 - Kanban, another example is the Andon board which usually displays the production flow with coloured icons. An icon that is green is indicating that the station is operating as normal, orange means that a supervisor has been called to the station, red means the station has stopped and interrupted the flow.

Other examples include tool stands where shadows are painted behind the tools so that they are placed in the right position, in some cases even numbers are painted to distinguish in what order they are supposed to be used in. (Volvo, 2009c)

The underlying idea is that a visual control system should help in creating a transparent working environment building on the fact that what you cannot see you cannot control, what you cannot control you cannot avoid and what you cannot avoid you cannot improve. (Volvo, 2009c)

2.1.9 Future factory concept

The Future Factory Concept (FFC) is a strategy of how to build trucks within the entire global organisation as efficient as possible and with the same technique in all plants across the world. The strategy is focusing on re-use before re-engineering, fulfil the VPS-guidelines and develop an industrial structure that follows the commercial plan. This is to be done by working with five defined cornerstones; product, production process, logistics and supplier involvement, methods and systems, people management and organisations. Each of these cornerstones have focus areas, e.g. the development of the products shall be done by using physical modules with common interfaces that can be used to create variations within a completed truck. Within the production process the concept is to strive for a fishbone layout, with sub-assembly stations docked to the main line, which shall decrease the complexity of building variations but also give a more flexible production process. It also defines that the sequence of the production is an important factor that is developed within FFC: The idea is to build the truck from the inside and out with a layer on layer principle. FFC should start to be implemented 2011 and fully implemented 2015. This means that already now, new projects must consider the strategies of FFC. (Volvo, 2009b, Hessel and Lindeberg, 2008)

2.2 Stopwatch time study

One type of time studies is the stopwatch method which as the name states is when timings are taken by using a stopwatch. There are two different categories of this method; continuous and snapback. Continuous is when the stopwatch is running and the observer is noting the time of the stopwatch at each breakpoint for the operations. The time for each operation is calculated later by subtracting the start breakpoint of the operation with the endpoint. The snapback method is when each operation value is read directly from the stopwatch resetting the watch after each operation. When comparing the two methods against each other the advantages of the snapback method is that there is no need for subtracting and operations are easily compared even if they are done out of order by the operator. Continuous measurements are easier to conduct when the operations are shorter because of less work for the observer while doing the actual measurements. It is also more accepted by the union and the workers due to the complete picture that the recording is showing instead of just single times for each operation.

When doing stopwatch time studies it is necessary to rate the performance of the observed operator to get a fair picture when comparing data and setting standards. This process is conducted by the observer by analysing the operator before the time study begins and setting a rate. There are several different methods to set the rate and speed rating is chosen to be described below cause of its simplicity. The rate could be either a percent or a value between zero and one, where 100 percent or a value of one is the expected performance of an experienced operator. The formula is then the rating multiplied with the real time equals the standard time. The rate is set for the work that is done by the operator compared to if an experienced should have done exactly the same work. Praxis, according to Almström (2008) and Freivalds and Niebel (2009) a work rate of 100 percent is the same pace as dealing a deck of 52 cards to four piles, The rating procedure is probably one of the things that create most questions from critics because it is a subjective process. (Freivalds and Niebel, 2009)

2.3 Work sampling

Work sampling is a method that is used to investigate and map out the proportion of time different activities take in relation to the total time of an operation or work task. The resulting distribution gives an effective and good overview of what activities (such as personnel utilisation, value adding time and production standards) takes place and their relative size. It works in a similar way to traditional time studies and the result is often the same. However work sampling has the advantage that it takes considerably less time and therefore comes with a lower cost in terms of resource usage.

When carrying out a work sampling study a sufficiently large number of samples, explained below, is taken at random intervals. By categorizing the activities that take place the ratio between the value added work and the non-value added work is made visible or any other ratio that might be of interest such as personal time in relation to total working time or waiting time in relation to actual activity. The accuracy of the result is determined by the number of samples taken and the time range during which the samples have been collected. It is critical that the sample size is sufficiently large and that the times for the samples reflects all the activities that normally takes place, otherwise the data might produce inaccurate results. The work sampling method has several advantages over the conventional time study. (Freivalds and Niebel, 2009)

1. It does not require continuous observation by an analyst over a long time.
2. Clerical time is diminished.
3. The total work-hours expended by the analyst are usually much fewer.
4. The operator is not subject to long-period stopwatch observations.
5. Crew operations can be readily studied by a single analyst.

2.3.1 Basic theory

To be able to calculate the right amount of samples in order to get accurate results the underlying theory must be understood. Work sampling is based in the fundamental law of probability, meaning the occurrence of an activity is either present or not present, this is explained by Equation 2.

$$P(x) = \frac{n!}{x!(n-x)!} p^x q^{n-x} \qquad \text{(Equation 2)}$$

where p = probability of a single occurrence
$q = 1 - p$ = probability of non-occurrence
n = the number of observations

These probabilities are known as the binomial distribution with mean np and variance npq. As n increases and becomes large the binomial distribution will resemble the normal distribution in accordance with the central limit theorem. Since work sampling is made up of a large number of samples the normal distribution can be used as an approximation. (Freivalds and Niebel, 2009)

2.3.2 Calculating the number of samples

By using the normal distribution as an approximation the total number of samples that is required to be within a predetermined accuracy can be calculated. If a sample size n is used to estimate p we can assume that 95 percent of the time the samples will fall within the range $p \pm 1.96\sigma$. Therefore if p is the true probability of a task occurring we can expect the estimated $\hat{p}$ to be outside the limits only about 5 times out of 100. This can be used to calculate the sample size needed to achieve the desired accuracy according to Equation 3.

$$z = \pm a\sqrt{\frac{p(100-p)}{n}} \Rightarrow n = \left(\frac{a}{z}\right)^2 p(100-p) \qquad \text{(Equation 3)}$$

where n = the total number of observations.
a = coefficient of the desired confidence level. For 95percent accuracy, which is often considered enough the factor, is 1.96.
z = mean error in percent for an activity with the likelihood p. By choosing this beforehand the accuracy of the study can be predetermined.
p = likelihood of an occurrence of a certain activity in percent.

It is often the case that p is unknown when conducting the study, due to the tasks being new or that no data exists on old tasks, and therefore needs to be estimated. This can be done either by a simple finger-in-the-air estimation or by conducting a pre-study. The pre-study is usually conducted over one to three days where all activities are written down and the numbers of occurrences are accumulated. From this p can be estimated for different activities with more certainty than with the first approach.

The samples need to be collected at random, as mentioned earlier, in order to ascertain the statistical accuracy. There are a few approaches to this; either the sample times are randomized or the study objects are picked in a random order. A variation of the last one is that the study objects are selected at random but the samples are taken as often as the analyst can record them, reducing the time the analyst has to wait. (Ohlsson, 2008)

2.4 Spaghetti diagram

In order to evaluate how the layout of the station or production flow is utilised a spaghetti diagram can be used. By following the operators around when they are performing their tasks, whether it is assembly, cleaning, fetching tools or any other activity, a view of their movement is created. The operator's movement path is drawn on a schematic or floor-plan of the current layout of the area of interest. This gives a good and easy view of the movement patterns directly in relation to the current situation. If the resulting drawing is very messy with lines going in all different directions there is an indication that some parts of the layout can be rearranged, moved or taken away in order to decrease the time spent on non-value added activities. The method of spaghetti diagrams is easy and very straight forward, an example of a spaghetti diagram with different operator's movement can be seen in Figure 8.

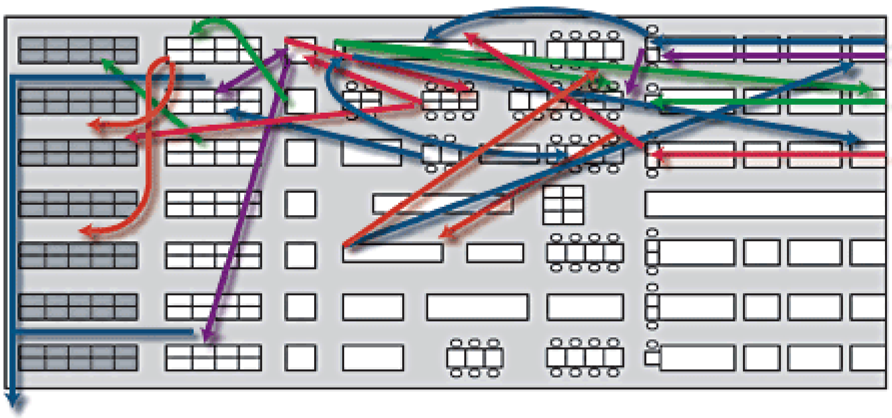


Figure 8: A spaghetti diagram showing different operators movement on the factory floor as they are carrying out their work

2.5 Methods engineering program

The Methods engineering program is a structured way to undertake an engineering task, independent if it is project to develop new product, improve an existing one or develop a process. The purpose of the program is to increase productivity and the quality of the product, which is an iterative process. Figure 9 presents the program and which steps to take. The following section describes each stage within the methods engineering program as described in Freivalds and Niebel (2009).

Select project

The first step is to identify the problem and the scope of the project, it is suggested that this is done by using Pareto, Fishbone, Gantt, PERT and worksite analysis. In this way the work is simplified and done in a logic sequence which is easy to understand and present to management.

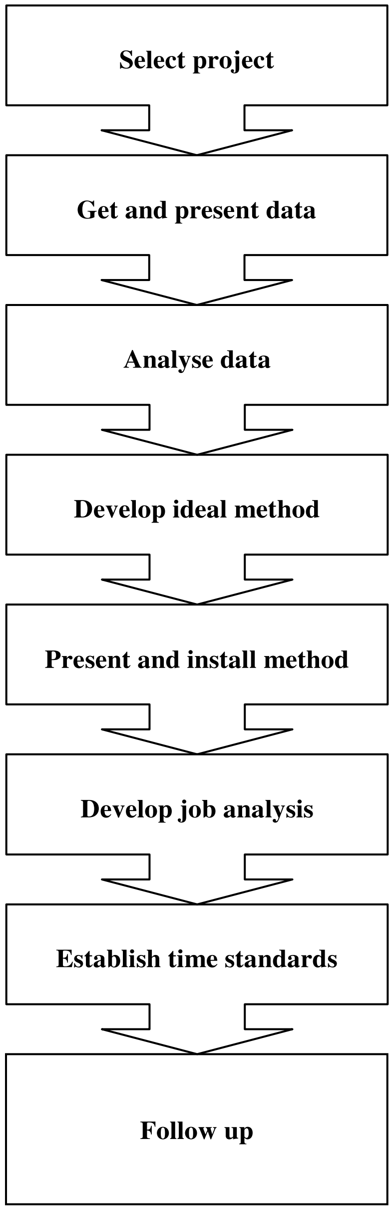


Figure 9: Steps in the Methods engineering program

Get and present data

When knowing the problem and what to look for, recording all data that could be interested for the analysis or the solution is to be conducted. The data could be everything between drawings to cycle times. This stage also includes structuring of the recorded data. Useful tools could be operation process chart, flow diagram or flow process chart.

Analyse data

The work to analyse every value adding and non-value adding operation, the layout, work breakdown structure (WBS) etc is done within this phase. By looking at the recorded data and asking questions such as why is this being done and why is it being done in that order etc, the analyst is starting to get an idea of how to minimize waste and simplify the problem. Much of the work done at this phase is conducted with lean manufacturing tools, e.g. seven wastes and 5S.

Develop ideal method

As the heading implies the best procedure for each function according to the project objectives should be developed. When the questions in the previous phase is answered more question is normally popping up, e.g. how can this be performed better and where is this best mounted. Answering these new questions with different tools, e.g. line balancing, VSM, an ideal method is generated.

Present and install method

The analyst now needs to sell the suggestions to management and operator. By involving people the resistance to change normally decreases and the suggestions is reworked once more to ensure that the details are correct.

Develop job analysis

After the implementation is done a new job analysis needs to be done to confirm that the implementation is giving the result as wanted. The analyst should take into consideration if the right worker is on the right position, the work environment, job descriptions etc.

Establish time standards

When the new method is stabilized and has passed its ramp up-time, time studies should be conducted to set a standard. This is done with suitable tools, e.g. work sampling, method time measurement (MTM) or stopwatch time studies.

Follow up

When all changes are implemented it is important to control that they are kept that way and not changed back to the origin, both the actual changes and the expected result. It is also at this stage you look into what kind of improvements could be done for further development.

2.6 MPU

According to Almström (2008), Laine and Elg (2006) and Ohlsson (2008) productivity may be measured with three factors, Method, Performance and Utilisation, which is the MPU method. The MPU method is based on two different concepts, Methods Design Concept (MDC) and Concept for Activating Performance (CAP) (Laine and Elg, 2006, Helmrich, 2008). The Method part of MPU is based on MDC which is about technical development while Performance and Utilisation is based on CAP. CAP is more concerning the objectives for Performance and Utilisation and how to reach them.

Method is how the work is done, in what sequence, tools, work content, distance to material etc. Laine and Elg (2006) and Ohlsson (2008) have defined it as how smart the work is done. According to Almström (2008) this is the factor within the MPU method that has the greatest potential for improvements. By using the best known assembly method the improvement potential is normally 10 to 50 percent but it almost always includes investments. The value for Method is calculated by just looking at the work, not personal time etc, and calculate how long time it takes originally. Then, by asking “How can the working method be made smarter?” a new time is calculated that can be reached with feasible improvements. Original time divided by feasible time equals the feasible increase in Method.

Performance is how fast and with what accuracy the work is done depending on work environment and complexity factor. Standard time is usually defined as 100 percent and is the same pace as dividing a deck of cards into four equally large piles in 30 seconds (Almström, 2008). Performance could be affected by training, motivation or support (Helmrich, 2008). The performance is normally less than 100 percent but most often only has a potential of about 0 to 20 percent.

To set a value of Performance an analysis of the work pace has to be done, either by computer software or by visual judgement (PPA).

Utilisation is defined by Ohlsson (2008) as how large the share of a working day that is spent doing value adding work. The U-value is most easily calculated by using some sort of time study, e.g. work sampling.

When all three factors are calculated the improvement in productivity is set by multiplying all three values, M, P and U. See Equation 4.

$$Productivity = M \times P \times U \qquad \text{(Equation 4)}$$

2.7 Hawthorne effect

The Hawthorne effect is the result of a study done by Elton Mayo at the Hawthorne works of the Western electric company, Chicago between 1924 and 1932. One experiment was conducted by changing number and lengths of breaks together with working hours per day. This experiment was done with six workers and one supervisor that were picked from the regular work force of around 100 workers. The changes were made with more breaks, longer breaks, shorter working days and the last change was to set it all back to normal again. The result was that the output reached the top when changing back to normal conditions. The conclusions were that when the workers were selected their self esteem increased. The motivation also increased because they felt important when the supervisor had a personal interest in their work and communication with the management was important for the feeling of being required. (Åhlström, 2004)

One definition of the Hawthorne effect is

"An experimental effect in the direction expected but not for the reason expected; i.e. a significant positive effect that turns out to have no causal basis in the theoretical motivation for the intervention, but is apparently due to the effect on the participants of knowing themselves to be studied in connection with the outcomes measured." (Draper, 2008)

However, Liker (2004) describes this problem in the opposite way. At first, when mass production was implemented everywhere, together with an army of production engineers doing time studies, workers tried to help the engineers to increase the productivity. But as time went on the workers noticed that they worked more for the same wage which made them suspicious and they started to slow down the work pace whenever the production engineers where observing to set the expectations low. (Liker, 2004)

3 Method

This chapter will describe the method used to carry out and guide the project. This includes an explanation of how the work is performed, in what sequence and what different stages that exists.

To be able to get a good insight in how the problem could be solved a pre-study in the pipe and valve area in Volvo Trucks Tuve is done together with literature studies within the subject. The pre-study in Tuve is done for five days studying VPS and the material and information flow. The study is a mix of observing the process, reading literature and having seminars with experts within the different areas.

When conducting this project a method based on the methods engineering program described in Freivalds and Niebel (2009) is used. This chapter is divided into the five first stages of the model with a descriptive text of what this project went through to reach the target for each stage. The last three stages, Develop job analysis, Establish time standards and Follow up is outside this project's boundaries. Every project within Volvo is supposed to use the concept of VPS and several of the VPS tools are used and described in following stages.

3.1 *Stage 1* - Select project

The first stage in a project is to learn the problems and the project environment. This chapter presents what tools that are used within this project and how the main problems are identified.

3.1.1 Worksite analysis

The first tool that is used in this investigation is the worksite analysis which will give a brief idea of what type of problems that exists within the specific area and gives a hint of what kind of tools that should be used later on. This analysis is done by observing the worksite for two days and writing down notes of things that comes to mind. This can be questions such as "How long time does it take to cut all pipes for one truck?" or reflections such as "Low utilisation of workers after finishing a chassis, can talk for up to twenty minutes." This is sort of a brainstorming with the eyes which is the base of a Fishbone diagram that is formed later.

3.1.2 Fishbone diagram

A fishbone diagram, Appendix A – Fishbone diagram, is formed using the categories humans, environmental, materials and equipment, methods and management. The fishbone diagram is then used, in a structured way, to identify the most important issues that the project should focus on. It also gives an overview of what is causing what.

3.2 Stage 2 - Get and present data

At this time in the project it is suggested by the model to collect all necessary data and gather it in a structured way to be able to make an analysis later on. Several methods are suggested, such as Flow diagram and Flow process chart, but this project is using VPS tools instead to get the same result and the different methods are similar.

3.2.1 Spaghetti diagram

One spaghetti diagram is drawn for each place of parked chassis within the area of interest, disregarding if Mack or Volvo is produced. The purpose of the spaghetti diagram, to show the pattern of movements, is still reached because the differences of movements between the two brands are not that big. The process of piping is separated into several diagrams because the chassis are in different locations these operations are performed.

3.2.2 Time studies

To be able to analyse waste within the production some sort of time study must be performed and it's decided that stopwatch time studies and work sampling are going to be performed. The purpose is to find out the different tasks performed within the areas together with the actual work content needed. Lead times within the areas are also collected to be used in the continued analysis work.

Lead times

To be able to analyse WIP, VSM and other models the lead times need to be calculated which is done by manual time measurements of chassis from entering the area until it exits. The potential buffers in the beginning and end of the valve and pipe area are also selected to be measured to be able to do a rough calculation of the buffer sizes. This is done by noting the time when a chassis is entering and leaving such buffers, see Appendix C – Lead times. The study is conducted over the course of 18 days and 101 chassis in total is observed whereof 38 Volvo and 63 Mack.

Stopwatch time study

The stopwatch time study is suited for processes with any length of cycle time and large variations of the product (Freivalds and Niebel, 2009). This is the case according to our observations in the area of concern. These studies are done with the continuous method by following one chassis through each process, not an operator, with the purpose to note how much working time each process stage is adding, see Appendix E – Time study data. This means that if an operator is working on the chassis being observed he is recorded, but if he changes chassis and another operator takes over his work the second operator is recorded. This will give suitable data regarding the work content to be used later on and also some data for waste analysis.

The stopwatch time study is done for three cycles for each process which is recommended by Freivalds and Niebel (2009) to get a reasonable result. It is observed that for each stage in the process there is one brand that is more or less difficult to produce. To be able to handle this within the stopwatch time study every process that is observed to take longer time when producing Volvo is studied twice with Volvo production and once with Mack production. Likewise for the processes that takes longer time when producing Mack.

Work sampling

The work sampling method is used when there is a large variation between the cycles and data for interruptions and utilisation is needed (Freivalds and Niebel, 2009). This is a good description of the area for this project. The data collected from the work sampling will give a result that can be used to analyse different waste and also answer how much of the time of a working day is spent on different operations. The difference to the stopwatch time study is that the work sampling is not that detailed, meaning it is divided into larger groups of operations, which will, together with the stopwatch time study, complete the picture. The work sampling begins with a pre-study which includes one day of sampling the work (879 samples in valve area and 1157 samples in pipe area) in the two areas of valve and pipe. It is decided that these two areas are separated because of the large differences in the work tasks. The two brands are not separated in this study because it is estimated that the work pattern is quiet the same independent of brand. The workload will differ but that is the case between different variations within the same brand as well, which therefore will be considered in the analysis instead. The pre-study is basic data for the calculation of the total samples that will be collected and gives an idea of what operations to sample. When decided which operation or operations to focus on and with what accuracy the calculation of how many samples that must be taken can be done. From the pre-study following operations were discovered.

- **Assembly:** In the assembly activity, all operations that directly relates to components being mounted to the chassis are counted. Included are also tightening bolts, mounting protective tape, securing components with zip-ties and routing pipes.
- **Handling tools:** This includes all activities related to handling the different tools that are used in the operations. For instance grabbing a zip-tie gun. Also, fetching air-pressure nozzles to be able to use the tools and changing settings of the tools are included.
- **Materials handling:** All activities related to handling material at the work area. Removing packaging, fetching items from blue boxes containing material, cutting and sorting pipes, changing pipe rolls in the reels, fetching nuts and bolts and removing plastic bags around zip-ties are some examples of activities included.

- **Moving chassis:** When an operator has interrupted his work in order to move chassis within the valve or pipe area.
- **Administrative work:** When an operator is using the computer to look at order specifications, assembly instructions, S-notes or checking other information relevant to the task. Included is also writing information on white-boards, talking to section leaders and supervisors.
- **Help each other (piping only):** This category is only used in the piping study and includes every activity related to teaching co-workers on how to perform the job, whether it is giving them instructions or by actually showing them how to do.
- **Located in pipe area (valve only):** When an operator that is supposed to be working in the valve area is instead located in the pipe area.
- **Cleaning:** Every activity related to cleaning like throwing away empty boxes, sweeping the floor or picking up left over scrap material from the floor.
- **Unrelated talking:** Whenever an operator is talking to another operator or someone else regarding things that are unrelated to the completion of their work.
- **Moving:** When an operator is walking within their working area, for instance to fetch material or move to another chassis or walking around to find something to do.
- **Personal time:** This includes the time spent on activities not related to work such as bathroom visits, smoking, eating and drinking that is not performed during the normal breaks.
- **Idle:** When an operator is idle, either due to not having any work or when waiting for someone else to finish their work to be able to start. Also included is when operators are idle even though they have work to do.
- **Other:** This includes all activities that do not fit into any of the categories above.

The number of samples for the main study was calculated by setting a desired level of the mean error and then calculating the number of samples using Equation 3 chapter 5.4 - Work sampling. The number of samples was set to 5000 for both the valve and the pipe area. This means that every activity with an expected occurrence of more than 3.5 percent will get a relative deviation of less than 15percent.

The rest of the 5000 samples are collected over sixteen following days in randomized time. Each day approximately 275 samples for the pipe area and 200 samples for the valve area are collected. The randomization of time lies in that the samples are collected when one of the project team members has time.

To randomize whom and in which order to collect samples a list with values from one to five at each position (275 positions for the pipe area and 200 for valve area) is randomized with the function rand() in Microsoft Excel. Each value is connected with one operator that is randomly selected with the rand() function in Microsoft Excel. Five of five operators in the valve area and five of seventeen in the pipe area are selected.

3.2.3 Interviews

To get more qualitative data compared to the quantitative data described above interviews are conducted with six operators from production and one from the office. The criteria for selecting the ones to be interviewed are that they should have good knowledge of their area and be willing to share their thoughts. From each major operation within the valve and pipe area one operator is interviewed. The area is divided into valve assembly, harnessing, Mack-piping and Volvo-piping which gives four of the operators. Two more are selected because of their wide general knowledge of either the valve area or the pipe area. The interview questions are open questions with the purpose to start a discussion, see Appendix G – Transcription of interviews, and are planned to keep the interview going for approximately 30-45 minutes.

3.2.4 Work breakdown structure

A WBS is constructed, one for piping and one for the valve assembly, by the project team members in the end of the data collection. This since at this time the knowledge of the process is high enough. The WBS is presented and completed together with the persons being interviewed and the two section leaders for the area. In this way the structure should include all operations that are supposed to be done within the valve and pipe area. The purpose for this is to have a common view of what is happening in more detail at the work stations in the area.

3.2.5 VSM of current state

Compared to WBS, VSM helps to understand the overall picture of the process with everything between the work stations as well. A draft of one VSM for Volvo and one for Mack is done by the project group team members. It is done by using pen, paper and a stopwatch following chassis flow upstream to make a sketch of the process. This creates a snapshot of the process and could differ from time to time. The result is presented to Material engineer David Curtis and at the interviews with the two persons from production with wide common knowledge. The two models are changed to reach a common view of the overall process.

3.2.6 Data collection from various sources

Different kind of small data is collected from the organisation overall. Such sources can be persons from another department within the plant, persons working in another plant but within the valve assembly and pipe area but also records kept within the computer network.

3.2.7 MPU

To be able to analyse the improvement potential, the result of MPU, collected data from above is used to state the three current values of M, P, and U. The method value is calculated by using the data from the work sampling and time study. By just looking at the time when the operator is actually working, i.e. reducing time such as personal time etc, a current value could be estimated. The performance value is calculated by observing the pace of the work and estimating the skill level of the workers. Utilisation is set by using the data of the work sampling by calculating the actual working time compared to one work day.

3.3 Stage 3 - Analyse data

In reality the analysis is done over a long period of time because when data is collected questions like "Why is it like this?" are asked. This means that stage three has already begun before ending stage two. By then summarising the data collected in tables that can easily be reviewed, a pattern can be interpreted. When the analysis is done the VPS principles, see Figure 2 chapter 2.1 - Volvo Production System, is used as a base. This would help the project group identify which principle, and problem, to address. By then choosing from the tools connected to the identified principle the data is analysed in a structured way.

3.4 Stage 4 - Develop the ideal method

When the project group is developing the ideal system several different methods are to be used to decide which of the solutions that should be used. The last stage resulted in several suggestions of how to solve the problem and achieve the objectives presented. By then using tools like line balancing and VSM, to name a few, the ideal method could be selected. Discussions with the reference group and within the project team is also a tool that frequently is used, for instance when selecting which layout to choose. The systems considered are compared with the objectives for the project during the whole process.

3.4.1 MPU

The improvement potential is calculated by using the three current values that is presented in 5.10 - MPU and the analysed data. This results in an estimation of the potential for each value. By than using the current and potential values the MPU value is calculated, Equation 5.

$$Method = \frac{time\ with\ current\ method}{time\ after\ improvements\ implemented}$$

$$Performance = \frac{work\ pace\ after\ improvements\ implemented}{work\ pace\ with\ current\ method}$$

$$Utilization = \frac{utilization\ level\ after\ improvements\ implemented}{utilization\ level\ with\ current\ method}$$

$$Productivity = Method \times Performance \times Utilization$$

(Equation 5)

3.5 Stage 5 – Present and install method

The final solution is now presented as a future immediate state and a future ideal state. The immediate state is suggested to be implemented within two to three months and the goal for the ideal state is to reached within one year.

4 Current state

This chapter will describe and explain the current situation in the valve and pipe area. It covers the layout and how the work is organized and what problems exist in the two areas. Information is taken from the interviews mainly, but also from observations gathered by observing the processes.

The levelling of production today is done by logistics at two different levels. The first levelling is done when deciding how many Volvo and how many Mack that should be produced each week. This decision is based on order income and not that much on how the production should be levelled. The second levelling is based on if the variation is heavy, number of axels and if a sleeping cab is to be mounted. This means that the areas considered when levelling is the trim line and pipe and valve area.

Common for both the valve area and the pipe area is the way the chassis are moved. In most cases one or two electrically powered tuggers is used to move the chassis. The tuggers are secured in the chassis dollies and require one operator for each of the tuggers. Therefore in the ideal case only two operators should be needed to move one chassis. However there are not enough tuggers to support the movement of several chassis and they move very slowly. This means that if the tuggers available are used to move a chassis in the valve area, or if they are simply located in the valve area, the pipe area will have to move their chassis without any help. This means that more than two operators are needed, often six to eight, which causes a lot of interruption to their work.

4.1 Valve area

The valve assembly area is located after the chassis have been painted and dried in a heating oven. The area is currently manned by three and a half operators together with one operator that handles the sub-assembly of the valves. The process is similar for both Mack and Volvo with the difference that Mack is somewhat more work intensive as the brake hoses are fitted in the valve area on Mack as opposed to Volvo where they are fitted in the pipe area. Generally the area is disorganised with a lot of things lying around making the work area cluttered and hard to overview. There are toolboxes and cabinets that are hardly used, the few times they are used the tools located inside and actually needed are mixed with tools that are never used.

The sub-assembly and the mounting of the valves will be described in more detail in the following sections.

4.1.1 Sub-assembly

The sub-assembly of the valves consists of two workbenches, one for assembling the Volvo valves and the other for the Mack valves. The station layout can be seen in Figure 10. On both sides of the workbenches there are several boxes with small parts needed for assembling the valves, such as fittings, nuts and bolts. Opposite the workbenches is a computer together with the carrier that contains the valve-kits for different chassis.

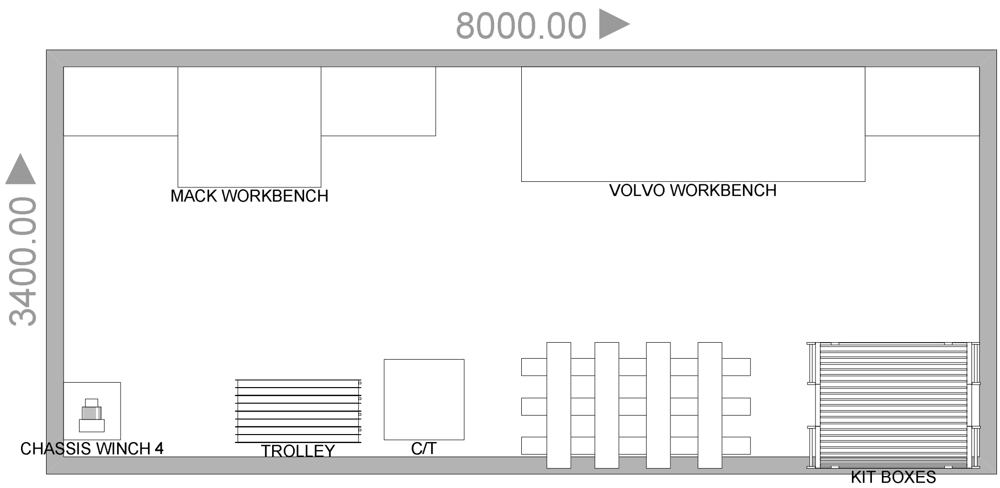


Figure 10: Station layout of the valve sub-assembly

The first thing that takes place when the valves for a new chassis are to be assembled is that the operator checks the computer. By entering the chassis number a list of all the parts needed is displayed. The operator writes this information down on a piece of paper and plans how he is going to carry out his work. An empty blue box is placed at the workbench where the finished valves will be placed. The operator then moves over to the carrier to get the valve-kit and then proceeds with assembling the valves. The unassembled valves for each chassis are contained in a blue box where all material except small parts is also included. This means that once the operator is finished with one chassis the blue box should be empty which provides some means of error proofing.

The supply of material to the station is delivered in carriers containing valves for eight trucks at a time, the current daily production volume. The operator has the ability to order additional picks meaning there is no real restriction to the amount of chassis he can produce during the day. This sometimes causes inventory build-up, particularly for the air-filters for which there is often an inventory of a few days of production.

In this area the battery box is also sub-assembled if the chassis is supposed to be equipped with one. This is taken care of by one additional operator that only works with sub-assembling and mounting the battery box to the chassis. Once the battery box is complete it is usually mounted to the chassis in the pipe area.

Also located in this area is Station 120, which is a pre-cutting station for pipes that are used at the different mainlines. The operator working at this station shares the work load between Station 120 and working in the valve area mounting valves. This creates inconsistency in the manning when mounting valves together with creating a very uneven distribution of work at Station 120.

4.1.2 Mounting of valves

The area where the valves get mounted to the chassis is located after the oven that dries the chassis after painting. The layout of the valve area can be seen in Figure 11. On the left hand side there are several pallets and blue boxes containing brake hoses and air-filters. There is however a large amount of other material that during the observations was never used. This extra material takes up unnecessary space and clutters the working area. On the lower part of the area there is a computer used for checking order specifications and other information related to the chassis. There is also a workbench that is used to store tools and sub-assemble certain valves. On the left hand side of the workbench is a storage of small parts that contains items needed for both the sub-assembly at the workbench but also nuts and bolts for mounting the valves to the chassis. On the right side of the workbench is an inventory of other parts such as edge protection and protective tape.

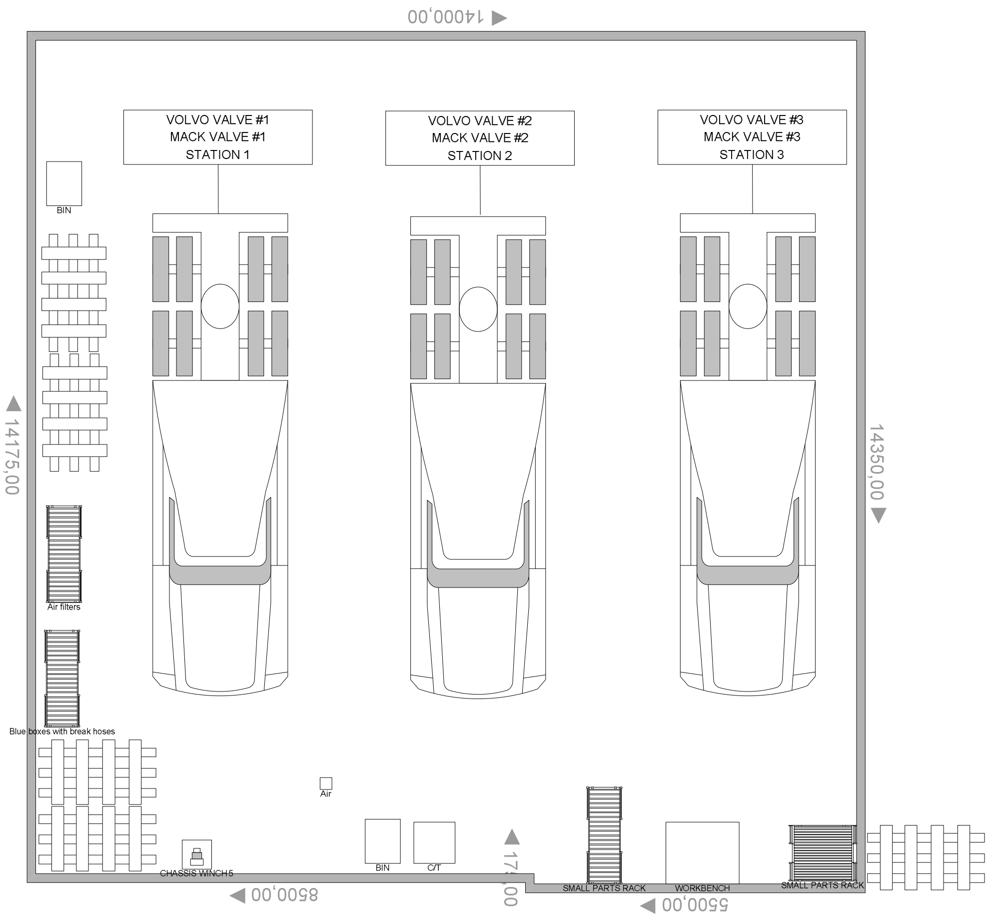


Figure 11: Station layout of the valve assembly area

Currently there is no defined way of working in the valve area regarding what tasks are to be performed, in what order and by what operator. It is up to the operators themselves to distribute the work and make sure that the chassis are finished when they are to be moved into the pipe area. This sometimes creates confusion as they need to look at the chassis when they are working on it to see what has already been done. Despite this the operators are usually carrying out their work using roughly the same sequence of events.

The work that takes place in the valve area can be seen in the WBS in Table 3 chapter 5.2 - Work breakdown structure. The first thing that happens when a chassis is finished in the oven is that one of the operators, using the winch located straight across from the oven door, moves the chassis out of the oven and into the valve area. The chassis should be left to cool off for 10-20 minutes but the operators have found that it is easier to remove the masking, which has been applied in the paint booth to protect certain bolts and mounting places, from the chassis when the paint has not entirely settled.

Therefore the operator that moves the chassis out of the oven starts directly with removing the masking. After this is finished the cooling time has in most cases passed and the operator starts mounting the different valves. The valves needed for a particular chassis is fetched from the kit-box prepared by the sub-assembly. Usually the box is fetched and placed on the chassis in order to have closer access to the material. However the operator still needs to move back and forth to the workbench in order to fetch nuts, bolts and tools needed to mount the valves. The operator usually stays with the chassis and continues to mount valves until it is time to move the chassis.

When the chassis has been moved one step further the first operator usually continues mounting valves until it is time to move another chassis out of the oven. At this point the other operators are usually finished with the chassis one step ahead in the sequence and start to work on the current chassis. It has been expressed that the way they are trying to work is that the first operator mounts the valves in the front, the second operator works on the middle part of the chassis and the third operator works in the rear part. However since the workload differs substantially between chassis this is not something that can often be identified and as a result the operators are usually working on several parts of the chassis. At this second stage the chassis usually gets finished and when it is time to move it is placed in a buffer slot before eventually being moved into the pipe area.

There are some differences between the Volvo valve and the Mack valve process. The Mack is equipped with what is called a trailer bar. When the chassis comes out of the oven the trailer bar has to be dismounted from the chassis and sub-assembled with valves at the workbench by the operators and then remounted on the chassis. Another difference is that the brake pipes are mounted at the valve station for the Mack trucks as opposed to the Volvo where they are mounted in the pipe area.

The material to the valve assembly area is mainly supplied by the sub-assembly through the blue boxes containing all the valves needed for each chassis together with the air-filters and hoses found at pallets on the left hand side as mentioned before. The small parts and the other material at the workbench are supplied by logistics whenever the inventory starts to get low. The small parts all have a two box buffer for each article and are replenished on a weekly basis; the other material follows the same procedure but is only kept with a one box buffer.

4.2 Pipe area

The pipe area is located between the two mainlines. In Figure 12 the Volvo and part of the Mack pipe area can be seen and in Figure 13 the rest of the Mack pipe area, furthermore in Figure 14 the arrangement of the Mack pipe area is shown when Volvo is being produced, why this is the case will be explained later. The layout is based around six stations of harnessing and piping together with an extra two chassis buffer for the Volvo mainline. The reason that there is a buffer before the Volvo mainline is that the Volvo piping is exceeding the Takt time. It is often the case that piping still needs to be done at the first station on the mainline, thus interfering with their work, as they have not been able to finish within their own area. Therefore to ensure that the Volvo mainline doesn't have to wait for the pipers to finish a buffer is used which is replenished using overtime. Furthermore the station layout doesn't really work like intended. This will be explained in the sections to come, but generally there exists no set of predefined working tasks at each station which basically turns the area into a work site without any sense of flow or standardised tasks. The current number of operators is 17 and the work distribution is somewhat different depending on what type of brand that is currently produced.

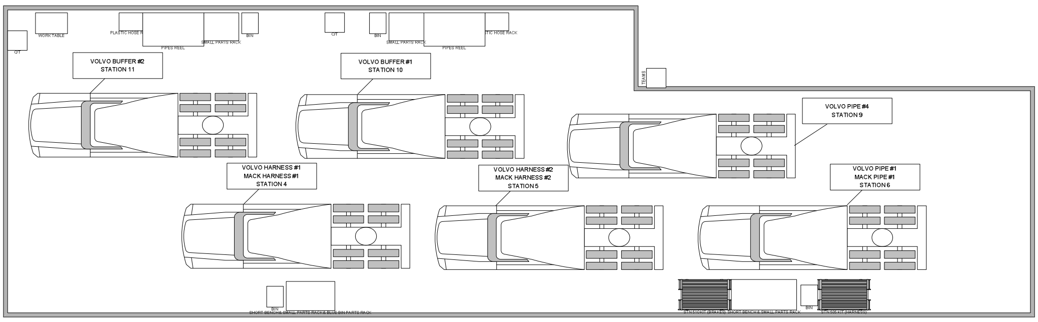


Figure 12: Layout of the area where harnesses get mounted and part of the piping gets done

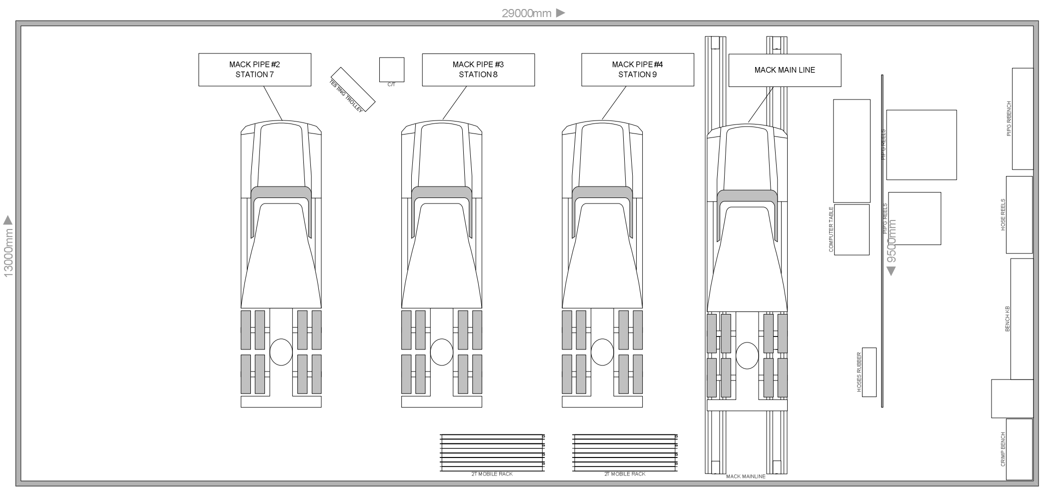


Figure 13: Mack pipe area as it looks when Mack is produced

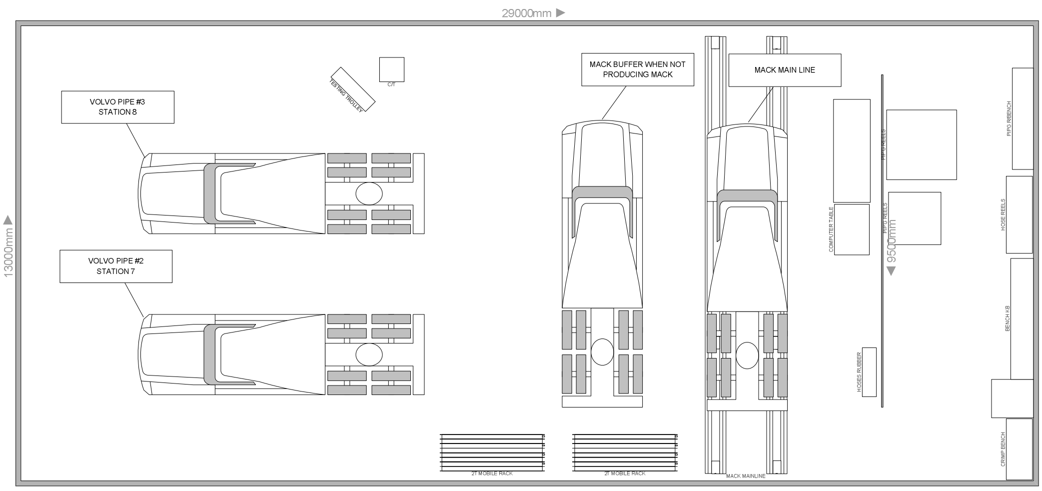


Figure 14: Mack pipe area as it looks when Volvo is produced

Another issue is that the valve assembly area described earlier generally has a shorter cycle time than the pipe area. This has the effect that chassis are constantly pushed over to the pipe area whenever there is free space which is causing unnecessary WIP and shortage of space. An additional side effect to this is that more time is needed to move the chassis when there is a greater WIP.

One of the larger issues currently present in the pipe area is design errors related to S-notes. The main reason behind this is the time consuming process that each detected error has to go through. When production notices that there is a problem with a customized solution, for instance a moved air tank can't be piped because a cross member is in the way, they contact the Production Engineering (PE) department. The PE department in turn contacts 3P which is responsible for the design of the customization. When 3P have reviewed the problem and reached a decision they go relay that information to PE which in turn informs production. This chain of information passing can sometimes take several hours whilst the chassis have to move further through the pipe area without any work being done.

Related to this there are the issues of brackets not being mounted at the chassis line (located before the oven) as well as valves that are not possible to mount. Both due to missing holes in the chassis frame. The result of this is that the pipes cannot be routed or secured properly which means that it needs to be fixed at some point, either by drilling the needed holes on the spot or by letting the truck go to rectification once finished.

The different areas of the pipe area will be explained in more detail in the following sections, divided into harnessing and brake pipes, Volvo piping and Mack piping.

4.2.1 Harnessing and brake pipes

The harnessing starts when the chassis arrives at the first slot in the pipe area. The process is somewhat different for the Mack compared to the Volvo therefore each will be described by itself.

The Volvo harnessing has been expressed as the more difficult of the two since the Volvo variants are usually more complex with more connections that need routing and it also has two harness bundles instead of one as for Mack. In addition to this the brake hoses also needs to be fitted, something that is completed on the Mack in the valve area as described before. There are three operators working on harnessing and one operator working on brake hoses. The harnessing starts with the operators fetching the harnesses they need for the particular chassis. These are found at the lower right side of the pipe area when looking at Figure 12 and are supplied as kits in blue boxes that contain all the material needed apart from zip-ties. This area is located far from the actual mounting area which causes unnecessary movement. The operators proceed by laying out the harnesses in the chassis rails to get an overview of how the actual routing is going to be done. After this the operators starts routing the harnesses and securing them to the brackets in the chassis rails with zip-ties. During this time the operators are fairly stationary, but they still need to climb out of the chassis at times to replenish their supply of zip-ties. The work is divided so that one operator harnesses the left side of the chassis and the other one harnesses the right side. When one of them is finished he proceeds and helps the other one until the harnessing of the chassis is finished. The work involved is very dependent on what type of variant it is, a short 6x4 tractor has little work content compared to an 8x4 rigid with a battery box. This means that the process time differs substantially between different trucks.

Parallel to the harnessing the brake hoses are mounted by one operator. The operator starts by fetching the material needed which is located in the same area as the harnesses. The hoses are delivered as kits in a blue box that also contains some electrical cables and other parts that are needed. Depending on what operator is carrying out the work the process looks different, why this is the case will be explained shortly. The main tasks however that needs to be done is to mount the fittings for the hoses in the chassis rail, mount the hoses and finally route and secure electrical cables from the brakes.

The harnessing on the Mack side is similar to the Volvo with the same amount of operators, which is three, but as mentioned before the work is easier. The main reason behind this is that the harnessing on the Mack only runs on one side of the chassis which effectively cuts the work in half. In addition to this the Mack has less connections and the harness bundle itself is more standardised than on the Volvo side where many of the trucks have unique harnesses.

The method of working is the same as on the Volvo but here the operators instead work on the same side of the rail, usually one starts in the front and the other one in the back and they meet in the middle.

The reason that the work is rarely carried out in the same way is that there exist no assembly instructions and there is no description as to what needs to be done and in what order, this is true for both the harnessing and the brake pipe mounting. Therefore the assembly sequence is entirely dependent on the operator and knowledge about the work content and sequence is simply passed on through the operators training each other. One problem is that the knowledge level and experience is currently low in the area which means that the process is taking longer than it should. When the harnesses and brake pipes are fitted the chassis is moved one slot in the area and the piping can begin.

The operator working with brake hoses when producing Volvo is assembling the power steering when Mack is produced. The power steering is assembled in the end of the Mack pipe area or at the Mack main line, i.e. depending on how the operator is organising the work.

4.2.2 Volvo piping

The Volvo piping begins at the chassis slot after the harnessing and brake hoses. Volvo piping is the biggest problem in the valve and pipe area and is constantly struggling to meet Takt time. There are a few main reasons why this is the case. First of all the Volvo trucks are more complex than the Mack equivalent when it comes to the pneumatic systems. More complexity means that there are more valves, air tanks, distributor blocks and accessories that need pipes routed to them. One thing however that has improved the Volvo piping is the introduction of global fittings, which eliminates the need for special end fittings of the pipes. The pipes can now be directly inserted into the global fittings mounted on the valves. Second the operators currently have a low level of knowledge and experience when it comes to the Volvo piping. Finally it is the issue of work standardisation, lack of instructions and lack of information that the operators have access to. All of these issues will be described further down. The layout of the Volvo pipe area can be seen in Figure 12 and Figure 14. The idea is that the piping should be done at the two stations located in the Mack pipe area. This is however something that is not working at the moment, both due to the fact that the operators find it to be too far away from the pipe reels but also because there is no real need to move the chassis all the way down to the Mack pipe area when the work can be carried out in the Volvo pipe area.

The general breakdown of the work can be seen in the WBS in Table 4 chapter 5.2 - Work breakdown structure. The work is generally divided between rear and front pipers. However this is somewhat dependant on the variant of the truck that is to be piped. When work begins on a new chassis it is in most cases the rear pipers that starts the work. The first task is to investigate the chassis to see where all the valves and tanks are located and how the routing can be performed. After that the operators estimate what pipes are needed and how long they should be. This information is not something that is available to the operator so this has to be done for every chassis. The estimations are generally very rough, often in terms of arm lengths. This is a problem since it will inevitably lead to material waste as it is considered better to cut the pipes too long and then just remove the excess material once they are routed and secured in the chassis. The pipers work in pairs, one operator usually works inside the chassis and does the actual routing and securing of pipes while the other operator is fetching material and cuts the pipes that are needed. Since there are no lists or instructions on what pipes are needed it is often the case that operators have to go back to the pipe reels to cut a single pipe because they had missed that in the initial planning. The internal work breakdown within the team is however not always the same, it depends to a large extent on which of the operators that are working with each other and no standardisation exists in terms of how the work is supposed to be carried out or in what order. Also the work force is not always balanced, which means that some pipers have to work on their own, doing both the cutting and the routing and securing. This generates a lot of movement within the area as the operator constantly needs to run back and forth to fetch pipes and then climb inside the chassis to route and secure them.

After the initial planning it is just a matter for the operators to route and secure the pipes until it is time to move the chassis one slot further in the area. As mentioned earlier there is no real station layout where the operators carry out a specific set of tasks at their station each time. Instead the operators' follows the chassis they are working on through the entire process from start to finish which means that the actual movement of the chassis between slots is of no real benefit. It just interrupts the operators in their work as they have to secure all pipes to the chassis frame to be able to move it, and then remove the securing once the move is complete in order to continue their work.

The front piping works in the same way, the operators are divided into pairs, the only difference is that the front piping is considered somewhat more difficult and usually takes longer time to complete. It is also often the case that the rear pipers are not finished once the front pipers start their work. This can in some cases cause obstructions and operators have to wait for one another to finish securing some of the pipes. This is also the case when the front pipers exceeds the time they have to finish their job. But in that case they have to continue with their piping when the truck is already on the mainline which can cause some disturbance at the initial station. Currently there are seven operators working with rear piping and six operators working with front piping.

From the description of the work flow above it is evident that there is a big problem with standardisation in the work tasks, in what order the work has to be completed, how to do it and by whom. Currently there are no assembly instructions where the operators can find information on how the routing is supposed to look or what pipe should go to what valve. It is entirely up to the operators currently working in the area to pass on their experience and knowledge to new operators. This creates problems regarding in what order the pipes are supposed to be routed which means that operators often have to undo already completed work, by cutting already tightened zip-ties and reapplying them. This also touches on another big issue that is currently present in the Volvo piping.

The knowledge and experience is currently low when it comes to the Volvo piping. With the recent market downturn and reduction of the workforce a big part of the knowledge base and experience have disappeared. This means that the work is taking longer than it should, together with the fact that the more experienced operators needs to dedicate much of their time to teach the more inexperienced operators how to carry out the work which further adds to the problem of not meeting Takt time.

The supply of material to the pipe area is currently based on operators ordering material through the AS400 terminal once one of the pipe rolls is empty. This is something that works in most cases; the only problem that can occur is if the operators forget to order material which can lead to material shortage and delays in the piping process.

4.2.3 Mack piping

The Mack piping process works somewhat different compared to the Volvo piping. The initial planning of the routing of the pipes and the length estimation is something that doesn’t have to be done. The reason for this is that the pipes for the Mack trucks are placed on a moving carrier which means that no pipes have to be pre-cut; they can simply be pulled directly into the chassis and cut after they are in place. The Mack is generally also a less complex truck which requires fewer pipes to be routed and secured. The layout of the Mack piping can be seen in Figure 12 and Figure 13. The idea is that the piping should be completed on the two slots at the leftmost side in the Mack pipe area. However since the piping process is much faster on the Mack side it is often the case that piping commences already at the stations in the Volvo pipe area. Currently the operators can produce the intended amount of piped chassis on the Mack side. However there are still problems present in the area.

When work begins on a new chassis the carrier with pipe rolls is placed in front of the chassis. The operator then proceeds by taking all of the pipes that are supposed to be routed from the front of the chassis to the distributor block and pulls all the pipes at the same time through the chassis to the middle where the block is located. After that the operator cut the pipes at the rolls and proceeds by securing them to the chassis rails. One operator is enough to handle the piping that needs to be done in the front of the Mack. However since the same number of operators are allocated to the piping regardless of what brand that is being produced, which is 13, there is often two people working in the front, where one is feeding the pipe and the other is routing it through the chassis. The Mack pipes are colour coded which helps the process and makes it easier and faster to distinguish where the pipes should be fitted. The pipers continue to route and secure the pipes until it is time to move the chassis forward one slot. The pipers follow the chassis through the piping process, like on the Volvo side. This means that the moving of chassis has no real use with regard to the process itself, it just something that is needed to supply the mainline with a new chassis.

The rear piping of the Mack is set up in a similar way, but here there are two operators working. The pipes used in the rear are also in this case located on a moving carrier that is rolled right up to the chassis once the pipes are to be pulled through the chassis. However when it comes to the Mack piping there is no real distinction made between front piping and rear piping.

Although the Mack piping process is meeting the production demand there is still problems within the process. The problem of non standardised work is present also in the Mack process. As mentioned before, although the work is organized around having the chassis move through different stations this has no real use as the work is organized at the moment. No instructions or descriptions exist on what is supposed to be done at the different stations. Basically the operators have the task of piping a chassis, how they do it and in what order is entirely up to the operators themselves. Therefore the same problem exist here as in the Volvo piping, namely that the knowledge and experience is passed on from operator to operator. No overreaching information or assembly instructions exist. This also causes a problem with standardisation in the actual routing of the pipes. Some operators might find a particular way of routing to be the best while another operator has an entirely different view on what is best, which also means that the redoing of already completed work is present as well. This means that the length of the pipes will vary depending on what operator is doing the routing.

The Mack piping however does not suffer from the same problem of low knowledge level as the Volvo piping. This is due to the fact that the Mack trucks are much easier to learn and therefore new operators catch on quickly and the more experienced operators can focus on piping instead of teaching others on how to perform the job.

The supply of material to the Mack piping process works the same way as on the Volvo side, when one of the pipe rolls runs out new material is ordered through the AS400 system. This means yet again that if the operator forgets to order material once it runs out there is the possibility of material shortage which can slow the process down.

5 Results

In this chapter the data collected in order to investigate the problem is presented. The results include current state VSMs, work breakdown, lead times, work sampling distributions, stop watch time study data, spaghetti diagrams together with an investigation of problems coming in to the two areas. Also presented is a calculation of the current state MPU-score in order to have a comparable measurement once improvements have been made.

5.1 Value stream mapping

In order to create a current state VSM of the valve and pipe area for the Mack and Volvo brand a lot of information has been collected from production. The parameters needed in order to create the VSM is cycle times and manning for the different segments in the process, inventory and buffer levels together with the information flow present in the area. Details regarding how the information gathering was performed are described in 3.2.5 - VSM of current state. Both the current state VSMs have been shown during interviews with the section leaders of the valve and pipe area, David Hassack and Franky De Bruyn in order to ensure their correctness. Discussions and guidance has also been provided by Material engineer David Curtis. Each of the brands and the collected data will be presented individually below.

5.1.1 Mack current state

The data collected for the Mack brand regarding cycle times and manning is presented in Table 1. Together with this inventory levels, buffers and the information flow were also recorded and inserted into the current VSM of the Mack valve and pipe area.

Table 1: Cycle times and station manning for the Mack valve and pipe area

Station	Cycle time (min)	Manning
Valve sub-assembly	45	1
Valve assembly	191	5
Harness assembly	46	3
Piping	169	4
Power steering	125	1
TOTAL	***576***	***14***

When all the necessary data is available the lead time can be calculated easily and for the Mack process the total lead time from the start of the valve area to the end of the pipe area is 711 minutes or 11.9 hours. The complete current state VSM for the Mack process can be seen in Appendix F – Value stream mapping.

5.1.2 Volvo current state

The data necessary to draw the Volvo current state VSM is shown in Table 2. Similarly to the Mack brand information regarding inventory levels and buffers were also recorded together with information about how the information flow is working.

Table 2: Cycle times and station manning for the Volvo valve and pipe area

Station	Cycle time (min)	Manning
Valve sub-assembly	62	1
Valve assembly	95	4
Harness assembly	233	2
Brake hose assembly	102	1
Rear piping	274	2
Front piping	211	2
TOTAL	***977***	***12***

As mentioned before, when all data is available the calculation of the lead time is a straight forward procedure. For the Volvo process the lead time is 1113 minutes or 18.6 hours from the beginning of the valve area to the end of the pipe area when the truck is put on the mainline. The VSM for the current state Volvo process can be seen in Appendix F – Value stream mapping.

5.1.3 Problem areas identified

Several problem areas have been identified within the processes when conducting the VSM; they are similar for both brands so a common list will be presented as follows:

- The valve sub-assembly has the possibility of over producing causing unnecessary inventory build-up.
- The buffer between the valve sub-assembly and the valve assembly area is unnecessarily large.
- The valve assembly area is constantly pushing chassis into the pipe area regardless if they can cope with the workload or not.
- There are several cycle times that exceed the Takt time in many of the stations identified within the process.
- Much of the information flow is redundant leading to time wasted doing administrative work and also causing confusion and misconception.
- One piece flow is not present in either of the areas which mean that there are sometimes several chassis which no one is working on.
- Buffers exist between the stations within the process, for Volvo there are five chassis in buffer which equals 300 minutes of WIP and for the Mack brand the same figure is 180 minutes of WIP, which is three chassis.

- The buffers and the lack of one piece flow results in much time being lost due to moving more chassis than needed.
- Uneven work distribution and non-standardised work is causing operators to have to wait for others to finish, either on the same station or other stations downstream in the process.
- Poorly placed areas where material is fetched is contributing to unnecessary movement waste.

5.2 Work breakdown structure

In order to understand the different tasks involved in the valve and pipe area, a work breakdown structure was developed in collaboration with David Hassack section leader of the valve area and Franky De Bruyn section leader of the pipe area. The different tasks are very general and do not try to reflect the work involved in any great detail, for instance from operation to operation, but instead the large basic tasks needed in order to complete the work related to a chassis.

5.2.1 Valve assembly area

In order to assure the correctness of the WBS it has been created and approved by, as mentioned, the section leader for the valve area David Hassack. Information about dependencies within the WBS was investigated, that is if there exists any operation that needs to be performed before any of the others.

Table 3: Work breakdown structure for the valve area

	WBS Valve
1	Dry
	Take away cover
	Put sub-assembled valves on the chassis
	Mounting valves
	Un-mount parts from chassis to sub-assemble
	Mount brake hoses (Mack only)
	Mount edge protection
	Mount filter
	Mount zip ties holders
	Mount zip ties
11	Tape

The WBS for the valve area is shown in Table 3 and consists of eleven basic operations. Out of these there are two operations that need to be carried out at specific instances. The first one is the drying of the chassis that has to be performed first out of all the operations. This is not as much of an actual operation but more a state that the chassis has to pass through, but it is still part of the work content since no assembly tasks can be performed before the chassis has finished drying. The other operation that has to be performed at a certain time is when the operator applies protective tape to the chassis.

This has to be done as the last operation in the valve area to make sure that the tape does not stick to the paint which will cause the paint to tear off once the tape is removed by the end customer.

Other than these two operations there are no dependencies within the WBS, all the other operations can be performed in any order. Shown in the table is the current way the work is structured and carried out albeit with differences now and then since there is no standardised way of working and therefore operator dependant. Note also that the brake hoses are only mounted at the valve area when there are Mack trucks being manufactured.

5.2.2 Pipe area

In a similar way as for the valve area the WBS for the pipe area was constructed in collaboration with, as previously described, Franky De Bruyn section leader of the pipe area. Also in this case information about dependencies within the WBS was investigated.

Table 4: Work breakdown structure for the pipe area

	WBS Pipe	
1	Harnessing	(incl. Battery cables that has to be mounted after harnesses)
1	Brakes (Volvo only)	
2	Rear piping	Plan (incl. visually check valves/fittings)
		Cutting pipes
		Applying attachment point with zip tie
		Routing and securing pipes, cutting pipes and moving chassis
		Order and the routing of pipes depends on operator
2	Front piping	Same procedure as for front piping

In Table 4 the WBS for the pipe area is shown. The dependency that is present is that the harnessing and brake pipes (brake pipe assembly only applies to the Volvo brand) needs to be mounted and completed prior to the start of the piping. This is mainly because the harnesses are used as attachment points to the pipes, but also because the harnesses are much bulkier than the pipes which would make it very hard to route them in a correct manner if they pipes were already in the way.

The other operations can be conducted in any way irrespective of each other. This means that the front piping can be done prior to the rear piping. Note however that even though there is no real dependency between routing the pipes and securing them, there is naturally the prerequisite that some pipes are routed in order to have something to actually secure. How many pipes that is routed and secured at a time is however something that can be varied.

There is a large variance in how the pipes gets routed depending on what operator is doing the work, even the same operator can route differently on different days. This again is the result of non-standardised work which makes the WBS different for different operators.

5.3 Lead times

As mentioned in 3.2.2 - Lead times, lead times have been recorded for a great number of chassis. This is made in order to see the process stability over a sufficiently long time span, but also in order to see the effects of a reduced WIP. The data presented below is a summary of what can be found in Appendix C – Lead times, where each of the chassis is shown in detail.

Table 5: Lead times for the Mack valve and pipe process

Valve area	Lead time (hh:mm)	Pipe area	Lead time (hh:mm)	Total	Lead time (hh:mm)
mean	03:06	*mean*	07:52	*mean*	10:47
min	01:20	*min*	04:55	*min*	07:20
max	05:05	*max*	10:00	*max*	12:20

In Table 5 the lead times for Mack chassis is shown divided into the valve area, the pipe area and the total lead time. The mean lead time represents an average consisting of all the chassis observed whereas the max time represents the worst case scenario and the min time represents the best case out of all the chassis.

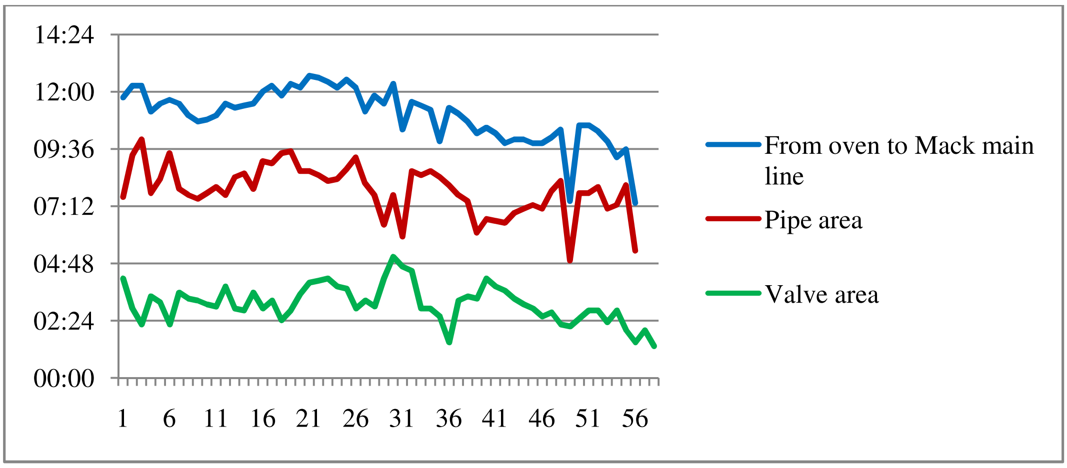


Figure 15: Process stability of the Mack brand

To visualize the process stability Figure 15 represents the fluctuations in lead time for the Mack brand. The vertical axle displays the lead time in hours and minutes, whereas the horizontal axle represents different chassis. As can be seen it is not uncommon that differences of several hours occurs.

Table 6: Lead times for the Volvo valve and pipe process

Valve area	Lead time (hh:mm)	Pipe area	Lead time (hh:mm)	Total	Lead time (hh:mm)
mean	03:11	*mean*	09:54	*mean*	13:08
min	01:20	*min*	08:20	*min*	10:20
max	06:10	*max*	12:40	*max*	15:45

In a similar way as for the Mack lead times Table 6 presents the Volvo lead times. Again the mean time represents the average taken for all the chassis observed whilst the max and min times represents the worst case and the best case out of all the chassis. Worth noting is that the best case lead time for the Volvo pipe process is still above the one hour Takt time based on a layout with eight stations.

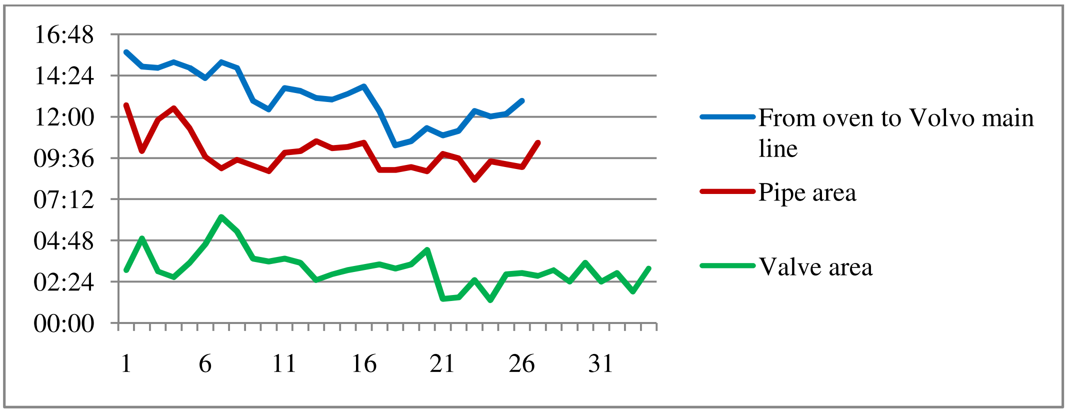


Figure 16: Process stability of the Volvo brand

The visualization of the Volvo process stability is shown in Figure 16. Again differences of several hours are not uncommon and the maximum range spans almost half a working day.

5.4 Work sampling

The results from the work sampling study will be presented in the following section. The data presented is a shortened version of the complete collection and a detailed presentation of the work sampling data can be found in Appendix D – Work sampling data. The presented data will be divided between the valve assembly area and the pipe area as described in 3.2.2 - Work sampling.

5.4.1 Valve assembly area

The resulting distribution from the work sampling study conducted in the valve assembly area can be seen in Table 7. As mentioned in 3.2.2 - Work sampling the samples have been collected by observing all five operators in the area in a randomized order.

Table 7: Work sampling data from the valve assembly area

Activity	Total number of samples	Percent spent on activity	Working time spent on each activity
Assembly	1664	33.28%	02:40
Handling tools	163	3.26%	00:15
Materials handling	624	12.48%	01:00
Moving chassis	109	2.18%	00:10
Administrative work	565	11.30%	00:54
Located in pipe area	96	1.92%	00:09
Cleaning	34	0.68%	00:03
Unrelated talking	359	7.18%	00:34
Moving	851	17.02%	01:22
Personal time	108	2.16%	00:10
Idle	234	4.68%	00:22
Other	193	3.86%	00:18
TOTAL	***5000***	***100.00%***	***08:02***

5.4.2 Pipe area

The work sampling data collected in the pipe area is presented in Table 8. As mentioned in 3.2.2 - Work sampling the sample collection in the pipe area have been collected similarly to the valve area. However in this case the operators were also selected randomly at each observation session.

Table 8: Work sampling data for the pipe area

Activity	Total number of samples	Percent spent on activity	Working time spent on each activity
Assembly	1699	33.98%	02:43
Handling tools	235	4.70%	00:22
Materials handling	440	8.80%	00:42
Moving chassis	165	3.30%	00:15
Administrative work	196	3.92%	00:18
Help each other	128	2.56%	00:12
Cleaning	83	1.66%	00:08
Unrelated talking	368	7.36%	00:35
Moving	705	14.10%	01:07
Personal time	125	2.50%	00:12
Idle	508	10.16%	00:48
Other	348	6.96%	00:33
TOTAL	***5000***	***100.00%***	***08:02***

5.5 Stop watch time studies

A summary of the stop watch time studies is presented in the tables below. What is displayed is a summary of the three activities value adding time, supporting value adding time and non-value adding time. The times displayed is the total time for each of the activities, which means the time content of each chassis studied if one operator were to do all the work. Also presented is the mean time required, simply calculated as the average of the chassis studied. The complete stop watch time study data from which the data has been taken, and also used as the base in 6 - Analysis, can be found in Appendix E – Time study data.

Table 9: Time studies conducted in the valve sub-assembly area

Valve sub-ass **Chassis**	**Model**	**Value adding time**	**Supporting value adding time**	**Non-value adding time**
131514	FM 84R	0:41:40	0:08:51	0:11:30
131531	FH 64T	0:39:06	0:04:05	0:07:24
800846	CSM 84R	0:26:30	0:17:25	0:01:05
Mean		*0:35:45*	*0:10:07*	*0:06:40*

In Table 9 the three chassis numbers, two Volvo and one Mack, studied in the valve sub-assembly area is displayed. The average value-adding and supporting value adding time required to sub-assemble the valves for one chassis is about 45 minutes. The average non-value adding time is about seven minutes.

Table 10: Time studies conducted in the valve assembly area

Valve **Chassis**	**Model**	**Value adding time**	**Supporting value adding time**	**Non-value adding time**
131505	FM 84R	1:16:49	0:27:52	2:00:44
800973	CMM 64T	1:24:12	0:30:21	0:54:27
800825	CLX 64T	2:13:16	0:52:58	3:28:10
Mean		*1:38:06*	*0:37:04*	*2:07:47*

The three chassis observed in the valve assembly area is presented in Table 10, two Mack and one Volvo. Together the value adding and supporting value adding times add up to about 2 hours and 15 minutes of working time. The average non-value adding time is 2 hours and 7 minutes.

Table 11: Time studies conducted in the harness process

Harnessing **Chassis**	**Model**	**Value adding time**	**Supporting value adding time**	**Non-value adding time**
131524	FH 64T	1:46:01	0:23:40	0:47:59
131503	FM 84R	3:06:18	0:31:27	1:05:39
800928	CMM 64T	1:17:07	0:08:57	0:29:52
Mean		*2:03:09*	*0:21:21*	*0:47:50*

From Table 11 the three chassis studied in the harnessing process can be seen. Two Volvo and one Mack were observed and the average value adding and supporting value adding time is about 2 hours and 25 minutes. The non-value adding time is on average about 48 minutes per chassis.

Table 12: Time studies conducted in the task of mounting brake hoses

Brake hoses **Chassis**	**Model**	**Value adding time**	**Supporting value adding time**	**Non-value adding time**
131505	FM 84R	0:42:02	0:34:41	0:25:16
131523	FM 64R	0:29:29	0:13:58	0:14:46
131526	FH 64T	0:42:13	0:08:05	0:05:05
Mean		*0:37:55*	*0:18:55*	*0:15:02*

Since the assembly of brake hoses done separately only on the Volvo brand, all three chassis studied and presented in Table 12 are Volvo. The value adding and supporting value adding time is on average about 55 minutes and the non-value adding time is about 15 minutes on average.

Table 13: Time studies conducted in the piping process

Piping **Chassis**	**Model**	**Value adding time**	**Supporting value adding time**	**Non-value adding time**
800928	CMM 64T	4:12:16	0:16:27	2:33:34
Front				
131541	FH 84R	3:43:38	0:50:31	2:24:42
131551	FM 64T	2:26:21	0:18:51	0:38:52
131544	FH 64T	3:24:59	0:29:30	0:55:05
Mean		*3:11:39*	*0:32:57*	*1:19:33*
Rear				
131541	FH 84R	5:14:27	0:39:37	1:44:47
131551	FM 64T	4:37:58	0:36:33	2:15:07
131544	FH 64T	3:14:42	0:29:47	2:15:40
Mean		*4:22:22*	*0:35:19*	*2:05:11*

The times collected from the piping process is presented in Table 13. For the Mack chassis studied the value adding and supporting vale adding time is about 4 hours and 30 minutes. For the two Volvo chassis observed the process has been divided between front and rear piping as there is a clear distinction between these two tasks. For front piping the average value adding and supporting value adding time is around 3 hours and 45 minutes, with a non-value adding time of about 1 hour and 20 minutes. If instead looking at rear piping the value adding and supporting value adding time is approximately 3 hours and 45 minutes with a non-value adding time of around 2 hours and 5 minutes.

Table 14: Time studies conducted in the cutting and mounting of power steering hoses

Power steering Chassis	Model	Value adding time	Supporting value adding time	Non-value adding time
800983	CMM 64R	0:43:25	0:14:10	0:27:30
800919	CSM 84R	0:44:55	0:43:25	0:36:15
800982	CSM 64R	0:26:20	0:11:10	0:18:20
800974	CSM 84R	0:24:45	0:19:10	0:14:55
Mean		*0:34:51*	*0:21:59*	*0:24:15*

The power steering pre-cutting and assembly is only conducted on the Mack brand whereas every chassis studied is Mack. The times for the four chassis studied is presented in Table 14 where the value adding and supporting value adding time is about 55 minutes and the non-value adding time is on average around 25 minutes. The goal was to study three chassis but because of the operators unstructured way of working and being used to other tasks the result of the study was four chassis.

5.6 Spaghetti diagrams

The result from the spaghetti diagrams can be found in Appendix B – Spaghetti diagrams. They have all been created by following one operator during one hour of work or approximately one Takt time. The only exception is the spaghetti diagram for the Volvo harnessing process where two operators have been followed and drawn in the same diagram. The operator chosen at each of the instances is the one who is most experienced in order to get a fair picture of the actual walking included in the time period studied.

5.7 OMS Scorecards

Production uses OMS Scorecards to keep track of different parameters in order to be able to provide feedback. One parameter that is put into the scorecard is problems that arise causing production to deviate from normal operations. A new scorecard is created for every week. Data collected through the OMS Scorecards are based on information from week one until week thirteen. The problems are arranged into a number of categories in order to identify the source. The resulting numbers of chassis that have problems already coming into the pipe area are shown in Figure 17 for the Volvo brand and in Figure 18 for the Mack brand.

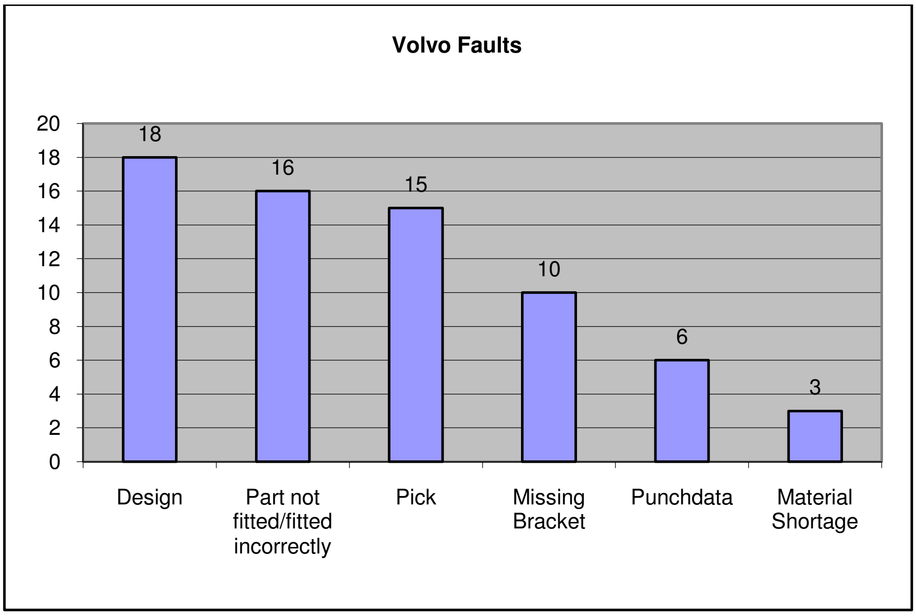


Figure 17: Summary of OMS scorecards showing faults for the Volvo brand

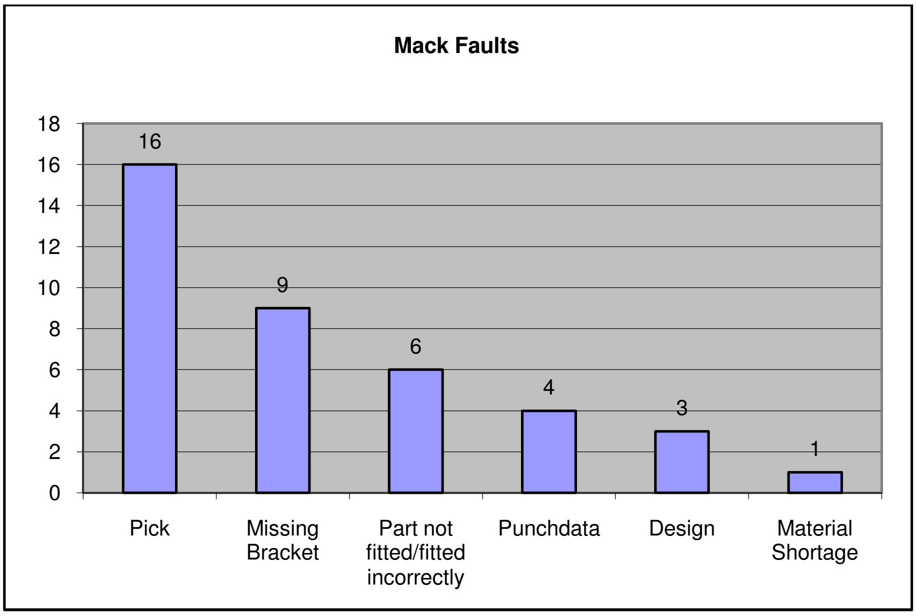


Figure 18: Summary of OMS scorecards showing faults for the Mack brand

The design category consists of all the faults and problems related to the design of customer specific trucks, for instance when a tank or a cross-member has been moved from its standard location causing problems to mount a valve. A part not fitted or fitted incorrectly is whenever a part that is supposed to be mounted is either missing or mounted in the wrong way. Pick is when logistics have either supplied the wrong parts in the pick or not supplied the pick at all or if the pick is late. Missing bracket is whenever the chassis line has missed to mount a bracket in the chassis rails. Punch data is when the problem can be related to an error in the schematic that the punching machine is working with. This usually consists of missing holes in the chassis rails.

Materials shortage is whenever there is a shortage of some material, for instance 12mm pipe. What is common for all these problems is that they either cause a complete stop in the piping process or contribute to large delays. As can be seen the total number of faults for the Volvo brand is 68. During this period 130 Volvo trucks where produced which means that roughly 52 percent had errors on them. The same figures for the Mack brand is 39 faults on 178 trucks produced which equates to roughly 22 percent having faults.

5.8 Interviews

The results from the interviews have been used mainly to verify other information collected such as the work breakdown structure and the current state VSMs. However some additional information was gathered regarding changes that the interviewees considers as improvements to the process, these were as follows:

- The information flow and problem solving capabilities, when a problem arises, between production and 3P needs to be improved. It is suggested that 3P has one person ready to come out and investigate the problem as soon as it is discovered to shorten the lead time.
- A trolley containing all the material and tools needed to mount the valves in order to reduce the walking distance of the operators.
- Moving the Volvo brake-hose mounting to the valve operators is not seen as something that should be an issue. Thus reducing the manpower need in the pipe area by one operator.
- Ensure that there is enough tools in order for everyone to be able to do their work, this in order to counter the situation were tools gets borrowed and never returned.
- Relocating the areas where material gets dropped off by logistics in order to reduce walking distance for the operators.

The interviews were recorded and a summary transcript of what is said can be seen in Appendix G – Transcription of interviews. In addition to this the cost of a WIP chassis has been investigated by asking the finance department, the details of the provided calculation can be seen in Appendix H – WIP cost calculation of chassis.

5.9 Experiences from other factories

Throughout the project several Volvo factories around the world has been contacted to discuss their solutions within the area in concern. The factories are Volvo Brazil, Volvo South Africa and Volvo Tuve Sweden. Below is a description of the result from these discussions.

Tuve Sweden

Tuve Sweden is working in a totally different way compared to Wacol with less variations and models. For instance Tuve has 50 percent S-notes compared to Wacol that has roughly 90 percent and Tuve uses a separate organisation to handle the S-notes, both at the planning level and assembly level. Tuve also has a pre-cutting station that is highly automated with a machine that cuts and bundles the pipes. The lengths are gathered from the computer system SPRINT automatically to the machine and this system is not available in Wacol. Tuve also sub-assemblies the pipes to the battery box that nearly all their trucks are equipped with. Battery boxes are rare for the trucks in Wacol. Those differences between the factories make it difficult to gain experiences from Tuve. However, two principles that Tuve is using when improving the production could be useful at Wacol. The principles are that when line balancing the goal is to utilise the operators 80 percent of the Takt time. Also when redesigning the layout of a work station the movement to fetch equipment and material should not be more than three meters (Jacobsson, 2009).

Brazil

Brazil is somewhat working in the same way as Tuve with a pre-cutting station and the battery boxes, which also in this case makes it hard to gain some experiences. Brazil is also working with computer software that contains the pipe information regarding the lengths and which sort to cut for each truck variance. The information within this software was once recorded and is adjusted to how they route the pipes in Brazil. This database of information is used to cut the pipes and then the pipes are bundled in the right order at a tailor-made bench, see Figure 19. The bench has four sides and each side is devoted for one model and uses clamps for specific variations of that model. In this way it is possible to organise the bundles in the correct order from the beginning. After this the bundle is assembled to the battery box and later on to the chassis (Tavares, 2009).

Figure 19: Pipe bundling jig used at the factory in Brazil

South Africa

The Volvo plant in South Africa is sub-assembling mostly battery boxes before the pipes are routed at one station and connected to the valves. South Africa uses a new approach to line balancing where they use a normal work flow of line balancing, see Figure 20, but the supervisors and section leaders are more involved than normal. The Production manager is conducting the work using the section leaders and production engineers to handle the work. The first step is to measure the work which includes observing the process to identify the operations that are done, measure the identified operations and then draw a balancing chart of the current state. This is done by the Production manager and if extra resources are needed, for instance when the time measurements of the operations are done, the section leader is used. When the times are measured and the current state is to be drawn the standard time of the operations are agreed upon together with the operators with the measured times as a standard. The second step is to define the new process which is the balancing of the work. This step could also need extra resources which are added by production engineering. The last step is to plan the implementation and implement the new standard. This whole process is done within two weeks in the pipe area and in one week for some of the other stations. This way of working is creating a process organisation that does the line balancing and at the same time involving production so they are updated about what is happening and what changes that are implemented. At the plant in South Africa this method is used at one station at a time with a standard 6x4 truck as the object. This way the plant will be balanced within a couple of months and then the next iteration can start. The next iteration will continue the balancing in the same way but with another truck model as the object. The experiences gathered in South Africa are positive using this approach, operators and section leaders are standing in line to get their stations balanced.

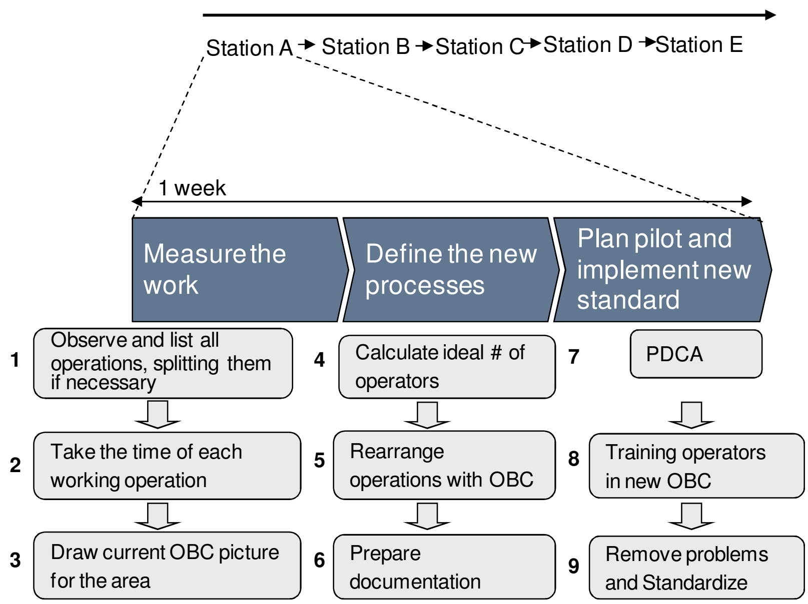


Figure 20: Proposed station balancing work flow

5.10 MPU

Below it is described how the current state is mapped according to the MPU technique and the result. This is later compared to the analysed and improved situation to get a value for the feasible productivity increase.

5.10.1 Method

The method value is set to 6h 7 min, Equation 6. By selecting all categories from the work sampling study that includes work tasks this value is generated. Equation 6 is calculated as the average between pipe and valve areas total time of the selected categories, Table 15.

Table 15: Selected categories that are included in the Method variable

	Valve categories	Pipe categories
	Assembly	Assembly
	Handling tools	Handling tools
	Materials handling	Materials handling
	Moving chassis	Moving chassis
	Administrative work	Administrative work
	Located in pipe area	
	Cleaning	Cleaning
	Moving	Moving
Total time	6h 35min	5h 39min

$$Method = \frac{6h\ 35\ \mathrm{min} + 5h\ 39\ min}{2} \qquad \text{(Equation 6)}$$

5.10.2 Performance

The performance value is set to 70 percent. This value is calculated from two sub values, pace and skill level. The pace is observed to be 100 percent compared to the general standard, defined in 2.6 - MPU. The skill level is set to 70 percent which is, as stated in 4 - Current state, a result from a turbulent time and new personnel. The skill level is set by observations and data from the interviews with people knowing the area. Some processes within the area have less skilled personnel, e.g. valve assembly, harnessing and Volvo piping, while others are more skilled, e.g. valve sub-assembly and Volvo brake piping.

5.10.3 Utilisation

The utilisation value is set to 33.6 percent, Equation 7. This value is calculated by taking the average of the two values for the assembly category from the work sampling study.

$$Utilization = \frac{33{,}98+33{,}28}{2} \qquad \text{(Equation 7)}$$

6 Analysis and discussion

This chapter begins with an evaluation of the methods used and the correctness of the data collected. It also analyses the current state of the two areas using the data collected together with the concepts and ideas presented in the theory. Emphasis is put on waste elimination and a discussion together with suggestions how to reduce them is presented. In addition to this an analysis regarding process stability, WIP and the guidelines of VPS is discussed.

6.1 Collected data and method

The following two sub-chapters are a discussion of the reliability of the methods used and the collected data. The methods could for instance be questioned regarding if they are primary or secondary in nature while the collected data might for instance be affected by the Hawthorne effect.

6.1.1 Methods

All the collected data is, if possible, primary. This means that information flows, material flows, work flows and timings are collected directly by the project group. However such things as how other factories within Volvo solve the assembly of pipes and valves, how different tools are to be used etc are secondary. The project team were at Volvo's plant in Gothenburg to collect as much primary information as possible in the beginning of the project, but while the project moved on several new questions came up and had to be asked from secondary sources. The collected OMS Scorecards are to be treated as secondary because it is production that is gathering the information and writing it down, while the project team is only summarising it. With the secondary information it is always a risk that the person who edited it have left out important information or that the reader is mislead in some other way. For instance, the OMS Scorecards are used to identify how many chassis are coming into the actual area with defects that are showstoppers for valve assembly or piping, it is possible that production have missed some faults or described them wrong which would give a faulty picture. The primary information is not validated just because it is primary, e.g. when doing a VSM the system is only looked at once and how it is right then. If the system would be out of normal condition at that time the VSM won't be validated by means that it is not representative for the normal situation. However, when using this kind of qualitative information the analysts are aware of how it has been collected to be able to use it in the right way. Qualitative methods can be better to use to get a deeper understanding of a process, e.g. when comparing interviews with surveys where an interview gives an opportunity for a deeper understanding while surveys is possibly more accurate in order to get a general overview.

This project has used both primary and secondary sources, trying to use secondary sources only where it is not possible to get hold of the primary source. Secondary sources are mostly used when gathering information about tools and alternatives to a solution which means that the information will be analysed to see if it is possible to use for this project and not used as facts. Secondary data is also crosschecked more than primary data by looking up the same information from several independent sources. The data in this project has been validated by both using qualitative and quantitative methods.

Because there are guidelines within Volvo that says that VPS should be used in every project this is also used in this project. One negative effect of this could be that the project members are unwittingly narrowing down their search for tools and solutions instead of being open minded. This could affect what type of data that has been collected and how it is analysed. However this has been prevented by using tools from other sources than those which describe lean manufacturing, though in most cases the tools are the same but sometimes named differently.

6.1.2 Collected data

The primary data, such as times and work flow, could to some extent be misguiding because of the large variations within the products and production. One such issue is that during certain periods several highly customer modified trucks are produced that does not reflect the normal state of production. In order to avoid this, the selection of trucks to be studied has been based on the most difficult brand for the specific process. This means that for instance that when studying the pipe area two Volvos and one Mack have been studied since Volvo is the most difficult model, whereas in the valve area two Mack and one Volvo have been studied. In addition to this the specific models studied have also been varied to get a broader picture. When trying to conduct time studies one prerequisite should be that the work is somewhat standardised. This is not the case in this project therefore the time studies have been made on a low detail level to better fit the general conditions. But as the results shows the variations are large which means the data must be used with care and with the variations in mind. The result from the studies should be seen as temporary and evaluated every time they are used.

As described in 2.7 - Hawthorne effect, the Hawthorne effect should be considered when doing time studies. This has been noticed when conducting the studies that some of the personnel are working harder when studied. However, it has also been noticed that most of the personnel seems to work as normal while others work at slower pace. Working at slower pace is an effect of thoughts of fooling the system by setting the standards lower than it really is, also described in 2.7 - Hawthorne effect. With the low detail level of the studies and great variations in mind the project team thinks that these psychological effects are negligible.

Because the assembly within this area is highly complicated without any standardised way of work it is more important to know the product itself to be able to analyse it. The project team's knowledge of the product is limited and to overcome this situation interviews have been conducted, among other things, and a close relationship to production has been developed. Using this approach the project team takes advantage of all experiences within production and also gives them a chance to get more involved in the solution that will in the end affect them.

Because of the financial downturn that has evolved during this project several production changes have been made, e.g. changes of Takt time, reduction of personnel etc. This has affected the result in the way that short term improvements have been implemented, e.g. a buffer within the pipe area. However the studies have been adapted to the situation as much as it will not affect the result. The main impact of the downturn is that the results are collected when different working conditions have been present, but by letting the results and conclusions be general they can still be used independent of Takt time and personnel etc.

6.2 Productivity

Based on the collected data and with support from the theory, several ways of increasing the productivity can be evaluated. The main part of the analysis focuses on the seven different sources of waste and how these can be mitigated. Since the production area that is investigated is divided into several sections, for example valve sub-assembly, harnesses and pipes, the analysis will also be split up where necessary in order to treat different problem areas individually.

Over production

By looking at the first of the wastes mentioned in 2.1.3 - Waste, over production, differences exist within the studied area. The main reason that over production is present is that the production follows a master productions schedule instead of the actual customer demand. Which in turn means that a certain amount of trucks is to be produced each day irrespective of how the actual processes within the production is able to cope with the workload.

Starting with the valve sub-assembly area, over production is possible due to the fact that the operator receives material for eight trucks at a time together with the fact that delivery of finished valves is also made to a carrier able to hold eight chassis of sub-assembled valves at a time. To further add to the problem the operator can if needed order additional picks to be delivered to the station even though the production demand for that day is completed. Also the air-filters are assembled individually and are not part of the kit box that is delivered to the carrier. This means that they can be assembled in arbitrary amounts without any real control. To counter these problems several options are available. One is to change the deliveries of material from the station, kit boxes with assembled valves, to a two bin system instead of eight. This would limit the operator to only be able to assemble one chassis at a time and since the change only affects the outgoing material, logistics does not have to change their routes as their supply stays the same. To remove the problem of the air-filter over production in this case one solution is to include it in the kit box. Another option is to change the incoming material so that material for each chassis is delivered each Takt, meaning that the operator cannot over produce since there is no material available once he is finished with chassis currently supplied, this would also solve the problem of air-filter over production. This however puts demands on logistics as they have to deliver material each Takt instead of a daily batch.

The problem of over production is also evident in the area where the valves get mounted to the chassis. Since the lead times in Table 5 and Table 6 shows that the valve process is faster than the piping process on both brands there is a possibility of over production. This problem is further increased by the fact that the drying oven pushes out chassis as fast as they can meaning that the valve area has to keep moving chassis into the pipe area even though they cannot cope with the workload. This inevitably also increases WIP, which will be analysed later. One option to mitigate this problem is to use one of the steps in traditional bottle-neck analysis, namely to subordinate the entire production flow to the slowest process, in this case the piping. This since no matter how fast the rest of the production flow is the trucks still have to pass the pipe area which therefore sets the pace. Another option is to physically stop the possibility to move finished chassis into the pipe area either by limiting the area with barriers or by rearranging the stations so that the next area in turn is not an empty area as it is today. Another alternative is to visually paint slots in the floor, in accordance with what is described in 2.1.8 - Visual control, where chassis are supposed to be. Adding to the problem is however that the Takt time is not followed as supposed, this is evident since if the Takt time would be followed the possibility of over production would not be possible since chassis are only supposed to be moved forward one slot each Takt making buffers impossible.

Problems of over production in the harness and pipe area are almost non-existent. The reason that harnessing is not able to overproduce is due to the fact that there exists no empty space between where the harnesses are mounted and where the piping starts as indicated by Figure 12. However if the harnessing operators are finished with the chassis they are supposed to work on they start to work on one of the chassis that valve has pushed into the pipe area, effectively working their way upstream in the process. This is mostly the case when Mack is produced as indicated by the stop watch data in Table 11 as the Mack harnessing is completed much faster than the Volvo. This problem of working backwards in the production flow can be solved by the same means as described for the valve area as it is an effect of chassis being pushed into the pipe area. When it comes to the piping process the only time there is a chance of over production is when Mack is produced, when Volvo is produced the downstream process is almost always ready to receive a chassis when piping is completed. Again the main reason for over production in the Mack case is that the Takt time is not followed; once a chassis is completed it is simply pushed further in the production flow. This is caused by un-standardised work, described in 4 - Current state, and explained in 2.1.6 - Standardised work, together with a non-existent balancing where operators don't know what they are supposed to do. One solution to this is to better follow the Takt time and not produce as fast as possible as this will only lead to increased WIP. Another solution is to set in place clearly defined working stations with predetermined work tasks together with a station balancing that make sure that each operator has an even workload throughout the entire Takt time.

Unnecessary processes

In the studied area several unnecessary processes can be identified. These problems are almost always related to either the valve area or the pipe area. The biggest and most evident problem is shown in 5.7 - OMS Scorecards where the summary of the OMS Scorecards are shown. Every time a problem occurs that gets recorded in the OMS Scorecards at least one additional process has to be completed. In the simplest form the problem might constitute for instance a missing bracket or a missing hole in the chassis rail. This means that it can be fixed fairly easily and quickly, however it is still an unnecessary process. In the worst case, for instance misplaced tanks or valve assembly points, an investigation must be set in place as described in 4.2 - Pipe area. One solution to this problem is to have a person, as mentioned in 5.8 - Interviews, responsible for just these types of issues that can respond quickly. However this contradicts the ideas described in 2.1.8 - Built in quality control which is also one of the cornerstones of the VPS framework. Therefore another solution is simply to make sure that no chassis with errors gets pushed forward in the process as is the case at the moment. By doing this the problems can be identified at the moment of occurrence and the process can be improved faster and at the right place. By pushing errors further downstream the real problems are hidden and it is very difficult to identify where measures need to be put in place in order to fix the root cause of the problem.

Another unnecessary process that is present in the pipe area is the fact that the operators have to cut the pipes during the actual cycle time. This consumes a lot of time, as shown by both the work sampling study and the stop watch time studies, and causes unnecessary movement in the area which will be discussed later. To solve this problem some form of pre-cutting can be set up in order to free more time for the operators to perform the actual routing and mounting of the pipes. However a pre-cutting station relies on the fact that the number of pipes and the lengths required for each chassis is known beforehand. One way to solve this is to have each model listed in a document with lengths, quantity and diameter. The operator then simply has to know which variant that is next in line to know what to cut. A pre-cutting station also puts additional demand on materials handling as the pipes for chassis coming down the line needs to be stored somewhere and the pre-cutting station itself needs to be located fairly close to the pipe area in order to minimize movement.

Due to the fact that work is not standardised and no predetermined sequence of operation exists the operators often have to undo and redo already completed work. This is most evident when routing pipes inside the chassis rails. Operators constantly have to cut zip-ties previously fastened by other operators in order to be able to route new pipes. This is caused by the fact that their working areas overlap and no information is available on how it is supposed to be done. This is yet another unnecessary process that consumes time. The solution is to have a predetermined sequence of operation that does not cause work to overlap. In some cases this might not be possible since certain pipes runs from the rear all the way to the front. In these cases the problem can be solved by having the operators not tighten the zip-ties so that more pipes can be routed through them, and only tighten them at the very end.

Waiting

In the valve and pipe area waiting waste is present in many situations. One such situation is related to the described problem above when defects makes continued work impossible. When a defect is discovered of the magnitude that it is impossible to either mount valves or pipes and an investigation needs to be carried out in order to solve the problem, all the operators currently working on the chassis has to wait until it is finished. This can in the worst of cases take hours as mentioned in 4.2 - Pipe area. To solve this problem the same reasoning as explained in 6.2 - Unnecessary processes applies. The problem of errors and defects will be further analysed and discussed further down in this chapter.

Another issue as evidenced by the OMS Scorecards summary in Figure 17 and Figure 18 is the problem regarding the delivery of picks. For the Mack brand it is the largest contributor to production disturbances and for the Volvo brand it is placed as the third most common problem. Problems with picks not only includes when they are not delivered, it can also mean that the wrong parts have been supplied or that they are damaged or broken at the time of delivery. All of these problems cause waiting delay since without the correct material it is impossible for the operator to carry out his work. Furthermore since most parts are delivered based on the chassis number they belong to it is often the case that the problem cannot be solved simply by using parts from another chassis as they are often unique. Therefore the operator has to wait for the correct parts to be delivered. In order to counter this problem logistics needs to make sure that the correct parts are placed in the picks, how this can be done is something that falls outside the scope of this report. This does not however fix the problem of parts being faulty upon delivery; this is a supplier quality issue which again is something that is not included in the scope of this report.

As previously mentioned, and shown in 5.3 - Lead times and, the lead time for the valve process is faster than for the piping process. This means that valve is pushing chassis into the pipe area in order to be able to receive new incoming chassis from the baking oven. This however only works to a certain extent as the pipe area will eventually be full of chassis. When this happen the operators in the valve process needs to wait until they can move an additional chassis into the pipe area and begin work on a new chassis. This is also further substantiated by both the results from 5.4 - Work sampling and 5.5 - Stop watch time studies where the time spent on tasks related to waiting is shown. To solve this problem one option, implied by the constantly lower process time, is to adjust the manning of the valve process. This however only solves the problem of the waiting waste in the valve area and not the actual throughput problem of the piping process. Therefore another option is to solve the issues in the piping process in order to ensure that they can produce in accordance with Takt time so the entire area becomes synchronized.

Another issue regarding waiting becomes evident both by the above problem of chassis being pushed into the pipe area but also due to how the station layout is currently organized. With the current number of stations and chassis almost constantly being pushed into the pipe area the number of chassis that has to be moved each time a move is made is causing waiting delays. Several operators are required in order to move a single chassis which causes constant interruptions and delays in their work. The same solutions as is described in 6.2 - Unnecessary processes are valid also in this case as the underlying issues are closely linked.

As expressed during the interviews, 5.8 - Interviews, there are not enough tools available for the operators to carry out their work. Therefore tools get borrowed between stations and even between the valve and pipe area. This means that operators often have to either wait for tools to be available or that they have look for the correct tool. This in turn means that they have to wait in order to be able to complete their work. If operators were given their own set of tools, customized to the task they are performing and colour coded to distinguish identity it would give the operator responsibility and thus create a better handling of the tools. It would also give instant feedback and control over who has borrowed what, should the situation occur. Another possibility is to take all the tools needed for a specific area and make them easily available, for instance by hanging them on the wall. Colour coding is also good in this case as it shows what area the tool belongs in. By using this approach it is directly visible what tools are currently being used and if any tools have been borrowed or are missing. Both of these solutions are based on what is described in 2.1.8 - Built in quality control and 2.1.5 - 5S in order to create a transparent and clean working environment.

Unnecessary transport

When looking into unnecessary transports not just movement of products and parts are analysed but also the handling of WIP and stocks. As described above in 6.2 - Over production there are several stocks and WIP, also described below in 6.4 - Work in progress, which lead to transports that the customer doesn't want to pay for. The kitting for valve sub-assembly and harnessing is on occasion pushing out several kitting carriers to the production which means that without having a standardised spot for two or more carriers they are placed arbitrarily. This arbitrary placement is forcing the production personnel to move the carriers because they are in the way when trying to work. However, the main unnecessary transport is the movements of the chassis. As seen in Table 7 and Table 8 in chapter 5.4 - Work sampling each day every worker spends 10 to 15 minutes moving chassis. This figure is just when they are actually moving a chassis, i.e. not including movement to and from the chassis and interruption of work. When observing the move of chassis it is seen that every chassis is moved by three to eight persons, if they are not using tuggers, and all of these are forced to stop their work, collect their equipment and move it along the chassis. Together with this an interruption is always a natural stop in the work to take some personal time, which the figures for personal time, unrelated talking, idle and other shows. Summarized, the figures to move a chassis are the actual moving chassis but it also includes time from the categories moving, personal time, unrelated talking, idle and others. One solution for this unnecessary transport is to let the personnel move more and let the chassis stand still. Disadvantages following with that solution are that the work is more difficult to overview for the section leader, it easily gets un-standardised because of the long cycle times and not only the personnel need to be moved but the equipment as well. Instead the movement of the chassis could be there but by reducing WIP and stocks the transport of unnecessary products are cancelled. Some transport is still going to be there but it may not be unnecessary and it is easier to have structured workflow and standardised work. The movement of chassis could also be made easier if there were some better tool to move them, e.g. an AGV, but this includes investments which are outside this projects limit. Another option is to use the tuggers in a more efficient way. For instance only use them in the pipe area where most of the movement takes place. Furthermore two operators can be assigned the task of using the tuggers to move the chassis as an included work element, thus enabling the rest of the operators who would otherwise be interrupted to continue their work.

Excess inventory

Inventories of chassis and sub-assembled parts are, as described in 6.2 - Over production, to a large extent present in the valve and pipe area. These inventories are built up because there is a push system instead of a pull system. Too much parts and material are pushed into the area which results in unnecessary inventory and handling costs. The inventory for sub-assembly is already described in 6.2 - Over production. However, one chassis used as inventory within the actual area ties up capital 146 000 AUD for a Volvo and 141 000 AUD for Mack, see Appendix H – WIP cost calculation of chassis. By briefly looking at the VSM, see Appendix F – Value stream mapping, an inventory is calculated for Volvo to be five chassis and for Mack to be three chassis. However the VSM should only be seen as a snapshot of the production which means that it can be more chassis in inventory but also less. The chapter 4 - Current state shows that it is suppose to be a buffer of two when producing Volvo and zero with Mack. This is the result of the previously mentioned push approach and the presence of overproduction. Inventory can be a good temporary solution when the cycle times for one process is varying (Liker, 2004). But problems are hidden when introducing inventory. Therefore inventories should according to lean manufacturing be avoided and if there is an inventory it should be controlled otherwise it will just cost money and hide underlying problems. To reduce the inventory for the valve and pipe area the WIP could be reduced, the product flow could be changed to a pull system and the personnel could be stationed at each chassis which means that each chassis is being worked at. However if reducing the inventory by letting the personnel work at each chassis the cost is still there but hidden which gives the main solution to reduce the WIP, described later in 6.4 - Work in progress.

Unnecessary movement

When observing the valve area it is seen that there is a lot of movement, the question then is if it is unnecessary movement, and if so could the movement be reduced? The data showing the presence of a lot of movement is, except observations, the spaghetti diagram and the work sampling data where one of the categories is moving. When looking at the spaghetti diagram for the valve sub-assembly area it looks quite good except for movement between the workbench and one rack of small parts to the left, see Appendix B – Spaghetti diagrams. This problem could be solved by changing the layout of the working area to move the necessary parts closer to the workbench. There are also some movement outside the work area to the right which is when the operator fixes some sort of defect that was discovered at the end of the pipe area. This is discussed more in 6.2 - Defects. The movement to the upper part is delivering parts to the customer battery box, which is only produced for special product variations. This is solved the same way as with the small parts, i.e. moving the delivery point closer to the working area.

When analysing the spaghetti diagram for valve assembly it seems that the movement is unstructured and inefficient. Table 7 in 5.4 - Work sampling shows that each operator within the valve area (including the sub-assembly area) is moving 1h 22min each day which out of approximately an eight hour working day could easily be seen as a problem. This is a result of bad layout, no standardised work, unnecessary transport (describe above) and defects coming into the area. To reduce the effect of the bad layout it could be rearranged to move necessary parts and tools closer to the working area. However this could be difficult due to the fact that the chassis have to be placed as they are, i.e. they cannot be rotated because some variants are too long. Another solution is to have small carriers for each operator where the operator puts the tools and small parts that is needed and then moves the carrier with the work flow. This has the prerequisite that there is enough tools and that the operators do not have to lend from each other. There is also a concern expressed in the interviews, 5.8 - Interviews, that there is a culture to lend tools from other stations without returning it which has to be conquered to make this solution work. Yet another solution is to let every operator wear some kind of tool belt and equip him or her with the necessary tools and parts. One disadvantage could be the safety concern when wearing a tool belt and climbing in and out the chassis and another disadvantage is that the equipment is not displayed in a good way when searching the pockets. The Volvo plant in Tuve has the objective to arrange the working layout such that the operator should just be necessary to move three meter from the chassis to fetch parts and tools, see 5.9 - Experiences from other factories, which could be used as a guideline for this plant as well.

By introducing standardised work at the workplace the operator should know what to do and in what order which would let him plan the work better and know what tools and parts to bring to the chassis. This could also be a start of the continuous improvement program within VPS because then there is a standard to try to improve which would reduce the unnecessary movements. To start with a low detailed plan of how every chassis should be worked with could be displayed at the working area, i.e. operator one work with the right side first, continue with the rear and operator two work with the left side first continue with the front or it could be operator one place the bolts in its place and operator two tighten the bolts. This way the movement pattern should be controlled and easier to improve.

The last two factors effecting unnecessary movements negatively is closely connected, unnecessary transports is to some extent an effect of defects coming into the area. Figure 17 and Figure 18 (chapter 5.7 - OMS Scorecards) is showing that there are 68 showstoppers for Volvo when 130 Volvos were produced and 39 showstoppers for Mack when 178 Mack's were produced. This means that the operator noticing this has to make unnecessary movements to notice the section leader. As long as that chassis is a showstopper it has to be handled as an inventory and the movements are adding up, see 6.2 - Excess inventory. Nevertheless, as described in 6.2 - Unnecessary transport as long as the system is a push system with overproduction it will produce inventory and too much WIP, which leads to unnecessary movement because of handling the products and inventory.

The result from the work sampling study shows that the movement in the pipe area is 1h 7min, as shown in Table 8. When looking at the spaghetti diagram for the entire pipe area it is seen that it also has a lot movements but it might not look that messy as for the valve assembly. This might depend on the fact that for instance the operators doing harnessing is working at one side at the time and that the operators doing piping is sitting inside the chassis and therefore wants to be sure that they have everything they need to minimize the effort of climbing in and out the chassis. It is observed that when one operator piping inside a chassis is missing a pipe or a tool he is asking another operator outside the chassis to get it for him. Still there is a lot of movement when fetching tools at some workbench maybe 40m away or when cutting pipes. The factors causing these movements are the same as described for valve assembly above and the solutions apply for this area as well. There is one special solution that could be to advantage for pipe assembling and that is pre-cutting the pipes. This, already described in 6.2 - Unnecessary processes, should reduce the movement to and from the pipe rolls and result in a movement when fetching the bundle of pipes that are pre-cut.

Defects

After the piping is complete the chassis are pressure tested using a special rig that tests all the functions related to the air system present in the truck. There is also one worker assigned to quality check all the routing and zip-ties that have been mounted in order to ensure that they comply with standards. Therefore the number of defects being pushed further on to the mainline has not been considered an issue. What is an issue however is that sometimes either the valves supplied by the sub-assembly are incorrectly assembled, or valves are mounted incorrectly on the chassis. This in turn means that the operators from the valve area have to walk over to the pipe area in order to fix the problem, thus interrupting their work.

Better assembly instructions are one way of ensuring that no errors will occur. Partly linked to this is the ideas described in 2.1.8 - Poka-yoke where the design is made in such a way that errors are impossible. This could for instance mean that valves can only be mounted in a specific way due to how the bolts are placed. This is however something that needs to be changed on a product level and thus falls outside the scope of this report. Both of these changes would however put the quality responsibility at the operator level in accordance with what is described in 2.1.8 - Built in quality control.

6.3 Process stability

"If the work sequence is different each time and motions are disorganized, there is no baseline for evaluation of improvements opportunities" Pinotti Moreira Matheus, IM VPS Lean consultant

As stated above the process needs to be stable to be able to retain the changes that are done. The pipe and valve area are not stable which can be seen from both the lead time study and the stop watch time study. The lead times for the whole area for Mack differs from 7h 20min to 12h 20min and for Volvo 10h 20min to 15h 45min, see 5.3 - Lead times. This means that there is approximately a variation of 50 percent in the lead time for both brands but the real comparison should be made by joining the figures from both brands. Because the process should have the same lead time independent of brand the data shows, when looking at both, a variation between 7h 20 and 15h 45min, a variation of 100 percent. When separating the two areas and looking at the valve area the variation is from 1h 20min to 6h 10min and for the pipe area 4h 55min to 12h 40min.

The instability could also be seen from the stop watch time study by for instance looking at the value adding time for each single process, 5.5 - Stop watch time studies. The time for valve assembly differs from 1h 16min to 2h 13min, for the harnesses assembly between 1h 17min to 3h 6min and the largest variation in time is found in the piping with times ranging from 4h 12min to 8h 57min. The least unstable process is mounting the brake hoses for Mack, which is a separated process compared to Volvo, with times varying between 29min to 42min.

The process is proved to be too unstable to a large extent, which makes it almost impossible to set a production plan for this area. The project team thinks that the process instability is one of the most urgent problems to reduce. To stabilize a process 2.1.5 - Stability presents levelled production, 5S and standardised work. As described in 4 - Current state the levelling is done by considerations of the trim line and pipe and valve area. This would mean that the levelling is done fair at the moment when analysing the pipe and valve area. However, it could be done in a better way if the leveller had the freedom to mix the both brands as he wanted, i.e. first one Volvo then one Mack and then one Volvo etc. When the production, as it is currently, is producing one brand at a time it would be easier than before when producing the brands at the same time to set up a mixed main line. Currently the personnel know both brands and several trucks from the brand not being produced are standing at the line which adds to the waiting costs. This is outside this projects scope but it would probably make the levelling for pipe and valve area more even.

5S is a five step program and would surely be one tool to make the stability better. By reducing unnecessary material at the work place the area would look much cleaner and the work environment would be better. But it would not only be psychological effects but also that movement of tools and products would not be obstructed by unnecessary material which would decrease cycle times and lead times. It would also make it easier to find those tools and parts that are needed at the moment because of less distracting objects which also leads to decreased cycle times and lead times. The second and third step in 5S includes organizing and cleaning. By going further and making the tools and products visible when needed and by organizing them close to where they should be used a lot of the movement waste could be reduced which would make it easier to get control over the movements and also the process. Organising also means using visual control as a tool, e.g. use one colour for the tools at one station to distinguish them from being moved to another station, which is a concern described in 5.8 - Interviews. Organising together with cleaning is a way to make the working area standardised, which in turn will make the process more controlled. If everyone is getting the same tool at the same place and leaving it there, the movement is controlled and could easily be identified and in the long run, meaning continuous improvements are possible. The fourth and fifth step in 5S is standardisation and sustaining of the work done so far. We think that using 5S at the pipe and valve area would give positive effects and be relatively easy to implement. The difficulty in the implantation is that the supervisors and section leaders have to be consequent and patient to follow up the changes. One solution to reduce that difficulty is to give close and patient support from PE and management.

The third tool to be used is standardisation of the work and not just the work area that 5S is considering but the work flow. By letting the operator, independent of which person it is, do the same work in the same order all times it is easier to get control of the work and the process. The quote in the beginning of this chapter and Figure 4 in 2.1.6 - Standardised work is clearly describing the importance of having the process standardised to be able to make improvements. We therefore think that standardisation should be one of the most important tools to implement in the pipe and valve area. 2.1.6 - Standardised work is describing seven benefits from standardisation where the first one is stabilization of the process. The result from standardising the work is that the throughput and results could be predicted which leads to a more stable process. The standardisation within the pipe and valve area has to start from the beginning and at a low level, already described in 6.2 - Unnecessary movement. When the first standardisation is in place the program for continuous improvements could start to make the process more standardised. This way the learning for new personnel will be made easier and the situation described in 4 - Current state where the process is unstable and slow because of inexperienced personnel will be easier to avoid. However, the difficulty that might be the hardest to overcome is to come up with a standard for this area because of the large variations of the trucks. That is why it is that important to start standardising at a low level and then work slowly to get is as standardised as possible.

As stated in the beginning of this chapter the analysis is that the instability of the process is one of the major problems within the area which must be addressed to be able to move on. Personnel are blaming the product variations but that is not the whole truth. We think one way to get a more stabilized process is to use the tools described above at a low level from the beginning. Then, the question is in which order should the tools be implemented and how should they be used. Because these are major changes in the long run it will take time implementing them which will result in the difficulty of patience and support from all levels within the plant.

6.4 Work in progress

The analysis of the WIP and how to reduce it is based on the two current state VSMs, explained in 5.1 - Value stream mapping and shown in Appendix F – Value stream mapping. It is also based on the current layout described in 4 - Current state where it is shown that are nine chassis for Mack and eleven for Volvo. When looking at the Volvo current state VSM the total WIP is twelve chassis and for the Mack it is ten chassis. But since the VSM is only a snapshot of a specific situation this is not entirely true and the WIP in the valve and pipe area fluctuates almost on a daily basis. Why this is the case and different steps that can be taken in order to lower the WIP will be analysed and discussed in this chapter.

The main reason that the WIP is constantly changing, which might seem strange for a line production environment, is the huge variation that is present in the lead times shown in 5.3 - Lead times and discussed in 6.2 - Productivity. This means that during certain periods of time the mix of products might be favourable for the pipe area which reduces the WIP between the valve and the pipe area since they can work faster than the rate at which the valve area can deliver chassis. At other times, which are the more common cases, the valve area supplies chassis faster than what the pipe area can handle which causes WIP to increase to the point where the pipe area is full.

As indicated by the above reasoning the production flow is currently conducted in a push approach where each section is trying to meet their daily schedule without taking into consideration if the downstream process can handle the workload. This is in complete contradiction to what is described in 2.1.7 - Just-in-time. To further add to the problem is the lack of coordination regarding when the flow should move one step ahead. There is, as mentioned several times, a Takt time that should be followed, however in the valve and pipe area this is non-existent and chassis are, to a large extent, moved arbitrarily in the area. This in turn creates confusion among the operators and often times they work on several chassis at the same time due to not having a predetermined working area with clearly stated working tasks.

To reduce the WIP a better balancing of the working area were operators have a defined area of work and predetermined working tasks will help create a stable base and raise their utilisation. This will help in making them work on the same chassis until it is finished and not move between different chassis. By doing so it effectively removes the need for inventory between the different stations. In addition better balancing might lead to the reduction of stations which also reduces WIP further. Thus creating a one piece flow in accordance with what is described in 2.1.7 - Just-in-time. The prerequisite though is that the production flow is synchronized since when the delivery takes place to the downstream process a new chassis needs to be moved into the station.

6.5 Volvo production system

When discussing the VPS and the implementations that are discussed earlier in this chapter it is seen that all suggestions are tools within VPS. The analysis is based on analysing the seven wastes described in VPS and the natural way to eliminate these is to use the tools connected. This means that every suggestion will lead to a better fulfilment of the VPS guidelines. The thing to remember is to build from the bottom of the VPS triangle and not try to implement JIT before there is a stable process to base the JIT on. This will limit the suggestions somewhat but when analysing the situation it seems natural to do it in that order, see Figure 2 chapter 2.1 - Volvo Production System.

One strategy that is close related to VPS is FFC, see 2.1.9 - Future factory concept, which states that the assembly line should have the layout of a fishbone with sub-assembly stations as the bones. This should make the production less complex and more flexible. There are also strategies that the truck should be built from the inside and out. When discussing different solution for this project the realization of FFC is to use as many sub-assembly stations as suitable. This should not be an objective by itself; the sub-assembly station must be to an advantage which for instance a pre-cutting of pipes perhaps would be. Pre-cutting of pipes might give an unstructured system because of the lack of data for what kind of pipes and lengths that should be cut but if this is overcome the project team thinks it would reduces waste. There are several sub-assembly processes in the current situation, for instance sub-assembling of valves, pre-cutting of hoses and pipes to the mainlines and sub-assembling the battery box when used.

7 Suggested solution

Based on the analysis this chapter presents a suggested solution as of how the problem can be solved and the productivity in both the areas can be increased. An immediate state is presented first where the implementation of changes can start immediately. Following this is a presentation of the future ideal state showing how the process and the two areas should look when the improvement work is complete. In addition, suggestions on how to reach this state from the immediate state are presented.

In order to achieve the purpose and goals initially stated, the problems and discussed solutions from 6 - Analysis and discussion must be accommodated. A time plan for the improvement work and changes to the areas can be seen in Appendix K – Implementation time plan. As can be seen it shows a sequence of steps that ultimately leads up to the future ideal state. The overall plan is divided into four distinct phases; these will be explained in more detail in the sections to come. After the first three stages are completed the valve and pipe area should have the basis to continuously and to a large extent individually improve their working environment, phase four. This phase is based on a concept used in the plant in South Africa, also described in more detail in 7.2.2 - Phase 4. Following this plan the process stability will increase resulting in shorter throughput times, less WIP, less waste which together equates to an increase in the productivity for the valve and pipe area. To further ensure that the implementation does not fail a comprehensive risk analysis has been made for the implementation. The analysis outlines the risks coupled with the changes being made and also ranks the risks in terms of probability and consequence, the risk analysis in full can be found in Appendix L – Implementation risk analysis.

As can be seen there are several additional tasks that is carried out concurrently together with the different phases. The reason that these tasks are not included in the different phases is that they should be worked with continuously. The *follow up* task is included to secure that the work being performed is continuously monitored and evaluated. This in order to stay on track with the current improvements but also to ensure that already implemented changes are kept and that work does not revert back to old methods.

The task of *reducing incoming problems* is one of the most important tasks in the entire improvement work. If the input to the process is not stable, it is impossible to implement the ideas of standardised work and synchronised production flow. If the work areas are balanced and a standard sequence of operations exist, then big disturbances as described in 5.7 - OMS Scorecards renders the entire balancing useless. Therefore the products coming into the valve and pipe area must be without faults. This is something that must be improved dramatically given the current situation in order to make the implementation of improvement changes possible. Ideally when a fault is detected along the production line it should not be passed on. Identification of the underlying cause of the problem becomes far easier if it is not pushed further downstream since the investigation only needs to find the cause and not where in the process it occurred.

By using the engineering resources available within Volvo the task of *develop the process with IM VPS lean expert as coach* is basically to make use of experience and knowledge already gathered and proven to be working. By doing so the improvement work can be conducted quicker and when problems or questions are raised there is a method of catching these and quickly resolve them.

The task of *reducing buffers* is something that should continuously be carried out. As the processes subject to improvement work becomes more and more efficient the need for buffers diminishes. This is something that needs to constantly be monitored and when it is obvious that for instance a safety buffer is no longer needed it should be removed.

7.1 Immediate state

The phases described in the immediate improvement state are those which can quickly and without delay be implemented immediately. This will give a quick increase of the productivity within the area. However it is important to standardise the changes and continuously follow them up in order to maintain the new level of productivity. After these changes have been implemented an increase of 49 percent in productivity is foreseen based on the MPU method of measuring, see chapter 7.1.3 - MPU for immediate state. The WIP will decrease from eleven that is stated in 4 - Current state to nine for Volvo and from nine to five for Mack. The lead time could be calculated with one hour per WIP because the Takt time is set to one hour. Manning will go from 21.5 in total to 19 for Volvo and to 14 for Mack, see Appendix I – Station balancing diagrams for immediate state.

7.1.1 Phase 1

The first action to be taken within the valve and pipe area is to start with the first stage in the 5S concept, namely *sort*. This will in a sense reset the working area and create an overview of what is really used, what needs to be repaired or fixed and what is missing in terms of equipment and tools. This step is a prerequisite for the continued improvement work since without the right conditions to start with, other changes will become hard to implement. This is also something that is supported within the VPS framework where it is stated that 5S should be implemented before any other improvement work is carried out.

The approach to implement *sort* is that the section leader for the specific area, possibly together with an operator, red and yellow tags items in the area. Red tags represent items that are not used or needed and thus should be removed. Yellow tags represent items or tools that are either broken and in need of repairs together with items in need or tools in need of service. When this process is complete only items that are used within the area will be left, creating a more organised and less cluttered working environment. This will help in reducing the time consumed by searching for tools and equipment. If uncertainties occur when tagging items regarding if they are used or not, they should be placed in a red tag area. This red tag area should be reviewed continuously and any item that has not been used during the time span between the reviews should be removed.

At the same time as *sort* is applied and implemented within the valve and pipe area the task of developing a *standard sequence* is carried out. This must be made in order to be able to set up a working station layout where each operator knows what he is supposed to do. Since there is currently no official sequence within the areas, this first standard sequence must be made at a high level. When this first sequence is implemented it needs to be followed up and continuously improved, this is something that is included in the South African approach explained in 7.2.2 - Phase 4. The work of mapping out a standard sequence should be made in a cross-functional group where a responsible person from PE leads the work together with one or two operators from the different processes, i.e. harnessing, piping, and possibly also the section leader from the specific area.

When the standard sequence has been developed, and distributed among the different stations, it should be made visible using large signs that describe the different operations and in what order they are supposed to be carried out. This will enable the operators to work in the same manner each time, reducing time needed for handling tools. Most importantly is that they follow the same movement pattern each time significantly reducing the amount of walking that they used to do.

7.1.2 Phase 2

To have a platform of standardisation phase two is implemented. Phase two includes *basic stations, pre-cut pipes* and *use of Takt time. Basic stations* are a concept with a new layout, Figure 21, where the operators work at one station and not moving around between chassis and stations. The layout is based on the station balancing, see Appendix I – Station balancing diagrams for immediate state, which presents the right amount of operators at each operation. Then the layout is created based on how many operators that can work on each station without being in the way for each other. The balancing is done with the data from the time studies presented in 5.5 - Stop watch time studies and Appendix E – Time study data. It is seen in Table 9 to Table 14that the stations with harnessing and piping is the only stations that differs between the brands worth mentioning. This gives the conclusion that those are the only ones that have to be separated with different balancing charts. Furthermore, the layout is focused on minimizing waste such as moving, transporting, over production etc which is done by moving material closer to the operator and balance the stations. Moving material closer is done both by moving racks and kit carriers close to the stations but also equip the operators with tool carriers in the valve area and tool belts in the pipe area. This way a larger part of the move and transport waste is reduced. Implementing a two bin system between the sub-assembly of valves and the valve assembly overproduction from the sub-assembly is limited. Balancing the stations is done with the collected data within this project with the main benefit of reducing waiting waste and lead time. The basic target is to keep the cycle time of the station at 80 percent of the Takt time in order to facilitate disturbances in the production. The operators also works according to the developed standardised work sequence, described above. By using this concept of basic stations a good platform of standardised work is in place and the valve and pipe area is easier to overview and control.

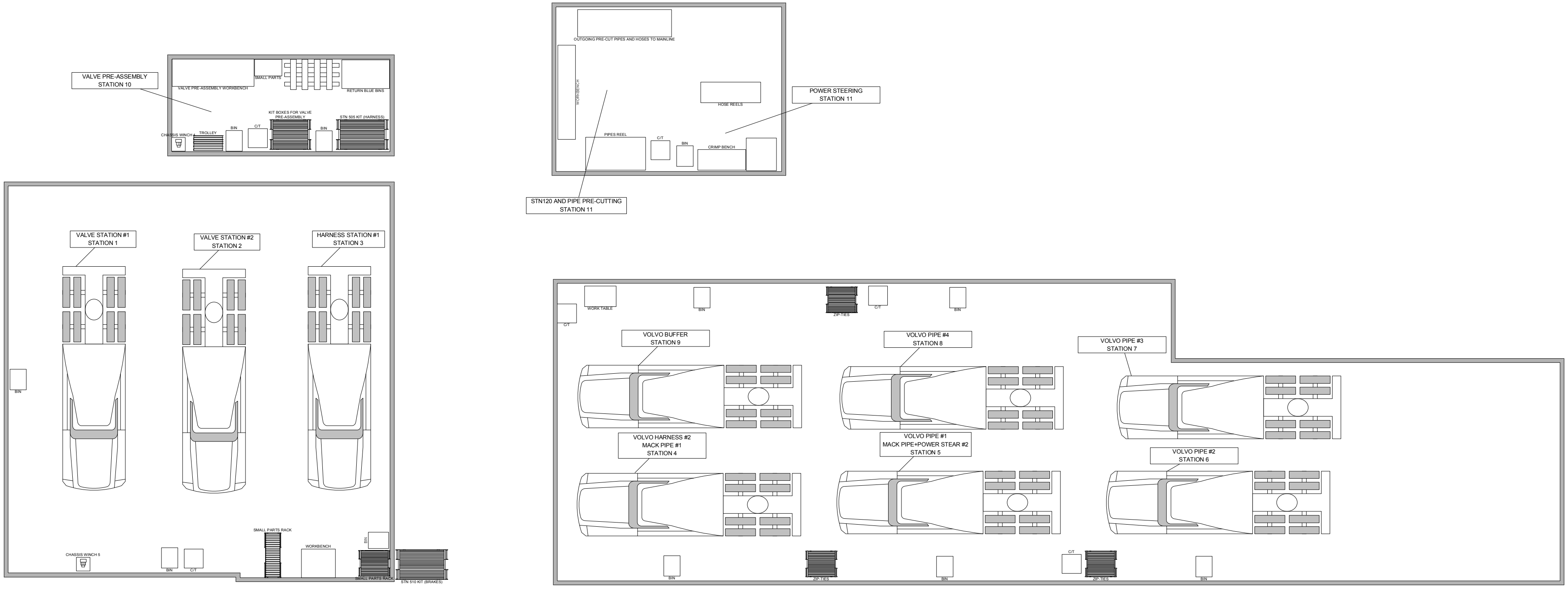


Figure 21: Future state layout

However, this is not enough the *Takt time needs to be used.* As it is today there is a Takt time but it is not followed within this area. Without following the Takt time the concept with basic stations will not work and therefore there must also be a plan for what to do when a station is not finished within Takt time. There are several solutions for this plan, in the long run the best way should be to stop the product flow to understand and highlight the problem that occurred. This could be hard to motivate in short term. Another way of solving it could be to let one operator move with the chassis to the next station, under control of the section leader or if the section leader has some extra resources available for these kinds of things to use where it is motivated. It is up to the management to decide how they want to use their resources.

By using a *pre-cutting station* the FFC is used and all similar tasks are collected at the same place. The station should include station 120, pre-cutting of power steering hoses for Mack and pre-cutting pipes for the pipe area. This will make the work more efficient and again, easier to overview and get an understanding for. The station is located in between the two mainlines to give shorter access for the old station 120 to its customers at the main line. It is located close to the pipe area to be close to that customer, which is also the case for the power steering assembly station. To get the lengths when pre-cutting pipes an operator has to be looking at each chassis when it arrives in the valve area and by looking up the specifications in the computer. This should be saved in a database to later skip the step by looking at each chassis but instead just look in the database. Ultimately this should enable the construction of a jig similar to the one described in 5.9 - Experiences from other factories so that the pipes can, in addition to being pre-cut, be put into completed bundles.

7.1.3 MPU for immediate state

The productivity is calculated to increase with 49 percent when immediate state is implemented, see Appendix J – MPU calculation. It is calculated by separately calculating the three values, method, performance and utilisation. By looking at the spaghetti diagram and the selected categories from the work sampling study, as described in 5.10.1 - Method, these categories can be recalculated for the immediate state. When doing the calculations the suggestions and analyse above is considered. For instance moving is reduced with approximately 50percent because of material and equipment being closer and the operator knows what to do according to the standardised work sequence. All three categories administrative work, located in piping area and moving chassis is also reduced mainly because of the standardised work sequence, i.e. the operators know what to do. This gives an improvement in method of 23 percent in an average of both the valve and pipe area.

The performance value is set to 70percent in 5.10.2 - Performance and is based on two factors, the work pace and the skill level. The pace is 100 percent while the skill level is 70 percent. The immediate state is supposed to be implemented within a few months and therefore the skill level cannot be raised to large extent. With these factors the performance is calculated to 72percent, see Appendix J – MPU calculation.

When recalculating the utilisation value the result is an 18 percent improvement to 39.5 percent. This is done by looking at all categories for the work sampling study except assembly as this is the single category seen as utilisation. Then the calculation from the method recalculation is reused but with adding the five categories that were left out at that calculation. Using the suggestions above new values for these categories is calculated, e.g. the category idle is reduced with approximately 30 percent because of balanced stations and standardised work sequence. Helping each other should also be reduced cause of standardised work sequence. The unrelated talking is reduced cause of the basic stations, i.e. the operator has one station to work at, so the operator is not that easily walking past some colleges and starting to talk. An average of valve and pipe area for the reduced time is then calculated. The utilisation at current state was approximately 30 percent which implies that 30 percent of the reduced time will be used as utilisation time. See Appendix J – MPU calculation.

The three values are multiplied, as described in 2.6 - MPU, with the productivity improvement of 49 percent.

7.2 Future ideal state

The phases described in the future ideal state are not prioritized in the beginning but used as a natural step later on to further improve the process. These changes are more about changing the mindsets and get everyone involved in the continuous improvement work. The VSM for this state is presented inAppendix F – Value stream mapping, which also is the base for this work, the picture to work towards. The VSM is not considering which brand is produced but it is obvious that it is not an objective to increase the WIPs to eight, which is the case for the VSM, when producing Mack. The immediate state did decrease the WIP for Mack to five. The authors' thoughts of not doing a Mack specific VSM for the future ideal state is that this is not a troublesome area compared to when producing Volvo. By just having one picture to work towards the focus will be on the Volvo brand and the Mack automatically when the improvements for Volvo are implemented. The improvements will not give the best result for Mack but Mack could be considered when that brand is at the same level as Volvo.

After these changes, presented below, have been implemented an increase of 107percent in productivity is foreseen based on the MPU method of measuring, see chapter 7.2.3 - MPU for future ideal state.

The VSM presents that the WIP should be eight for Volvo and 17 operators compared to nine WIP and 19 operators for the immediate state. As described above the VSM for this state is not valid for Mack.

7.2.1 Phase 3

Once phase two is implemented with basic stations and a suitable layout it is time to start realising the three steps in 5S following *sort,* these are *set in order, shine* and *standardise*. Since the station layout enables the operators to work at a designated spot is possible to see where material, items and tools needs to be placed in order to minimize the walking distance. This is one of the things included in *set in order,* although some of this work was already carried out in phase two; this phase is where it gets finalised. Furthermore all the tools not included on the tool carriers or in the tool belts should be visibly placed in the working area, either hung up on a wall or by placing them on a tool board. Every tool should have a designated location marked by either colour, a painted shadow or by name. At this point it should also be possible to see where the tuggers are most needed, where they should be placed and if there is a requirement for additional tuggers. This enables quick feedback when something is missing and it is easy to get an overview at the end of the day if something is missing.

All the kit carriers, trash bins and other material supplies should have its location marked on the floor together with a name tag describing what should be there. Again this enables quick feedback if something other than what is supposed to be there is placed in the area. Similarly all the stations should be clearly marked in the floor with the name of the station and the area it occupies to distinguish where WIP chassis are to be placed and worked on. Yet again this provides quick visual feedback as to where it is accepted to place chassis and will therefore help in relieving the problem of WIP being pushed through the system and placed in buffers. It will also help the operators even further with showing them where to be.

When everything has been organised and put in its correct place it is time to start with *shine*. This does not simply mean clean the work area, although it is part of it. *Shine* is a way of constantly striving to have a workplace that look like new. It also helps maintain a high safety level as leakages and debris are removed which could otherwise cause injuries. One important aspect of making this work is to have each operator responsible for one specific area, which will provide a sense of responsibility. Ten minutes at the end of each day should be spent cleaning once specified area. To help ease this work cleaning checklists should be issued where it is clearly stated what the operator should do, look at and at what time intervals, daily, weekly or monthly.

To be able to maintain the previous steps of the 5S concept *standardisation* is necessary. This includes checklists describing processes so that work is easy to carry out and to make sure that it is carried out in the same way each time. It also involves setting standards within the colour coding and markings so that every operator easily can identify the purpose of the visual marking. Much of the *standardisation* is about creating a visual working place. A visual workplace is an environment that is self-ordering, self-explaining, and self-regulating all of which helps create a stable process.

Together with these three 5S steps it is also suggested that boards expressing the seven wastes are put up in the work areas with a short description of what each of the wastes consists of. This will hopefully make the operators start thinking for themselves in terms of improvements that can be made in order to reduce waste and to further help drive the ideas of continuous improvement.

7.2.2 Phase 4

The main task in this phase is to iteratively standardise and balance the work, see Figure 20 chapter 5.9 - Experiences from other factories. The suggestion is to use the South African approach with getting the process organisation to do the work instead of creating a project. This will create benefits such as continues improvement and communication can be made easier. The process includes three main steps, identify and measure operations, define a new process, test and implement new process. The process should be done for one station within one to two weeks and the valve and pipe area should be done in parallel to gain benefits from comparing two areas. The actual observing and time study should be made by the section leader and the supervisor for the area while one resource from PE is conducting the work. Then it is easy for the supervisor to draw a current balance chart to present for PE and together with PE define a new process. This way the whole organisation is involved and the purpose of the work is easily communicated. It is important to remember to improve the standardised work each time a line balance is done, i.e. improving the instructions for the operators and rearrange the work to raise the productivity. By using the standardised instruction from phase two as a platform these should be improved and more detailed for every new defined process. Because of the work in phase four is iterative the control of the valve and pipe process is going to increase over time and with control improvements are easier to implement. The work in phase three with 5S is to be continued when line balancing because when new defined processes are implemented material and equipment has to be moved to suit the new work method.

Phase four also includes the last step in 5S *Sustain* which is really not a task but more of a new way to think, change of mindsets. This depends of the management and their way of promoting and continues thinking of 5S while moving on to other tasks and projects. 5S is standardised but could not be forgotten but instead a natural way of working for the whole organisation.

7.2.3 MPU for future ideal state

The productivity is calculated to increase with 107 percent when ideal state is implemented compared to current state, see Appendix J – MPU calculation. To do the calculations the same procedure as for the immediate state is done. The method value is calculated to an improvement of 34 percent compared to the current state while the improvement for the immediate state was 23 percent. This is mainly due to the fact that less moving is supposed to be necessary because of more standardised way of working and the operators have better routines. The performance value is the one improving the most compared to the improvement for the immediate state that was 3 percent. For the ideal state compared to the current state the performance is supposed to improve with 21 percent which is because of the skill level would increase over time. The skill level will improve both because the operators have more working time but also that the way of working is standardised and it is easier to learn with the included instructions. The ideal states value for utilisation is improving to 42.8 percent which is an improvement of 27 percent compared to the current state. The utilisation increases because of the standardised way of working, the operators know what to do and improvements within the working progress are more easily done. But the implementation of 5S and a standardised working environment, the operators know where to find the equipment and material they need, is also adding to the improvement of utilisation.

The three values are multiplied, as described in 2.6 - MPU, with the productivity improvement of 107percent.

8 Conclusions and future recommendations

The conclusions that can be drawn from the studies conducted will be presented in this chapter. The objectives stated in the beginning will be addressed and answered. In addition to this future recommendations on how to proceed will be presented.

To address the main purpose of the thesis: *How can the valve and piping process be changed, in accordance with the VPS framework, to increase productivity compared to the current situation?* This thesis presents, based on thorough data collection and analysis, a time plan with different phases that will increase the productivity. It has been shown that with the proposed immediate changes the productivity will increase by approximately 49 percent according to the MPU method. Furthermore it has been shown that the long term changes to the process will increase the productivity by 107percent according to the MPU method. This is possible by introducing a new way of continuously improving the process which is based on operator participation in order to catch the knowledge they posses.

In relation to the question: *Is it possible to change the production flow of the valve and piping process to increase process stability?* The conclusion is that it is feasible. It has been shown that by setting up basic work stations with standardised work content the workload will be more balanced and evenly spread thus creating a more stable throughput. However it has also been shown that the process stability to a large extent depends on the quality of the chassis coming in to the process. If this is not taken care of the idea of standardised work will not be possible to implement. The process stability will further increase once the continuous improvement work is set in place since that will in standardising the process even more.

Connected to the answer above are the conclusions that can be drawn in relation to the question: *How can the WIP be reduced within the area to reduce lead times and thereby increase the productivity?* By continually improving the stability of the process the need for buffers will diminish, meaning reduced WIP. It has also been shown that through changes in the station layout the WIP number can be reduced even further. When producing Volvo the WIP has been shown to decrease from eleven to nine in the immediate state to in the ideal state reach to eight WIPs. The suggested solution is shown to decrease the WIP for Mack from nine to five for the immediate state. However this builds on the fact that the processes looks different for the different brands, something that might prove to be a challenge to fulfil if work is to be standardised between the brands.

In order to make the continuation of this project easier the authors of this report have a list of recommendations that should be considered while new changes are to be implemented or tested within the factory. Some of the points are specific to the project in this thesis while others are also valid as a general guideline when undertaking projects regarding changes in the production.

- Develop and implement a process for following up changes within production.
- Use facts to decide what changes should be made in the production flow, which requires gathering data.
- Move the work of delivering products between station 120 and its customers from the operator at station 120 to logistics.
- Investigate how to implement pull production within the factory.
- Implement a mixed main line to decrease for instance inventory and complexity of the production flow.
- Develop a culture where more of other factories experiences are considered.
- Develop computer software for the pre-cutting station giving the specifications of pipes and hoses to be cut as done at Volvo Brazil.
- VSM is difficult to use when the production is instable to large extent because it is a snapshot of the process.

9 References

ALMSTRÖM, P. (2008) Productivity Potential Assessment. Göteborg, Chalmers tekniska högskola.

BAUDIN, M. (2002) *Lean Assembly: The Nuts and Bolts of Making Assembly Operations Flow*, Productivity Press.

DRAPER, S. (2008) The Hawthorne, Pygmalion, Placebo and other effects of expectation: some notes.

DUGGAN, K. (2002) *Creating Mixed Model Value Streams: Practical Lean Techniques for Building to Demand*, Productivity Press.

FREIVALDS, A. & NIEBEL, B. (2009) *Methods, Standards, & Work Design*, McGraw-Hill Science/Engineering/Math.

GROSS, J. & MCINNIS, K. (2003) *Kanban Made Simple: Demystifying and Applying Toyota's Legendary Manufacturing Process*, AMACOM.

HELMRICH, K. (2008) Productivity Processes & Harvesting. Göteborg, Chalmers tekniska högskola.

HESSEL, P. & LINDEBERG, M. (2008) 2 brands in 1 production line. *Product and production development.* Göteborg, Chalmers tekniska högskola.

JACOBSSON, JANINE. (2009) *Discussion regarding valve and pipe process in Tuve.* (Personal communication, Q1-Q2 2009)

JONSSON, P. & MATTSSON, S.-A. (2008) *Production and materials management,* Göteborg, Chalmers tekniska högskola.

LAINE, M. & ELG, D. (2006) Productivity Management at Nexans. *Industriel l Organisation och Ekonomi* Jönköping, Högskolan i Jönköping.

LANE, G. (2007) *Made to Order Lean: Excelling in a High-Mix, Low-Volume Environment*, Productivity Press.

LIKER, J. (2004) *The Toyota Way*, McGraw-Hill.

MASCITELLI, R. (2006) *The Lean Product Development Guidebook: Everything Your Design Team Needs to Improve Efficiency and Slash Time to Market*, Technology Perspectives.

MATSON, J. & MATSON, J. (2007) Just-in-time implementation issues among automotive suppliers in the southern USA. *Supply Chain Management: An International Journal,* 12**,** 432-443.

MATSUI, Y. (2007) An empirical analysis of just-in-time production in Japanese manufacturing companies. *Int. J. Production Economics* 108**,** 153-164.

MOORE, R. (2007) *Selecting the Right Manufacturing Improvement Tools: What Tool? When?*, Butterworth-Heinemann.

OHLSSON, C. (2008) Increasing the productivity by introducing a more efficient way to work. *Material- och tillverkningsteknik.* Göteborg, Chalmers tekniska högskola.

PASCAL, D. (2007) *Lean Production Simplified*, Productivity Press.

SANTOS, J., WYSK, R. & TORRES, J. (2006) *Improving Production with Lean Thinking*, Wiley.

TAVARES, LUÌS FELIPE. (2009) *Discussion regarding valve and pipe process in Brazil.* (Personal communication, Q1-Q2 2009)

VOLVO (2008) Training module – Value Stream Mapping.

VOLVO (2009a) Company: Volvo Trucks - Volvo Trucks Global.

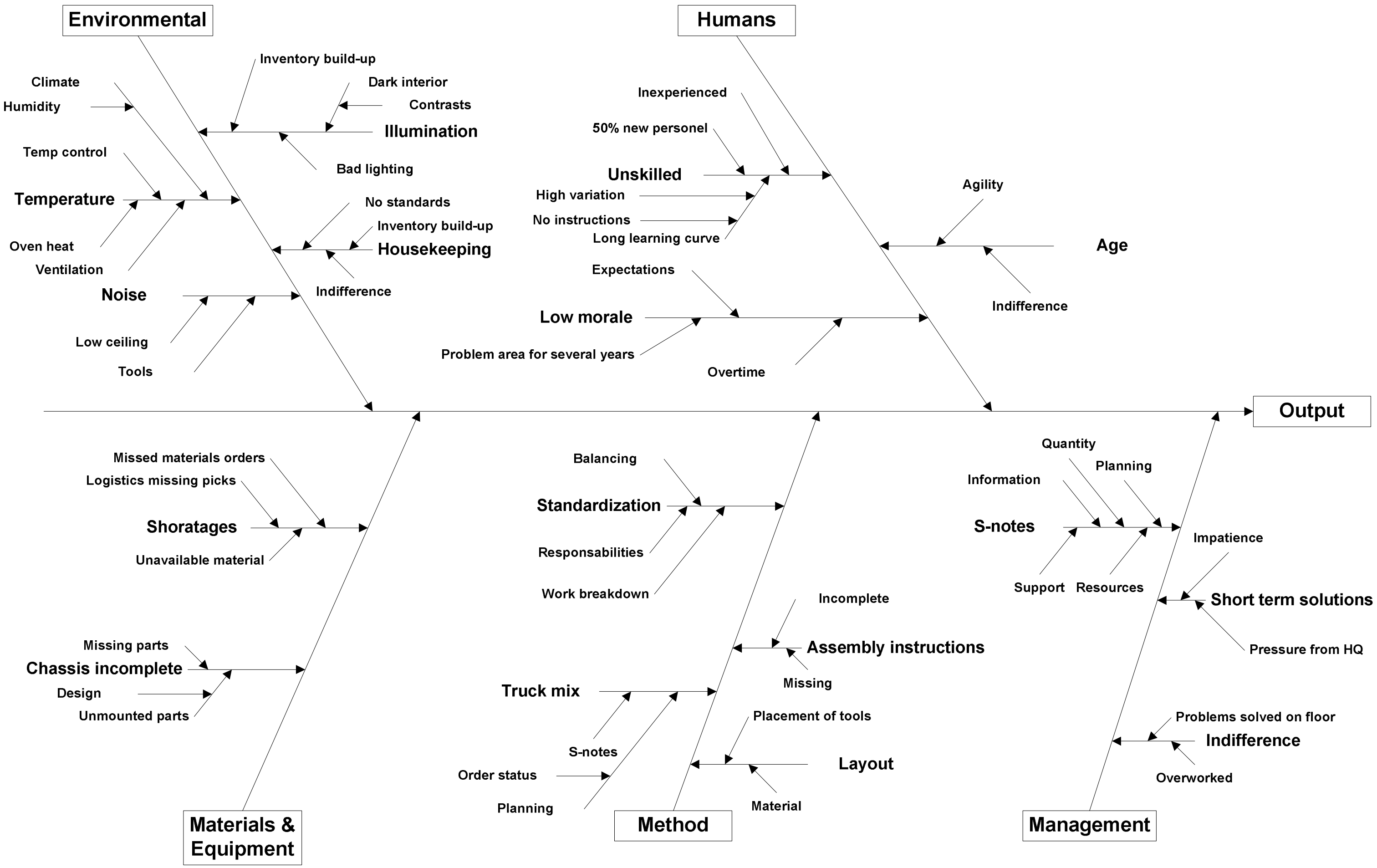
VOLVO (2009b) Global Manufacturing Business Plan.

VOLVO (2009c) Volvo Production Systems - Slides from training material.

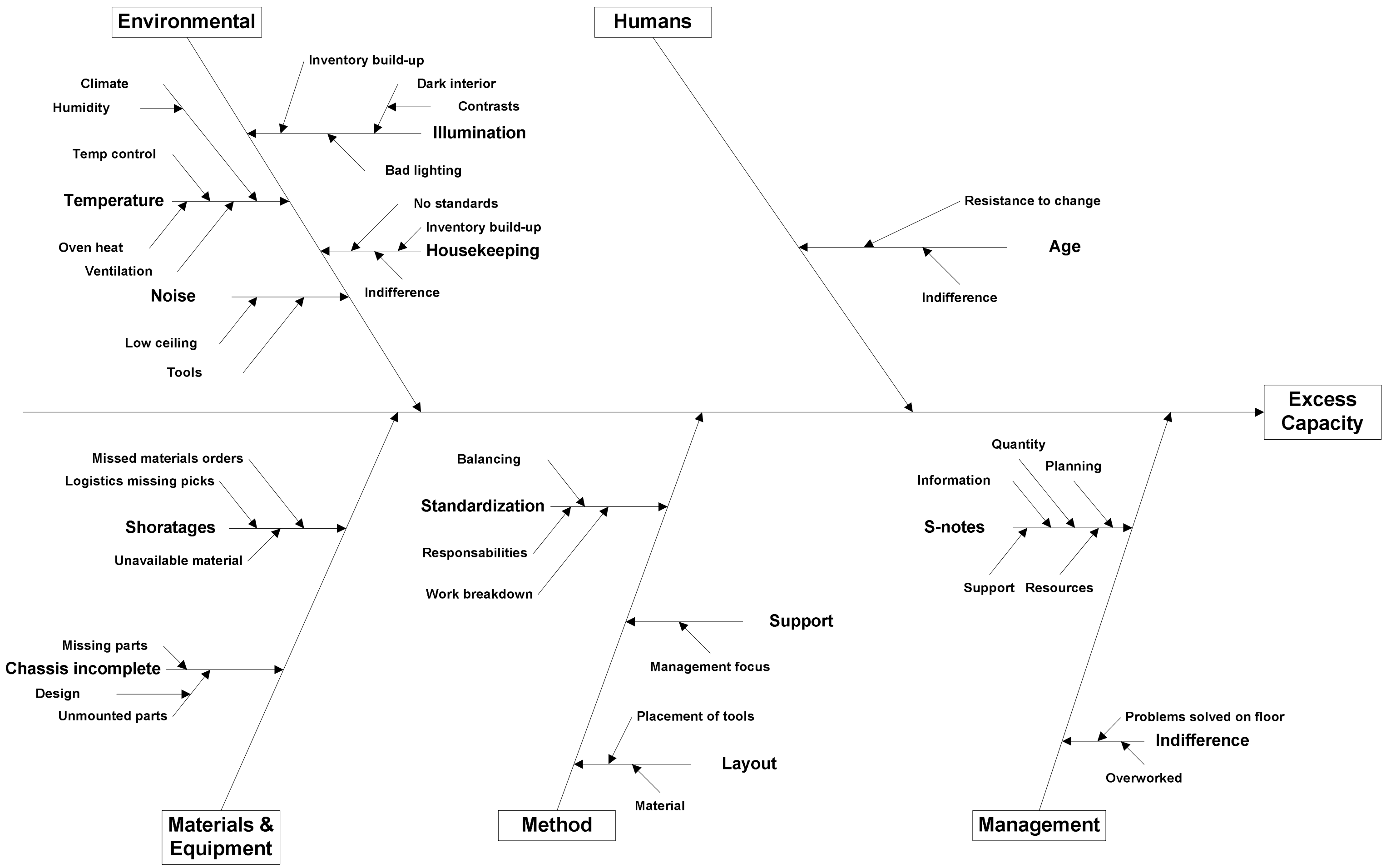
ÅHLSTRÖM, P. (2004) Humans Relations: Elton Mayo & the Hawthorne Investigation.

Appendix A – Fishbone diagram

Fishbone diagram showing potential problems in the pipe area



Fishbone diagram showing potential problems in the valve area

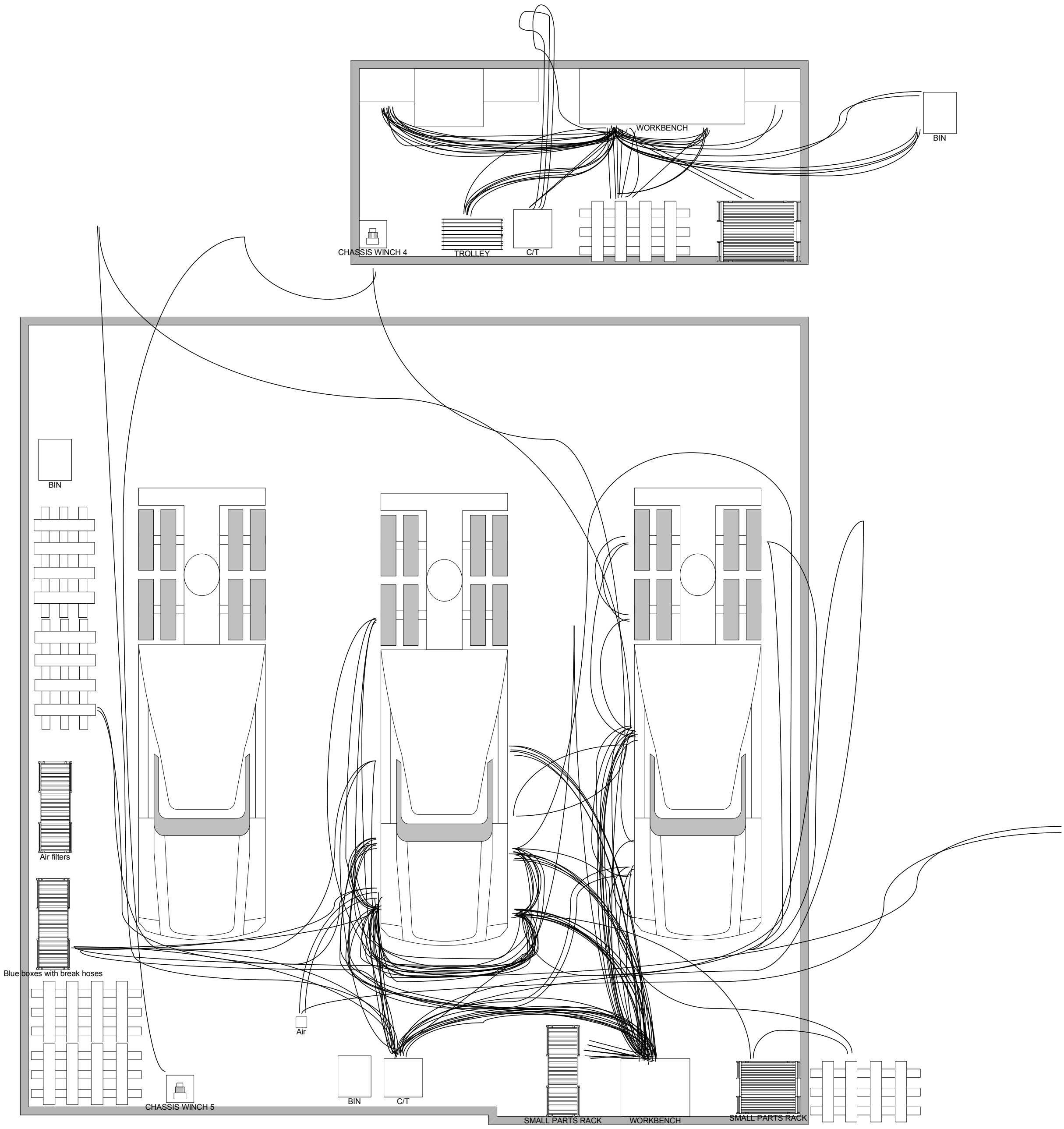


Appendix B – Spaghetti diagrams

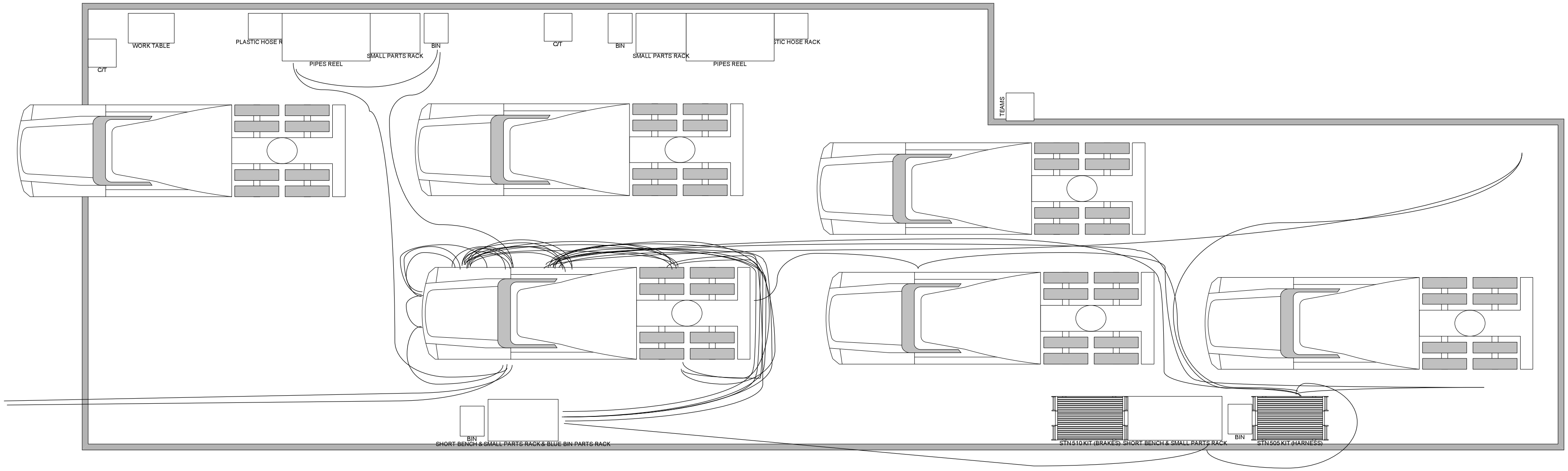
Spaghetti diagram showing the movement in the Valve area

The upper square shows the sub-assemble of valves with 1 operator working on 1 kit to 1 chassis in 1 hour

The lower square shows the valve assembling with 1 operator working on 1 chassis in 1 hour

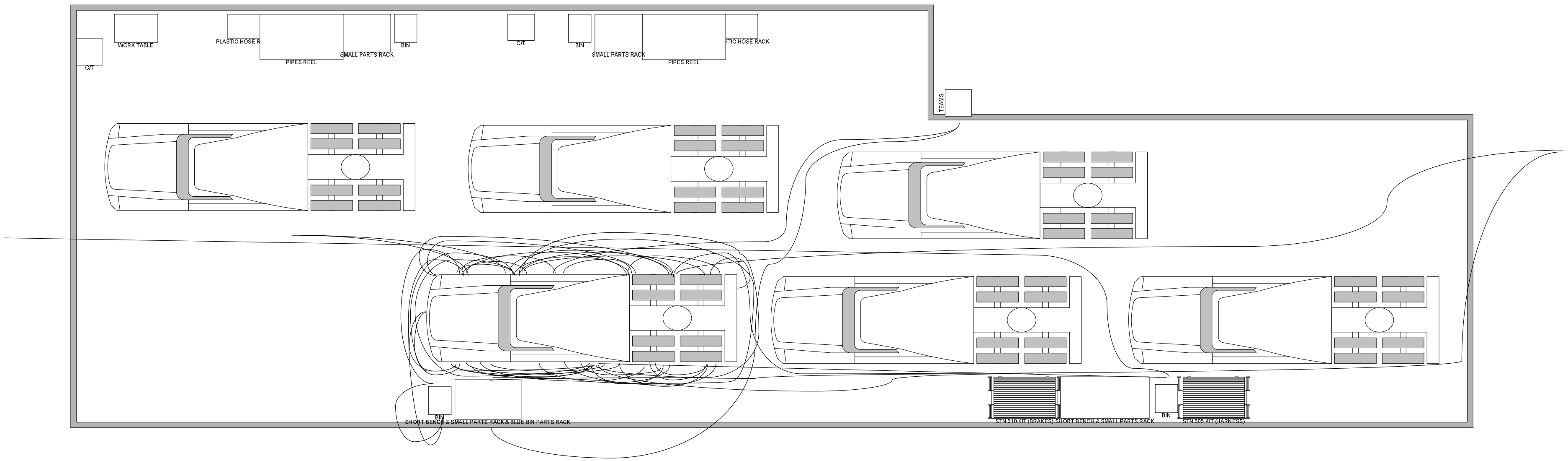


Spaghetti diagram showing the movement in Mack harnessing



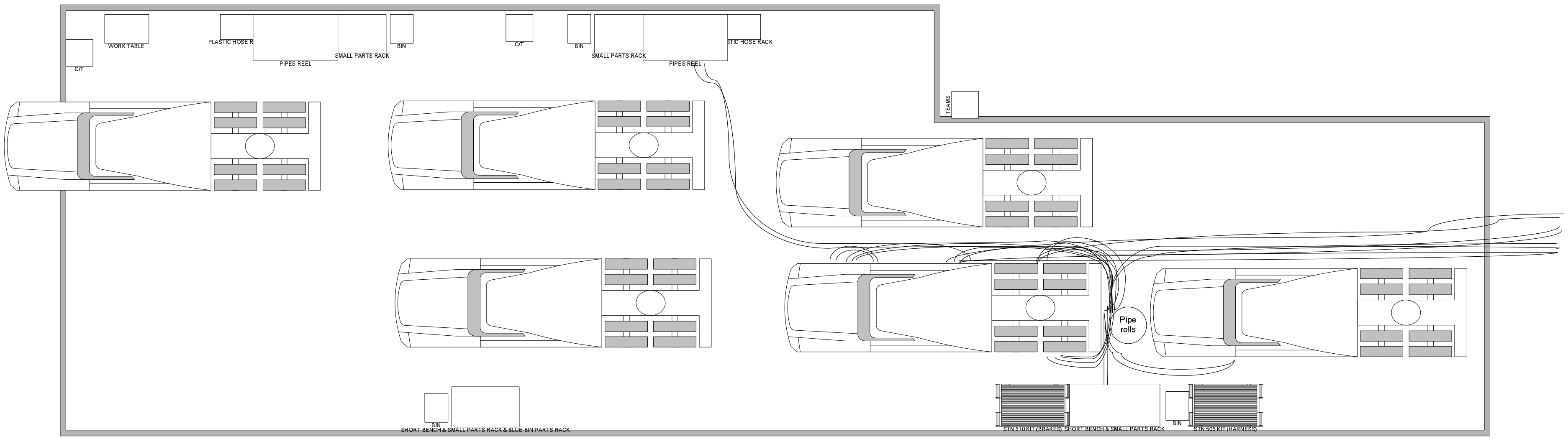
1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in the Volvo harnessing



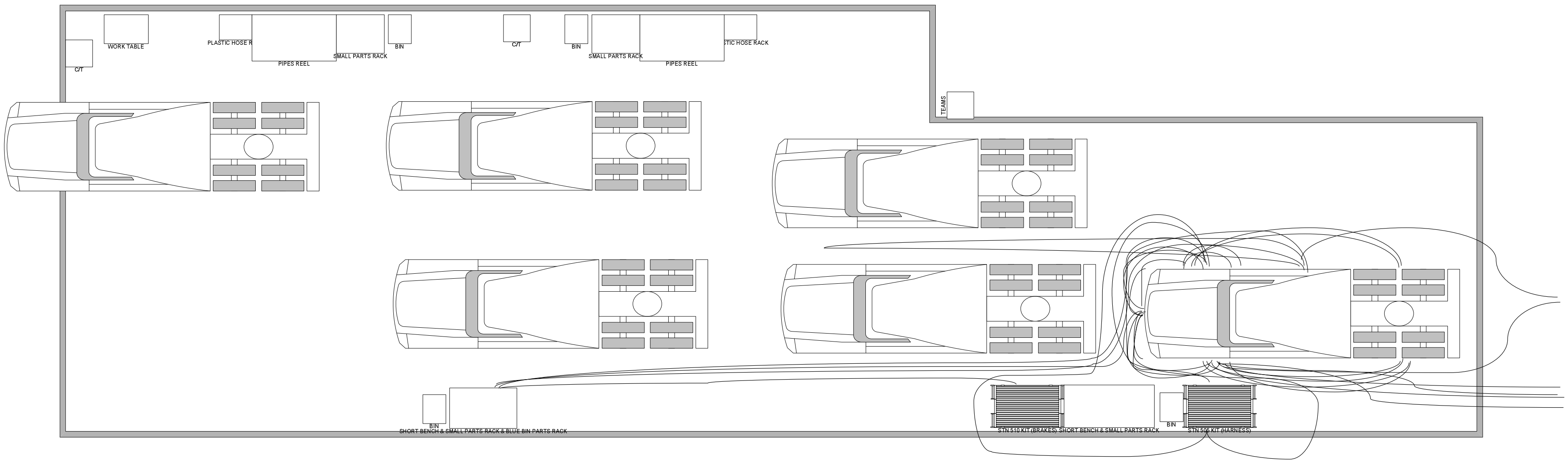
2 operators working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Mack piping station one



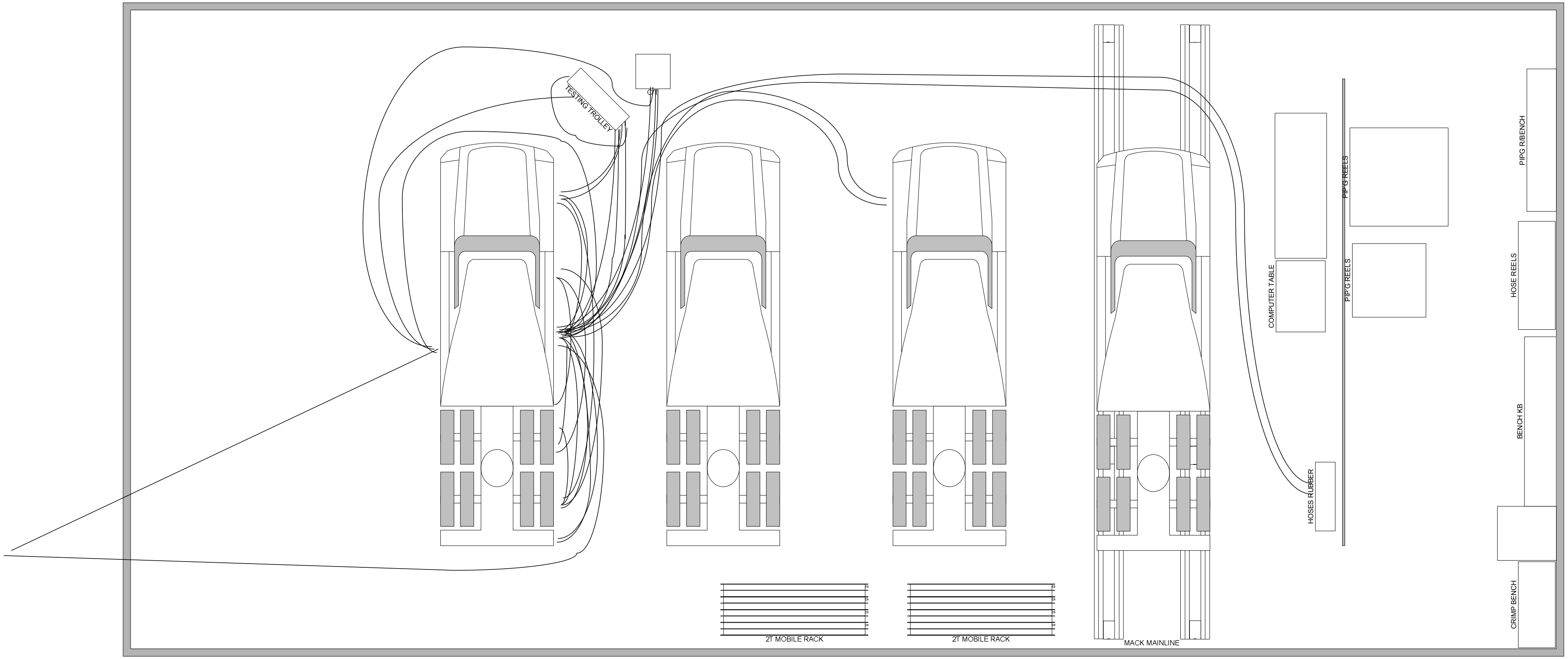
1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Mack piping station two



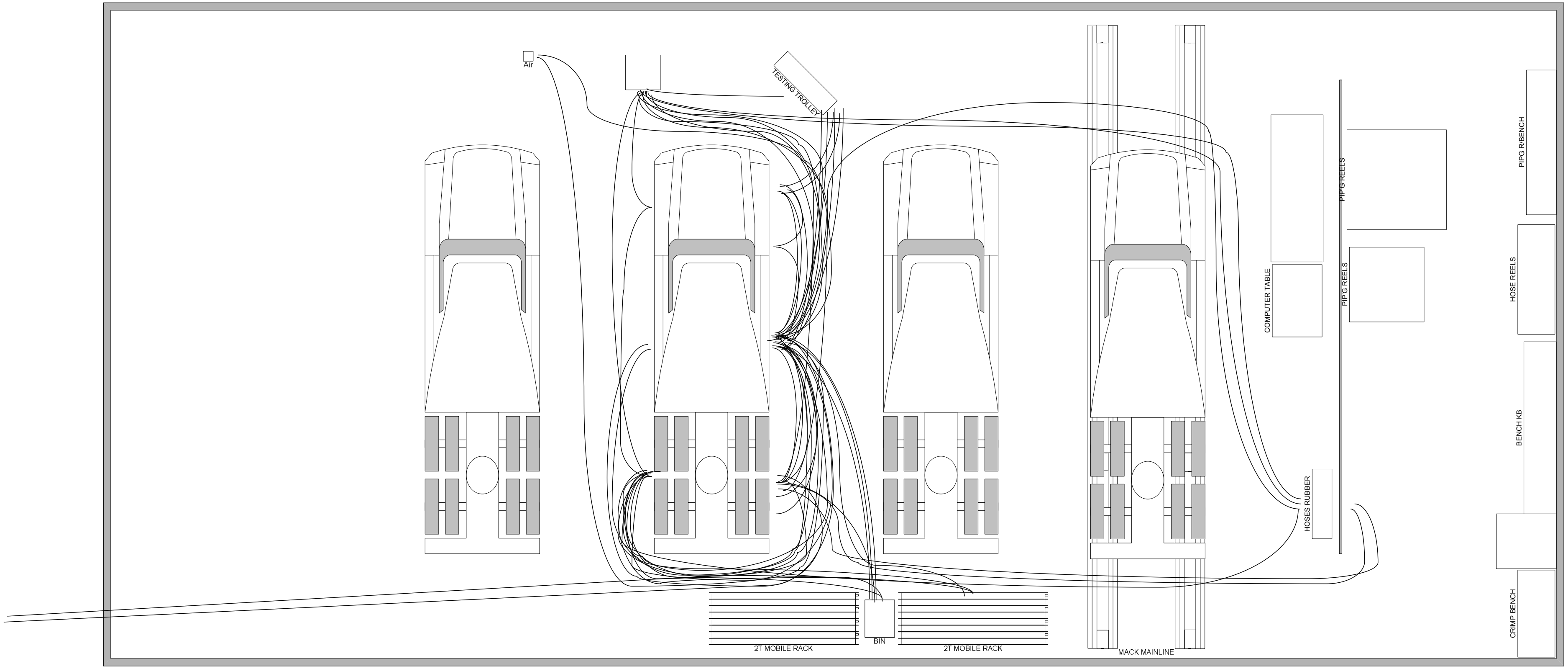
1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Mack piping station three



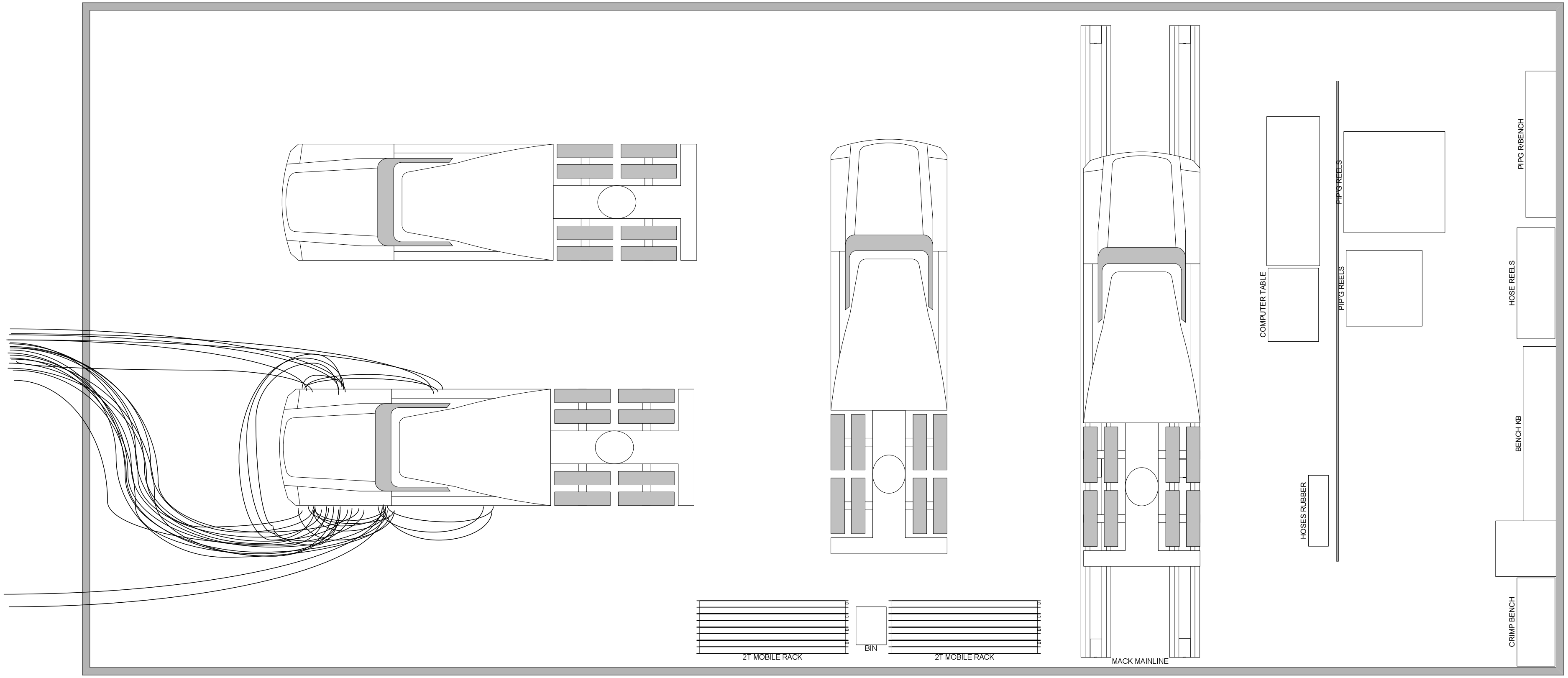
1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Mack piping station four



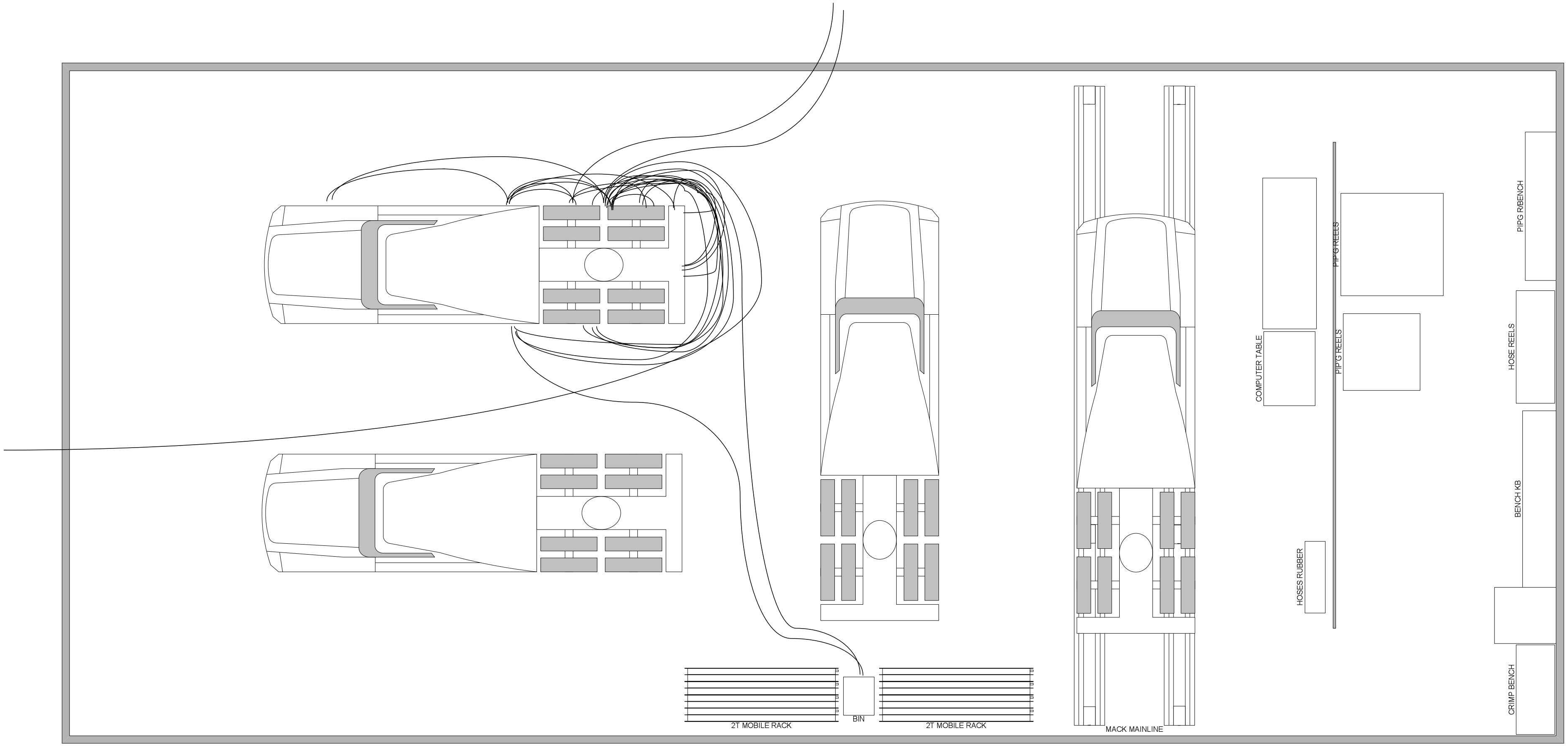
1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Volvo piping station two



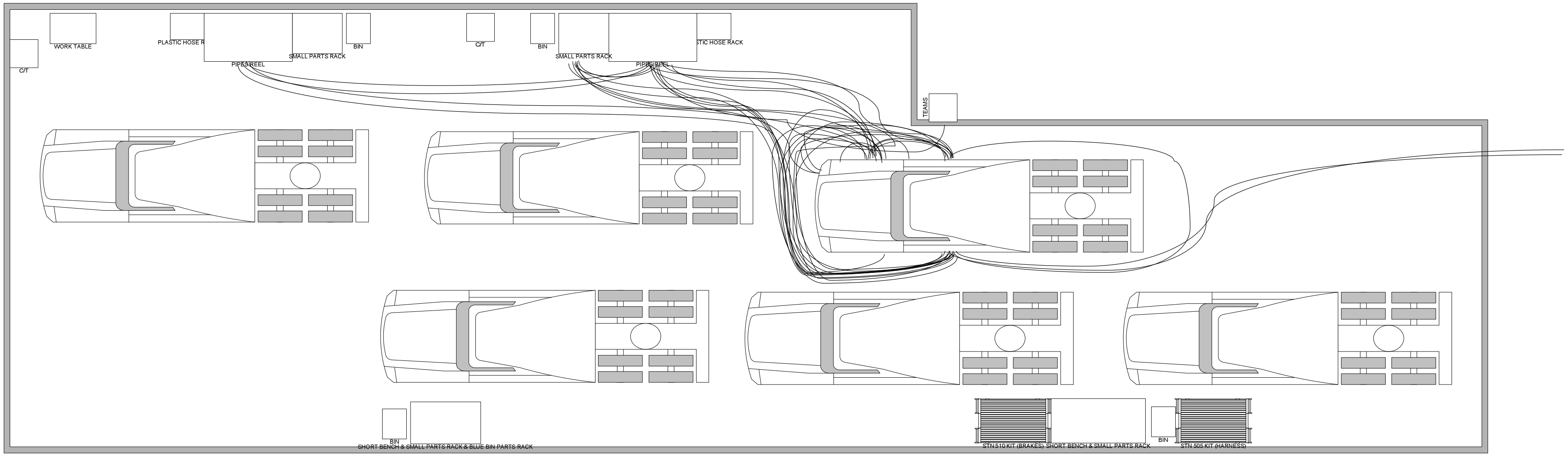
1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Volvo piping station three



1 operator working on 1 chassis in 1 hour

Spaghetti diagram showing the movement in Volvo piping station four



1 operator working on 1 chassis in 1 hour

Appendix C – Lead times

Date	Model	From oven	Valving	Buffer Valve area	Buffer Pipe area	Piping	Buffer Pipe area	To mainline	Lead time Valves	Lead time Piping	Lead time total
23/2 2009	CMM 64 R	13:00	x	x	08:15	08:20	12:15	07:45	04:10	07:35	11:45
	CSM 84 R	14:15	x	07:15	08:15	10:50	07:00	09:50	02:55	09:20	12:15
22/2 2009	CSM 64 R	06:05	06:30	07:45	08:20	12:00	07:30	10:35	02:15	10:00	12:15
	CMH 64 T	08:20	08:25	10:00	x	10:50	11:25	11:40	x	x	x
	CSM 84 R	09:20	09:40	11:10	13:35	06:05	11:55	13:15	03:25	07:45	11:10
	CLX 64 T	10:45	10:50	12:15	14:25	06:30	12:00	14:40	03:10	08:20	11:30
	CMM 64 T	11:45	12:00	14:10	14:30	08:50	14:20	07:20	02:15	09:25	11:40
	CSM 84 R	13:35	14:05	x	08:15	09:05	07:30	08:30	03:35	07:55	11:30
	CSM 64 R	14:35	14:50	08:40	09:50	x	x	09:55	03:20	07:40	11:00
25/2 2009	CLX 64 T	06:05	07:00	x	x	11:55	10:40	11:00	x	x	x
	CSM 84 R	08:20	08:50	x	11:55	13:45	10:40	11:50	03:15	07:30	10:45
	CMH 64 T	10:00	11:05	x	x	x	x	13:50	x	x	x
	CXX 64 T	11:10	12:15	-	x	07:15	-	14:50	x	x	x
	CMM 64 T	12:30	06:30	-	07:40	08:55	13:00	07:20	03:05	07:45	10:50
	CSM 84 R	14:15	07:00	08:10	08:45	10:15	14:30	08:40	03:00	08:00	11:00
26/2 2009	CLX 64 T	06:30	07:50	-	10:40	11:20	08:45	10:15	03:50	07:40	11:30
-25 min cause of morningmeeting 0600-0630	CSM 84 R	07:50	08:10	10:45	11:15	13:15	08:40	11:35	02:55	08:25	11:20
	CMH 64 R	08:55	08:55	-	12:05	14:30	10:10	13:05	02:50	08:35	11:25
	CLX 64 T	10:15	10:35	-	14:20	06:05	13:00	14:10	03:35	07:55	11:30
	CMM 64 R	11:40	11:45	-	06:05	07:00	13:25	07:05	02:55	09:05	12:00
	CLX 64 T	13:00	13:30	06:55	07:20	09:05	06:50	08:15	03:15	09:00	12:15
	CSM 64 R	14:30	14:45	07:40	08:00	11:10	07:05	09:20	02:25	09:25	11:50

Date	Model	From oven	Valving	Buffer Valve area	Buffer Pipe area	Piping	Buffer Pipe area	To mainline	Lead time Valves	Lead time Piping	Lead time total
27/2 2009	CLX 64 T	06:15	07:40	-	09:05	12:10	10:30	10:50	02:50	09:30	12:20
	CSM 84 R	07:20	08:05	10:35	11:20	14:10	11:20	11:55	03:30	08:40	12:10
	CSM 84 R	08:20	10:15	12:10	13:10	14:35	12:15	13:45	04:00	08:40	12:40
	CLX 64 T	09:45	x	13:45	14:20	06:20	x	14:45	04:05	08:30	12:35
	CSM 64 R	11:20	13:05	14:25	07:05	07:30	x	07:15	04:10	08:15	12:25
	CLX 64 T	13:10	14:20	-	08:05	09:05	-	08:20	03:50	08:20	12:10
	CSM 84 R	14:20	x	-	09:10	11:20	09:40	10:10	03:45	08:45	12:30
2/3 2009	CLX 64 T	07:10	07:20	09:50	10:25	11:55	x	11:35	02:55	09:15	12:10
	CMH 64 T	08:10	x	11:00	11:45	x	x	x	03:15	x	x
	CMH 64 T	09:20	09:45	12:15	13:10	06:30	x	13:15	03:00	08:10	11:10
	FH 64 T	10:20	11:00	13:10	13:55	07:35	14:30	09:05	03:05	12:40	15:45
	FM 84 R	11:20	13:00	x	07:50	09:40	10:15	11:05	04:55	10:00	14:55
	FM 64 R	14:05	06:05	07:10	08:10	09:50	10:50	12:15	03:00	11:50	14:50
3/3 2009	FH 64 T	06:05	06:15	07:55	08:45	13:00	10:10	14:00	02:40	12:30	15:10
	FM 84 R	07:10	07:10	09:20	11:00	14:45	-	14:45	03:30	11:20	14:50
	FH 64 T	08:20	08:25	10:25	14:45	06:35	14:45	07:50	04:35	09:40	14:15
	FM 64T	09:40	10:10	11:30	07:25	08:20	07:55	08:45	06:10	09:00	15:10
	FH 64 T	11:05	11:15	x	08:00	08:45	x	10:10	05:20	09:30	14:50
	FM 84 R	14:50	14:50	-	10:00	10:15	x	11:30	03:45	09:10	12:55
4/3 2009	FH 64 T	07:30	07:30	10:10	11:25	11:30	x	13:05	03:35	08:50	12:25
	FM 84 R	08:30	08:45	10:55	13:05	13:20	-	06:35	03:45	09:55	13:40
	FH 64 T	10:15	10:45	12:25	14:15	14:35	07:00	07:40	03:30	10:00	13:30
	FM 64 R	11:30	11:55	13:35	14:30	06:55	-	08:35	02:30	10:35	13:05
	FH 64 T	13:10	13:15	06:20	07:30	08:15	-	09:55	02:50	10:10	13:00
	FH 64 T	14:20	14:30	08:50	08:55	08:55	-	11:25	03:05	10:15	13:20

Date	Model	From oven	Valving	Buffer Valve area	Buffer Pipe area	Piping	Buffer Pipe area	To mainline	Lead time Valves	Lead time Piping	Lead time total
5/3 2009	FM 84 R	06:30	07:10	x	10:05	10:15	-	13:00	03:15	10:30	13:45
-25 min cause of morningmeeting 0600-0630	FH 64 T	07:55	-	09:05	11:40	11:40	-	13:20	03:25	08:55	12:20
	FH 64 T	09:10	09:40	10:25	13:10	13:30	Buffer		03:10	x	x
	FM 64 T	10:45	x	12:20	14:50	06:05			03:25	x	x
	FM 42 T	11:30	x	13:35	06:20	06:35			04:15	x	x
	CSM 64 R	13:20	13:35	x	08:35	08:45	-	08:10	04:10	07:40	11:50
	CSM 84 R	14:55	06:05	07:40	-	11:25	-	09:45	05:05	06:25	11:30
6/3 2009	CSM 84 R	06:30	x	08:20	11:30	11:30	09:50	11:05	04:40	07:40	12:20
	CSM 84 R	08:40	x	10:00	-	x	10:00	13:30	x	x	x
	CXX 64 T	10:25	10:25	11:25	-	06:30	13:00	14:45	04:30	05:55	10:25
	CSM 84 R	11:35	11:35	14:30	06:05	08:00	13:30	07:10	02:55	08:40	11:35
	CSM 84 R	13:30	x	07:05	07:30	08:20	13:45	08:25	02:55	08:30	11:25
	CMM 64 R	14:40	x	07:55	08:20	09:55	08:00	09:50	02:35	08:40	11:15
9/3 2009	CMM 64 R	08:05	07:10	08:30	09:55	10:05	08:30	10:45	01:30	08:25	09:55
-30 min cause of Monameeting 1200-1230	CMM 64 R	07:45	08:10	09:20	11:20	13:40	08:30	11:50	03:15	08:05	11:20
	CSM 64 R	09:00	09:00	10:40	13:45	14:35	X	13:20	03:25	07:40	11:05
	CMM 64 T	10:35	10:35	13:40	14:55	06:35	11:10	14:15	03:20	07:25	10:45
	CSM 84 R	11:40	13:10	14:40	07:55	07:35	11:50	14:50	04:10	06:05	10:15
	CSM 84 R	13:50	13:50	06:40	08:45	X	14:25	07:20	03:50	06:40	10:30
10/3 2009	CXX 86 T	06:05	06:25	08:25	10:05	10:10	07:10	08:15	03:40	06:35	10:15
	CMM 64 T	07:40	07:50	10:00	11:20	11:40	07:55	09:45	03:20	06:30	09:50
	CSM 84 R	08:50	08:55	11:10	12:15	13:35	08:40	11:05	03:05	06:55	10:00
	CMH 64 T	10:15	10:15	-	13:40	14:25	10:20	12:10	02:55	07:05	10:00
	CMM 64 R	11:35	11:55	14:00	14:40	06:10	11:45	13:50	02:35	07:15	09:50
	CSM 84 R	12:20	13:00	06:15	06:40	07:35	12:10	14:35	02:45	07:05	09:50
	CSM 84 R	14:10	14:25	07:10	07:30	08:35	13:40	07:40	02:15	07:50	10:05

Date	Model	From oven	Valving	Buffer Valve area	Buffer Pipe area	Piping	Buffer Pipe area	To mainline	Lead time Valves	Lead time Piping	Lead time total
11/3 2009	CSM 84 R	06:25	06:25	08:15	08:35	09:45	06:40	09:10	02:10	08:15	10:25
	CSM 64 R	07:10	07:10	09:00	10:00	10:30	07:15	10:20	02:30	04:55	07:25
	CMM 64 T	08:15	09:00	10:25	11:25	12:15	09:00	11:30	02:50	07:45	10:35
	CLX 64 T	09:50	10:05	13:00	13:10	13:45	11:15	13:15	02:50	07:45	10:35
	CSM 84 R	11:10	11:45	13:40	14:00	14:45	x	14:20	02:20	08:00	10:20
	CSM 84 R	13:00	13:00	13:40	07:20	07:20	11:20	06:20	02:50	07:05	09:55
	CMM 64 T	14:50	x	x	08:20	x	x	07:30	02:00	07:15	09:15
12/3 2009	CSM 84 R	08:10	08:10	x	10:00	10:00	x	10:00	01:30	08:05	09:35
-25 min cause of morningmeeting 0600-0630	CMM 64 T	09:15	09:45	-	11:35	11:35	x	08:30	02:00	05:20	07:20
	CXX 64 T	12:30	13:00	-	14:20	14:20	Buffer		01:20	x	x
	FM 84 R	14:10	14:10	-	06:40	06:50	07:15	07:30	01:25	08:55	10:20
13/3 2009	FH 64 T	06:05	06:15	-	07:35	07:35	07:15	08:35	01:30	09:05	10:35
	FM 84 R	06:50	x	x	09:40	09:40	-	10:25	02:30	08:50	11:20
	FM 64 T	x	x	x	09:45	10:50	11:05	11:30	x	09:50	x
	FH 64 T	09:00	x	x	x	x	x	13:55	x	x	x
	FH 64 T	11:30	x	x	x	13:55	14:15	14:45	x	x	x
	FM 64 T	13:00	x	x	x	06:05	06:05	07:00	x	x	x
	FM 64 T	14:05	14:05	-	06:30	07:00	07:35	08:00	01:20	09:35	10:55
	FH 64 T	14:55	06:30	08:40	08:50	08:55	08:55	09:05	02:50	08:20	11:10
16/3 2009	FH 84 T	07:50	08:45	-	11:05	11:05	-	12:25	02:55	09:25	12:20
	FM 64 T	08:50	x	11:25	11:55	x	11:40	13:35	02:45	09:15	12:00
	FM 64 T	10:25	10:45	13:10	14:00	x	-	06:05	03:05	09:05	12:10
	FH 64 T	11:25	12:05	13:55	14:20	14:35	06:05	07:50	02:25	10:30	12:55
	FH 84 T	12:25	13:05	07:00	07:25	07:25	-		03:30	x	x
	FM 64 T	14:05	14:15	-	07:35	07:35	10:05		02:25	x	x

Date	Model	From oven	Valving	Buffer Valve area	Buffer Pipe area	Piping	Buffer Pipe area	To mainline	Lead time Valves	Lead time Piping	Lead time total
17/3 2009	FM 64 R	06:40	07:30	08:20	09:55	09:55			02:55	x	x
	FH 64 T	08:05	08:15	-	10:15	10:35			01:50	x	x
	FM 64 T	09:40	09:45	11:15	13:20	13:30			03:10	x	x

One colour is one day
x is describing that the time was not recorded.
- describes that the chassis was not present in that category, e.g. moving directly from one station to the next not present in the buffer between.
One working day is 6:00 am to 3:00 pm.
The calculation is done by rounding off the end time of a working day to 3:00 pm from 2:57 pm.
All breaks ar excluded from the leadtime values (5 min morningmeeting, 20 min breakfast and 30 lunch)
Every Thursday 25 more minutes is excluded from the work time because of the sections weekmeetings, 6:00 to 6:30 am.
Models starting with a C is of the brand Mack and if they have a F in the beginning it is a Volvo.

Appendix D – Work sampling data

Work sampling data collected in the pipe area

Activity	Pre	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	Tot	%	Time of day
Assembly	386	92	100	93	94	109	77	103	78	56	90	100	122	97	102	1699	33.98%	02:43
Handling tools	120	11	15	4	11	1	9	8	17	10	2	6	8	7	6	235	4.70%	00:22
Materials handling	158	19	34	15	32	11	8	19	11	21	34	23	18	15	22	440	8.80%	00:42
Moving chassis	46	23	0	9	13	17	3	9	16	0	14	0	0	4	11	165	3.30%	00:15
Administrative work	33	7	4	3	14	8	13	16	20	23	2	9	14	12	18	196	3.92%	00:18
Help eachother	48	11	19	0	0	7	27	0	0	0	0	6	10	0	0	128	2.56%	00:12
Cleaning	29	5	4	0	6	1	10	0	7	6	2	0	0	5	8	83	1.66%	00:08
Unrelated talking	84	15	24	9	18	27	13	11	14	36	12	36	15	25	29	368	7.36%	00:35
Moving	131	35	18	41	44	60	45	36	43	43	56	29	32	52	40	705	14.10%	01:07
Personal time	31	3	0	2	0	1	1	10	7	16	10	17	11	3	13	125	2.50%	00:12
Idle	77	27	55	20	28	6	26	37	29	42	19	21	44	36	41	508	10.16%	00:48
Other	14	27	3	32	15	26	41	29	29	22	35	32	1	19	23	348	6.96%	00:33
Total	*1157*	*275*	*276*	*228*	*275*	*274*	*273*	*278*	*271*	*275*	*276*	*279*	*275*	*275*	*313*	***5000***	***100.00%***	**08:02**

Work sampling data collected in the valve area

Activity	Pre	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	Tot	%	Time of day
Assembly	339	370	52	60	63	88	63	81	66	55	65	59	76	27	68	62	70	1664	33.28%	02:40
Handling tools	9	50	5	14	11	12	3	1	5	17	8	2	9	1	6	4	6	163	3.26%	00:15
Materials handling	71	176	26	30	23	25	14	23	42	30	28	29	23	11	21	27	25	624	12.48%	01:00
Moving chassis	24	10	2	0	0	0	18	2	0	22	0	4	0	22	0	5	0	109	2.18%	00:10
Administrative work	73	117	32	8	18	2	0	31	24	32	2	28	45	52	45	34	22	565	11.30%	00:54
Located in piping area	0	4	2	0	0	8	27	6	0	16	0	20	9	2	2	0	0	96	1.92%	00:09
Cleaning	2	6	0	1	2	0	0	5	4	0	0	0	0	14	0	0	0	34	0.68%	00:03
Unrelated talking	119	45	26	21	33	7	15	3	12	2	12	16	0	18	2	15	13	359	7.18%	00:34
Moving	174	177	26	38	37	46	32	34	30	18	24	24	33	27	47	38	46	851	17.02%	01:22
Personal time	8	37	0	5	0	0	0	0	3	0	28	13	1	8	1	0	4	108	2.16%	00:10
Idle	29	80	11	11	6	8	15	11	1	1	12	3	4	15	3	14	10	234	4.68%	00:22
Other	31	34	20	14	9	6	14	4	13	7	21	2	0	4	5	3	6	193	3.86%	00:18
Total	*879*	*1106*	*202*	*202*	*202*	*202*	*201*	*201*	*200*	*200*	*200*	*200*	*200*	*201*	*200*	*202*	*202*	***5000***	***100.00%***	**08:02**

Appendix E – Time study data

Volvo piping chassis 131541 (FH84R)

Activity	Elapsed time (h:mm:ss)	Element time (mm:ss)	Value adding time (mm:ss)	Supporting value adding time (mm:ss)	Non value adding time (mm:ss)
Operator 1 - Rear					
Mounting pipes rear axle	0:34:00	02:04	02:04		
Walking away	0:36:04	00:52			00:52
Drinking	0:36:56	00:54			00:54
Getting pipe bundle	0:37:50	00:53		00:53	
Sorting pipes	0:38:43	01:16			01:16
Checking computer	0:39:59	01:46		01:46	
Securing pipes rear axle	0:41:45	00:49	00:49		
Sorting pipes	0:42:34	00:15			00:15
Routing pipes rear axle	0:42:49	04:19	04:19		
Writing on paper	0:47:08	01:46			01:46
Cutting pipes	0:48:54	01:26		01:26	
Routing pipes rear axle	0:50:20	00:40	00:40		
Material handling	0:51:00	00:14		00:14	
Moving away fetching stool	0:51:14	00:53		00:53	
Routing pipes rear axle to batt-box	0:52:07	01:39	01:39		
Fetching cardboard from trash to sit on	0:53:46	02:02		02:02	
Routing pipes to batt-box	0:55:48	11:04	11:04		
Moved away to fetch parts from valve area	1:06:52	03:08		03:08	
Routing pipes at batt-box	1:10:00	05:28	05:28		
Securing pipes at batt-box	1:15:28	00:14	00:14		

Fetching zip-ties	1:15:42	01:17		01:17	
Routing and securing pipes at batt-box	1:16:59	10:14	10:14		
Idle + talking	1:27:13	01:35			01:35
Routing and securing pipes at rear axle	1:28:48	02:52	02:52		
Cutting pipes	1:31:40	02:30		02:30	
Routing pipes at front rear axle	1:34:10	10:16	10:16		
Idle	1:44:26	01:01			01:01
Securing pipes rear axle	1:45:27	04:58	04:58		
Idle	1:50:25	00:31			00:31
Securing pipes	1:50:56	10:57	10:57		
Sorting pipes	2:01:53	02:05			02:05
Routing and securing pipes rear axle	2:03:58	13:04	13:04		
Moving	2:17:02	00:54			00:54
Securing pipes rear axle	2:17:56	10:18	10:18		
Idle	2:28:14	04:31			04:31
Break	2:32:45	21:37			
Idle	2:54:22	01:37			01:37
Routing pipes rear axle	2:55:59	01:13	01:13		
Cleaning	2:57:12	00:42		00:42	
Idle	2:57:54	04:04			04:04
Moving chassis	3:01:58	01:55			01:55
Cleaning	3:03:53	03:25		03:25	
Routing pipes rear axle	3:07:18	29:43	29:43		
Moved away	3:37:01	03:22			03:22
Routing pipes rear axle	3:40:23	06:36	06:36		
Moved away to valve area	3:46:59	00:27			00:27
Routing pipes rear axle + mounting part	3:47:26	06:54	06:54		
Idle	3:54:20	04:10			04:10
Drinking	3:58:30	00:48			00:48

Idle + talking	3:59:18	02:07			02:07
Routing pipes rear axle + securing	4:01:25	11:20	11:20		
Idle	4:12:45	00:33			00:33
Securing pipes rear axle	4:13:18	06:53	06:53		
Idle	4:20:11	00:58			00:58
Cutting pipes	4:21:09	01:01		01:01	
Routing pipes rear axle	4:22:10	07:33	07:33		
Cleaning	4:29:43	01:37		01:37	
Routing pipes front rear axle + securing	4:31:20	04:57	04:57		
Idle	4:36:17	11:46			11:46
Routing and securing pipes middle and front rear axle	4:48:03	08:35	08:35		
Idle	4:56:38	03:49			03:49
Securing pipes middle of chassis	5:00:27	03:17	03:17		
Putting tools in bucket and replenish zip-ties	5:03:44	02:45		02:45	
Idle	**5:06:29**	**4:32:29**	**2:55:57**	**0:23:39**	**0:51:16**
Operator 2 - Rear					
Securing pipes rear rear axle	1:39:36	04:50	04:50		
Idle	1:44:26	01:01			01:01
Securing pipes rear axle	1:45:27	02:35	02:35		
Idle	1:48:02	07:48			07:48
Securing pipes	1:55:50	03:54	03:54		
Fetching pipe	1:59:44	04:14		04:14	
Routing and securing pipes rear axle	2:03:58	02:50	02:50		
Cutting pipes	2:06:48	02:28		02:28	
Idle at chassis + moving	2:09:16	08:40			08:40
Securing pipes rear axle	2:17:56	04:32	04:32		
Idle	2:22:28	10:17			10:17
Break	2:32:45	21:37			

Idle	2:54:22	01:53			01:53
Routing pipes rear end	2:56:15	01:39	01:39		
Idle	2:57:54	04:04			04:04
Moving chassis	3:01:58	01:55			01:55
Fetching bucket	3:03:53	04:58		04:58	
Routing pipes rear axle	3:08:51	45:29	45:29		
Idle	3:54:20	07:05			07:05
Routing pipes rear axle + securing	4:01:25	14:17	14:17		
Walked away to get edge protection	4:15:42	01:08		01:08	
Mounting edge protection	4:16:50	03:20	03:20		
Walked away	4:20:10	01:52			01:52
Securing pipes rear axle	4:22:02	14:15	14:15		
Idle	4:36:17	00:52			00:52
Securing pipes rear axle	4:37:09	01:29	01:29		
Getting small parts	4:38:38	03:10		03:10	
Securing pipes rear axle	4:41:48	01:26	01:26		
Idle	4:43:14	04:49			04:49
Routing and securing pipes middle and front rear axle	4:48:03	12:38	12:38		
Drinking	5:00:41	02:45			02:45
Securing cables rear axle	5:03:26	05:46	05:46		
Idle	5:09:12	00:30			00:30
Securing cables	5:09:42	19:30	19:30		
Idle	**5:29:12**	**3:49:36**	**2:18:30**	**0:15:58**	**0:53:31**
Operator 3 - Front					
Planning front piping (writing down lengths etc)	1:48:41	11:02			11:02
Moving away	1:59:43	07:31			07:31
Planning front piping (writing down lengths etc)	2:07:14	10:54			10:54
Cutting pipes	2:18:08	03:16		03:16	

Bathroom	2:21:24	02:12			02:12
Fetching zip-ties	2:23:36	02:45		02:45	
Cleaning	2:26:21	01:52		01:52	
Idle	2:28:13	04:32			04:32
Break	2:32:45	21:37			
Idle	2:54:22	01:11			01:11
Cutting pipes	2:55:33	01:57		01:57	
Moving other chassis	2:57:30	05:09			05:09
Cutting pipes	3:02:39	01:14		01:14	
Routing pipes from front	3:03:53	03:15	03:15		
Cutting pipes	3:07:08	01:47		01:47	
Routing pipes from front	3:08:55	04:11	04:11		
Cutting pipes	3:13:06	10:30		10:30	
Routing pipes from front	3:23:36	01:58	01:58		
Cutting pipes	3:25:34	03:52		03:52	
Moved away	3:29:26	12:53			12:53
Routing pipes at batt-box to front	3:42:19	02:20	02:20		
Moved away to valve area	3:44:39	00:51			00:51
Routing pipes at middle	3:45:30	11:39	11:39		
Drinking	3:57:09	01:31			01:31
Getting footstand	3:58:40	00:38		00:38	
Idle + talking	3:59:18	00:58			00:58
Routing pipes at middle	4:00:16	00:44	00:44		
Fetching zip-ties	4:01:00	05:08		05:08	
Idle	4:06:08	02:29			02:29
Fixing global fitting connection	4:08:37	00:12			00:12
Moving away to valve area	4:08:49	02:59			02:59
Mounting global fitting	4:11:48	01:17			01:17
Routing pipes at middle	4:13:05	50:43	50:43		

Moved away	5:03:48	02:31			02:31
Securing pipes front	5:06:19	14:36	14:36		
Moving to valve area	5:20:55	03:12			03:12
Cutting pipes	5:24:07	01:41		01:41	
Moved away	5:25:48	07:30			07:30
Using computer	5:33:18	01:58		01:58	
Bundling pipes in front	5:35:16	05:10		05:10	
Idle	**5:40:26**	**3:51:45**	**1:29:26**	**0:41:48**	**1:18:54**
Operator 4 - Front					
Planning front piping (writing down lengths etc)	1:48:41	11:02			11:02
Moving away	1:59:43	07:31			07:31
Planning front piping (writing down lengths etc)	2:07:14	11:04			11:04
Idle at other chassis	2:18:18	10:38			10:38
Fetching pipe bundle	2:28:56	00:58		00:58	
Idle	2:29:54	02:51			02:51
Break	2:32:45	21:37			
Idle	2:54:22	09:31			09:31
Routing pipes from front	3:03:53	25:36	25:36		
Moved away	3:29:29	04:37			04:37
Routing pipes at batt-box	3:34:06	06:37	06:37		
Moved away	3:40:43	01:36			01:36
Routing pipes at batt-box to front	3:42:19	31:41	31:41		
Cutting pipes	4:14:00	00:51		00:51	
Routing pipes middle of chassis	4:14:51	36:56	36:56		
Cleaning	4:51:47	00:46		00:46	
Moving away	4:52:33	02:47			02:47
Routing and securing pipes	4:55:20	10:30	10:30		
Idle	5:05:50	01:01			01:01

Securing pipes in front	5:06:51	09:54	09:54		
Cutting pipes	5:16:45	00:35		00:35	
Routing and securing pipes front	5:17:20	12:14	12:14		
Idle + talking	5:29:34	03:10			03:10
Securing front	5:32:44	00:44	00:44		
Cutting pipes	5:33:28	05:33		05:33	
Idle	**5:39:01**	**3:50:20**	**2:14:12**	**0:08:43**	**1:05:48**

Volvo piping chassis 131551 (FM64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1 - Rear					
Applying zip-ties rear end	0:00:00	04:14	04:14		
Idle	0:04:14	02:19			02:19
Routing and securing pipes rear end	0:06:33	01:47	01:47		
Idle	0:08:20	02:25			02:25
Securing pipes rear end	0:10:45	04:09	04:09		
Moving away	0:14:54	00:45			00:45
Idle + talking at chassis	0:15:39	00:23			00:23
Securing pipes rear end	0:16:02	01:17	01:17		
Cutting pipes	0:17:19	01:59		01:59	
Idle at other chassis	0:19:18	04:21			04:21
Routing pipes rear end	0:23:39	01:36	01:36		
Moved away to get pipes	0:25:15	01:40		01:40	
Mounting pipes rear end	0:26:55	01:46	01:46		
Idle	0:28:41	01:19			01:19

Getting pipes	0:30:00	01:03		01:03	
Mounting pipes rear end	0:31:03	07:59	07:59		
Idle	0:39:02	04:52			04:52
Securing pipes rear end	0:43:54	03:04	03:04		
Idle	0:46:58	02:23			02:23
Securing pipes rear end	0:49:21	02:03	02:03		
Moved away	0:51:24	01:21			01:21
Securing pipes rear end	0:52:45	02:56	02:56		
Idle	0:55:41	02:13			02:13
Routing pipes rear axle	0:57:54	03:18	03:18		
Toilet	1:01:12	02:29			02:29
Routing and securing pipes rear end	1:03:41	11:37	11:37		
Routing and securing middle of chassis	1:15:18	05:46	05:46		
Idle	1:21:04	01:25			01:25
Routing rear end	1:22:29	06:58	06:58		
Cutting pipes	1:29:27	01:16		01:16	
Securing pipes rear end	1:30:43	19:06	19:06		
Idle + talking	1:49:49	06:33			06:33
Moving chassis	1:56:22	02:44			02:44
Getting small parts + material	1:59:06	01:34		01:34	
Idle at chassis	2:00:40	02:31			02:31
Break	2:03:11	24:42			
Idle at chassis	2:27:53	00:14			00:14
Mounting pipes at rear axle	2:28:07	05:28	05:28		
Moving	2:33:35	00:14			00:14
Routing and mounting rear axle	2:33:49	20:14	20:14		
Idle	2:54:03	05:37			05:37
Securing pipes rear end	2:59:40	03:19	03:19		
Discussing routing	3:02:59	01:58		01:58	

Securing pipes rear end	3:04:57	11:40	11:40		
Idle	3:16:37	15:40			15:40
Routing pipes rear axle	3:32:17	12:02	12:02		
Idle	3:44:19	01:18			01:18
Securing pipes rear axle	3:45:37	05:52	05:52		
Moving away	3:51:29	06:05			06:05
Securing pipes rear axle	3:57:34	02:23	02:23		
Idle + moving to new chassis	**3:59:57**	**3:59:57**	**2:18:34**	**0:09:30**	**1:07:11**
Operator 2 - Rear					
Getting bucket	0:07:10	00:50		00:50	
Moving to other piping area	0:08:00	07:39			07:39
Idle + talking at chassis	0:15:39	00:39			00:39
Talking at other chassis	0:16:18	00:29			00:29
Cutting pipes	0:16:47	16:50		16:50	
Moving to chassis with cut pipes	0:33:37	01:24		01:24	
Talking	0:35:01	01:06			01:06
Getting small parts	0:36:07	00:34		00:34	
Securing pipes	0:36:41	04:27	04:27		
Idle	0:41:08	03:28			03:28
Securing pipes rear end	0:44:36	02:14	02:14		
Talking	0:46:50	02:45			02:45
Securing pipes middle of chassis	0:49:35	04:27	04:27		
Looking at chassis	0:54:02	02:15			02:15
Idle	0:56:17	01:47			01:47
Securing pipes rear end	0:58:04	03:33	03:33		
Missing in action	1:01:37	07:13			07:13
Securing pipes rear end	1:08:50	00:24	00:24		
Looking at other chassis + move away	1:09:14	06:44			06:44

Securing pipes rear axle	1:15:58	04:27	04:27		
Missing in action	1:20:25	03:15			03:15
Securing pipes rear axle	1:23:40	01:56	01:56		
Idle	1:25:36	00:50			00:50
Securing pipes rear end	1:26:26	06:30	06:30		
Cutting pipes	1:32:56	02:21		02:21	
Routing and securing pipes rear end	1:35:17	14:13	14:13		
Cutting pipes	1:49:30	01:49		01:49	
Mounting pipes rear end	1:51:19	05:03	05:03		
Moving chassis	1:56:22	01:48			01:48
Cleaning	1:58:10	03:15		03:15	
Missing in action	2:01:25	01:46			01:46
Break	2:03:11	24:42			
Idle at chassis	2:27:53	04:38			04:38
Routing and securing pipes rear axle	2:32:31	01:35	01:35		
Moving chassis	2:34:06	02:04			02:04
Moving around	2:36:10	01:44			01:44
Securing pipes middle of chassis	2:37:54	25:05	25:05		
Discussin routing	3:02:59	01:58			01:58
Securing pipes rear end	3:04:57	18:01	18:01		
Idle	3:22:58	05:01			05:01
Routing and mounting cables	3:27:59	02:11	02:11		
Moving away	3:30:10	01:21			01:21
Routing pipes rear axle	3:31:31	03:38	03:38		
Talking at other chassis	3:35:09	01:50			01:50
Securing pipes rear axle	3:36:59	02:44	02:44		
Idle	3:39:43	04:02			04:02
Securing pipes rear axle	3:43:45	25:47	25:47		
Idle	4:09:32	02:48			02:48

Mounting pipes rear axle	4:12:20	10:25	10:25		
Missing in action	4:22:45	00:46			00:46
Securing pipes rear axle	4:23:31	02:44	02:44		
Moving to new chassis	**4:26:15**	**4:19:05**	**2:19:24**	**0:27:03**	**1:07:56**
Operator 3 - Front					
Routing pipes from front end	0:34:25	00:36	00:36		
Talking	0:35:01	01:01			01:01
Routing pipes from front end	0:36:02	01:08	01:08		
Idle	0:37:10	00:40			00:40
Routing pipes from front end	0:37:50	01:48	01:48		
Idle	0:39:38	02:53			02:53
Routing pipes at rear axle	0:42:31	08:35	08:35		
Moved to other chassis	0:51:06	03:07			03:07
Securing pipes rear end	0:54:13	01:20	01:20		
Moved away	0:55:33	14:17			14:17
Securing pipes rear end	1:09:50	01:08	01:08		
Talking	1:10:58	01:46			01:46
Getting pipes	1:12:44	00:35		00:35	
Mounting pipes rear end	1:13:19	07:55	07:55		
Getting pipes	1:21:14	01:15		01:15	
Routing pipes rear end	1:22:29	00:51	00:51		
Idle	1:23:20	00:37			00:37
Securing pipes rear end	1:23:57	03:51	03:51		
Moved away	1:27:48	03:14			03:14
Securing pipes rear end	1:31:02	06:45	06:45		
Idle	1:37:47	01:04			01:04
Getting pipes	1:38:51	00:38		00:38	
Mounting pipes middle of chassis	1:39:29	01:19	01:19		

Getting pipes	1:40:48	04:19		04:19	
Routing pipes from front end	1:45:07	04:42	04:42		
Idle + talking	1:49:49	00:20			00:20
Securing pipes rear axle	1:50:09	03:09	03:09		
Idle	1:53:18	03:04			03:04
Moving chassis	1:56:22	02:25			02:25
Moved away	1:58:47	03:48			03:48
Idle at chassis	2:02:35	00:36			00:36
Break	2:03:11	23:47			
Securing pipes middle of chassis	2:26:58	06:05	06:05		
Getting pipes	2:33:03	00:57		00:57	
Mounting pipes middle of chassis	2:34:00	23:39	23:39		
Getting pipes	2:57:39	04:58		04:58	
Routing pipes from front end	3:02:37	10:21	10:21		
Cutting pipes	3:12:58	01:46		01:46	
Routing pipes middle of chassis	3:14:44	01:10	01:10		
Cutting pipes	3:15:54	02:06		02:06	
Routing pipes middle of chassis	3:18:00	25:50	25:50		
Cutting pipes	3:43:50	01:26		01:26	
Routing pipes from front end	3:45:16	36:09	36:09		
Checking computer	4:21:25	00:51		00:51	
Moving to new chassis	**4:22:16**	**3:47:51**	**2:26:21**	**0:18:51**	**0:38:52**

Volvo piping chassis 131544 (FH64T)

Activity	Elapsed time (h:mm:ss)	Element time (mm:ss)	Value adding time (mm:ss)	Supporting value adding time (mm:ss)	Non value adding time (mm:ss)
Operator 1 - Rear					
Looking at instructions	0:11:19	00:19		00:19	
Moving away getting tool	0:11:38	01:12		01:12	
Walks to other chassis	0:12:50	21:48			21:48
Mounting part at rear axle	0:34:38	03:32	03:32		
Walking away	0:38:10	15:09			15:09
Mounting part at rear axle	1:53:19	02:26	02:26		
Getting small parts	1:55:45	00:35		00:35	
Moving to valve area to get parts	1:56:20	01:30		01:30	
Mounting part at rear axle	1:57:50	01:05	01:05		
Leaving tools	1:58:55	01:02		01:02	
Idle at chassis + measuring pipe	1:59:57	00:49			00:49
Cutting pipes + changing roll	2:00:46	11:39		11:39	
Routing and mounting pipes	2:12:25	02:24	02:24		
Idle	2:14:49	02:20			02:20
Break	2:17:09	22:28			
Working on other chassis	2:39:37	01:59			01:59
Mounting pipes at rear axle	2:41:36	02:04	02:04		
Getting small parts	2:43:40	00:50		00:50	
Mounting pipes at rear axle	2:44:30	03:16	03:16		
Cutting pipes	2:47:46	00:55		00:55	
Mounting pipes at rear axle	2:48:41	02:03	02:03		
Cutting pipes	2:50:44	01:00		01:00	
Mounting pipes at rear axle	2:51:44	12:04	12:04		
Looking at how to route	3:03:48	00:52			00:52

Routing and mounting pipes at rear axle	3:04:40	01:43	01:43		
Getting tool	3:06:23	00:15		00:15	
Securing and cutting zip-ties at rear axle	3:06:38	13:31	13:31		
Routing and mounting pipes middle of chassis	3:20:09	06:01	06:01		
Reading instructions	3:26:10	01:34		01:34	
Routing and mounting pipes middle of chassis	3:27:44	05:36	05:36		
Cutting pipe	3:33:20	00:47		00:47	
Routing and mounting pipes middle of chassis	3:34:07	04:02	04:02		
Moving to valve area	3:38:09	12:48			12:48
Securing pipes at rear axle	3:50:57	07:21	07:21		
Cutting pipes	3:58:18	03:55		03:55	
Routing pipes at rear axle	4:02:13	01:52	01:52		
Moved away	4:04:05	01:07			01:07
Talking to Carlos	4:05:12	01:48			01:48
Idle	4:07:00	00:28			00:28
Securing pipes at rear axle	4:07:28	11:14	11:14		
Moving away	4:18:42	01:35			01:35
Securing pipes at rear axle	4:20:17	11:06	11:06		
Cutting pipes	4:31:23	01:29		01:29	
Mounting pipes at rear axle	4:32:52	10:16	10:16		
Moving away to get zip-ties	4:43:08	00:58		00:58	
Securing pipes rear end	4:44:06	20:31	20:31		
Idle + moving	5:04:37	02:21			02:21
Securing pipes at rear axle	5:06:58	09:38	09:38		
Idle	5:16:36	01:10			01:10
Routing pipes rear end	5:17:46	00:57	00:57		
Securing pipes front rear axle	5:18:43	05:00	05:00		
Moved away	5:23:43	01:18			01:18
Lunch	5:25:01	30:59			

Securing pipes	5:56:00	04:21	04:21		
Idle	6:00:21	00:19			00:19
Securing pipes rear end	6:00:40	10:59	10:59		
Cutting pipes	6:11:39	00:17		00:17	
Mounting pipes rear end	6:11:56	05:30	05:30		
Getting small parts	6:17:26	00:55		00:55	
Securing pipes rear end	6:18:21	03:06	03:06		
Idle	6:21:27	01:41			01:41
Securing pipes rear end	6:23:08	13:46	13:46		
Materials handling at work bench	6:36:54	01:35			01:35
Securing pipes rear end	6:38:29	08:58	08:58		
Cutting pipes	6:47:27	00:35		00:35	
Mounting pipes rear end	6:48:02	02:58	02:58		
Moving chassis	6:51:00	00:51			00:51
Cleaning	6:51:51	02:37			02:37
Idle	6:54:28	03:05			03:05
Mounting pipes rear end	6:57:33	07:22	07:22		
Moving to new chassis	**7:04:55**	**6:53:36**	**3:14:42**	**0:29:47**	**2:15:40**
Operator 2 - Front					
Mounting zip-ties	3:28:23	04:03	04:03		
Leaving + getting material + cleaning	3:32:26	03:18		03:18	
Moving away	3:35:44	05:21			05:21
Mouting fittings rear end	3:41:05	00:46	00:46		
Moving away	3:41:51	15:55			15:55
Mouting rear end	3:57:46	02:07	02:07		
Cutting pipes	3:59:53	01:20		01:20	
Routing pipes from front	4:01:13	06:01	06:01		
Talking to Carlos	4:07:14	01:43			01:43

Routing pipes rear end	4:08:57	09:45	09:45		
Moving away	4:18:42	01:50			01:50
Securing pipes at rear axle	4:20:32	11:23	11:23		
Moving away	4:31:55	01:22			01:22
Cutting pipes	4:33:17	00:23		00:23	
Securing pipes	4:33:40	05:07	05:07		
Getting small parts	4:38:47	00:24		00:24	
Securing pipes	4:39:11	04:43	04:43		
Cutting pipes	4:43:54	01:05		01:05	
Moving to get blue box	4:44:59	01:01			01:01
Sorting pipes	4:46:00	00:56			00:56
Idle	4:46:56	02:43			02:43
Mounting pipes front	4:49:39	00:34	00:34		
Moving to valve area	4:50:13	02:12			02:12
Securing pipes front + routing	4:52:25	31:33	31:33		
Idle	5:23:58	01:03			01:03
Lunch	5:25:01	30:59			
Securing pipes	5:56:00	14:56	14:56		
Walking to valve area to get valve	6:10:56	02:49		02:49	
Mounting front end	6:13:45	01:12	01:12		
Getting small parts from valve	6:14:57	01:03		01:03	
Routing and securing pipes front end	6:16:00	12:50	12:50		
Moving to other chassis	**6:28:50**	**3:00:27**	**1:45:00**	**0:10:22**	**0:34:06**
Operator 3 - Front					
Mounting pipes middle of chassis	3:35:45	01:51	01:51		
Idle	3:37:36	01:09			01:09
Mounting pipes middle of chassis	3:38:45	02:09	02:09		
Idle	3:40:54	01:26			01:26

Preparing chassis for moving	3:42:20	02:28			02:28
Cutting pipes	3:44:48	07:08		07:08	
Sorting pipes front	3:51:56	01:55			01:55
Routing pipes front to middle	3:53:51	02:44	02:44		
Moving away	3:56:35	00:22			00:22
Routing pipes	3:56:57	00:13	00:13		
Cutting pipes	3:57:10	01:46		01:46	
Routing pipes	3:58:56	01:09	01:09		
Idle	4:00:05	01:25			01:25
Helping operator 2	4:01:30	00:25	00:25		
Cutting pipes	4:01:55	00:46		00:46	
Routing pipes	4:02:41	01:15	01:15		
Idle	4:03:56	00:29			00:29
Cutting pipes	4:04:25	05:30		05:30	
Routing pipes from front end	4:09:55	01:07	01:07		
Cutting pipes	4:11:02	02:24		02:24	
Routing pipes from front end	4:13:26	00:19	00:19		
Talking + idle	4:13:45	01:34			01:34
Getting bucket	4:15:19	01:34		01:34	
Moving to valve area	4:16:53	02:00			02:00
Idle at chassis	4:18:53	00:50			00:50
Routing pipes at middle of chassis	4:19:43	12:01	12:01		
Getting stool	4:31:44	00:34			00:34
Securing pipes middle of chassis	4:32:18	38:32	38:32		
Moving to toilet	5:10:50	03:13			03:13
Securing and routing pipes middle of chassis	5:14:03	10:58	10:58		
Lunch	5:25:01	30:59			
Securing pipes	5:56:00	17:54	17:54		
Idle	6:13:54	02:06			02:06

Routing and securing pipes front end	6:16:00	07:04	07:04		
Idle	6:23:04	01:28			01:28
Securing pipes front end	6:24:32	02:18	02:18		
Idle + moving to other chassis	**6:26:50**	**2:51:05**	**1:39:59**	**0:19:08**	**0:20:59**

Mack piping chassis 800928 (CMM64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Looking at what to do	0:00:00	00:34			00:34
Moving blue box	0:00:34	00:30			00:30
Moving + idle	0:01:04	00:36			00:36
Materials handling	0:01:40	00:45			00:45
Routing pipes from rear end	0:02:25	01:43	01:43		
Walking to get foot stand	0:04:08	00:24			00:24
Routing pipes from rear end	0:04:32	04:05	04:05		
Looking at valve plate to see where its going to be mounted	0:08:37	00:40			00:40
Walking to other piping area	0:09:17	01:26			01:26
Routing pipes from rear end	0:10:43	06:17	06:17		
Moving valve plate	0:17:00	00:19			00:19
Routing pipes from rear end	0:17:19	00:30	00:30		
Getting zip-ties	0:17:49	01:11		01:11	
Securing pipes at rear axles	0:19:00	00:44	00:44		
Walking to other piping area	0:19:44	01:27			01:27
Routing pipes + securing	0:21:11	15:10	15:10		
Idle	0:36:21	00:31			00:31

Securing pipes	0:36:52	00:25	00:25		
Idle	0:37:17	00:17			00:17
Cutting pipes	0:37:34	00:47		00:47	
Routing pipes front rear axle + securing	0:38:21	03:58	03:58		
Idle	0:42:19	01:05			01:05
Break	0:43:24	20:46			
Securing pipes front rear axle	1:04:10	12:06	12:06		
Walking to other piping area	1:16:16	01:41			01:41
Mounting pipes rear axles	1:17:57	03:23	03:23		
Moving chassis	1:21:20	00:40			00:40
Moving bucket	1:22:00	01:29			01:29
Securing pipes rear axles	1:23:29	12:33	12:33		
Walking to get material (zip-ties)	1:36:02	01:10		01:10	
Securing pipes rear end	1:37:12	02:28	02:28		
Getting material	1:39:40	00:30		00:30	
Assembling at rear end	1:40:10	00:31	00:31		
Idle	1:40:41	00:28			00:28
Securing pipes rear end	1:41:09	01:48	01:48		
Sorting zip-ties	1:42:57	00:44			00:44
Idle	1:43:41	00:14			00:14
Cleaning	1:43:55	00:45			00:45
Walking to other piping area	1:44:40	01:50			01:50
Securing pipes mid-crossmember	1:46:30	14:27	14:27		
Walking + idle	2:00:57	05:09			05:09
Testing pressure	2:06:06	01:27	01:27		
Idle	2:07:33	00:11			00:11
Applying liquid to test leaks	2:07:44	05:16	05:16		
Walking to other piping area	2:13:00	05:27			05:27
Moving chassis	2:18:27	01:15			01:15

Idle	2:19:42	00:36			00:36
Moving to other chassis	**2:20:18**	**2:20:18**	**1:26:51**	**0:03:38**	**0:29:03**
Operator 2					
Looking at chassi	0:00:00	01:30			01:30
Walking away	0:01:30	03:50			03:50
Laying out cable and putting in missing zip-ties	0:05:20	00:50	00:50		
Mounting brackets	0:06:10	01:05	01:05		
Mounting zip-ties	0:07:15	01:15	01:15		
Personal time	0:08:30	06:25			06:25
Looking at chassi	0:14:55	01:15			01:15
Getting material	0:16:10	01:50		01:50	
Mounting protective rubber	0:18:00	01:20	01:20		
Adjusting harnesses	0:19:20	00:45		00:45	
Preparing working area	0:20:05	00:35			00:35
Personal time	0:20:40	00:30			00:30
Working on other chassis	0:21:10	27:20			27:20
Personal time	0:48:30	00:30			00:30
Routing pipes	0:49:00	00:30	00:30		
Talking	0:49:30	00:10			00:10
Routing pipes	0:49:40	02:55	02:55		
Idle	0:52:35	00:55			00:55
Routing pipes	0:53:30	00:50	00:50		
Idle	0:54:20	00:40			00:40
Routing pipes	0:55:00	00:40	00:40		
Idle	0:55:40	00:15			00:15
Routing pipes	0:55:55	00:05	00:05		
Idle	0:56:00	00:25			00:25
Routing pipes	0:56:25	14:00	14:00		

Talking	1:10:25	00:25			00:25
Routing pipes	1:10:50	11:10	11:10		
Idle	1:22:00	00:40			00:40
Routing pipes	1:22:40	07:00	07:00		
Personal time	1:29:40	02:25			02:25
Looking at chassi	1:32:05	00:05			00:05
Personal time	1:32:10	01:10			01:10
Idle	1:33:20	00:30			00:30
Looking at chassi	1:33:50	00:20			00:20
Idle	1:34:10	03:10			03:10
Break	1:37:20	22:40			
Routing pipes	2:00:00	14:00	14:00		
Moving chassis	2:14:00	03:00			03:00
Routing pipes	2:17:00	01:20	01:20		
Idle	2:18:20	00:40			00:40
Routing pipes	2:19:00	03:00	03:00		
Getting material	2:22:00	00:40		00:40	
Mounting	2:22:40	01:35	01:35		
Walking away	2:24:15	02:25			02:25
Routing pipes	2:26:40	00:20	00:20		
Walking	2:27:00	00:20			00:20
Routing pipes	2:27:20	00:15	00:15		
Walking away	2:27:35	03:05			03:05
Routing pipes	2:30:40	05:45	05:45		
Idle + talking	2:36:25	00:15			00:15
Looking at chassi	2:36:40	01:00			01:00
Routing pipes	2:37:40	00:30	00:30		
Looking at chassi	2:38:10	00:40			00:40
Idle	2:38:50	02:40			02:40

Getting fuel hoses and routes them	2:41:30	11:30	11:30		
Gone	2:53:00	07:10			07:10
Testing pressure	3:00:10	01:00	01:00		
Idle	3:01:10	01:25			01:25
Gone	**3:02:35**	**3:02:35**	**1:20:55**	**0:03:15**	**1:15:45**
Operator 3					
Arriving with bucket	0:49:20	00:10			00:10
Talking	0:49:30	00:10			00:10
Routing pipes	0:49:40	01:10	01:10		
Idle	0:50:50	02:10			02:10
Routing pipes	0:53:00	03:00	03:00		
Moving things	0:56:00	00:20			00:20
Routing pipes	0:56:20	00:40	00:40		
Moving things	0:57:00	00:10			00:10
Routing pipes	0:57:10	02:30	02:30		
Idle	0:59:40	00:20			00:20
Routing pipes	1:00:00	00:30	00:30		
Idle	1:00:30	00:30			00:30
Routing pipes	1:01:00	02:00	02:00		
Discussion valve plate	1:03:00	00:35			00:35
Routing pipes	1:03:35	01:35	01:35		
Discussion valve plate	1:05:10	00:15			00:15
Routing pipes	1:05:25	01:35	01:35		
Idle	1:07:00	00:10			00:10
Routing pipes	1:07:10	03:15	03:15		
Talking	1:10:25	00:25			00:25
Routing pipes	1:10:50	04:30	04:30		
Idle	1:15:20	00:20			00:20

Routing pipes	1:15:40	01:00	01:00		
Idle	1:16:40	00:40			00:40
Routing pipes	1:17:20	08:15	08:15		
Getting material	1:25:35	01:00		01:00	
Routing pipes	1:26:35	04:55	04:55		
Searching for things	1:31:30	00:25			00:25
Routing pipes	1:31:55	05:25	05:25		
Break	1:37:20	22:40			
Routing pipes	2:00:00	01:15	01:15		
Getting material	2:01:15	00:20		00:20	
Routing pipes	2:01:35	01:15	01:15		
Moving	2:02:50	00:40			00:40
Routing pipes	2:03:30	03:50	03:50		
Mounting valve plate	2:07:20	00:15	00:15		
Getting material	2:07:35	03:00		03:00	
Mounting valve plate	2:10:35	00:50	00:50		
Moving	2:11:25	00:25			00:25
Mounting valve plate	2:11:50	01:05	01:05		
Moving	2:12:55	00:15			00:15
Mounting valve plate	2:13:10	00:20	00:20		
Moving	2:13:30	00:15			00:15
Mounting valve plate	2:13:45	00:50	00:50		
Moving chassis	2:14:35	02:25			02:25
Mounting valve plate	2:17:00	06:20	06:20		
Idle	2:23:20	01:10			01:10
Walking away	2:24:30	06:10			06:10
Mounting valve plate	2:30:40	01:00	01:00		
Idle	2:31:40	01:05			01:05
Walking away	2:32:45	03:40			03:40

Idle	2:36:25	00:15			00:15
Routing pipes	2:36:40	00:45	00:45		
Fetching foot stand	2:37:25	00:10		00:10	
Routing pipes	2:37:35	01:15	01:15		
Idle	2:38:50	00:10			00:10
Routing pipes	2:39:00	00:40	00:40		
Fetching cables	2:39:40	00:20		00:20	
Routing pipes	2:40:00	01:30	01:30		
Idle	2:41:30	00:50			00:50
Laying out hoses	2:42:20	00:50		00:50	
Idle	2:43:10	03:05			03:05
Routing pipes	2:46:15	02:00	02:00		
Idle	2:48:15	00:45			00:45
Routing pipes	2:49:00	02:20	02:20		
Cleaning	2:51:20	01:20		01:20	
Idle	2:52:40	00:20			00:20
Walking away	2:53:00	03:00			03:00
Mounting pressure tester	2:56:00	02:40	02:40		
Cleaning	2:58:40	01:00			01:00
Walking away	2:59:40	03:15			03:15
Applying liquid to check for leaks	3:02:55	04:45	04:45		
Cleaning	3:07:40	03:35			03:35
Walking away	**3:11:15**	**2:21:55**	**1:13:15**	**0:07:00**	**0:39:00**
Operator 4					
Inspecting harnesses and pipes	2:26:48	04:09			04:09
Walking away getting tool + small parts	2:30:57	01:44		01:44	
Mounting	2:32:41	08:38	08:38		
Walking to get zip-ties	2:41:19	00:50		00:50	

Mounting zip-ties	2:42:09	02:37	02:37		
Inspecting harnesses and pipes	2:44:46	05:37			05:37
Walking to other chassis	**2:50:23**	**0:23:35**	**0:11:15**	**0:02:34**	**0:09:46**

Volvo valve chassis 131505 (FM84R)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Removing chain from trolley	0:00:00	00:25			00:25
Removing wheel mount protection	0:00:25	00:54	00:54		
Remove masking from paint booth	0:01:19	06:23	06:23		
Write on white board and use computer	0:07:42	00:48		00:48	
Laying out valves (preparing)	0:08:30	02:29		02:29	
Looking at what to do	0:10:59	00:21			00:21
Laying out valves (preparing)	0:11:20	01:05		01:05	
Getting small parts from workbench	0:12:25	00:50		00:50	
Mount valve rear front axle	0:13:15	01:49	01:49		
Looking at what to do	0:15:04	01:27			01:27
Mount valve front rear axle	0:16:31	00:32	00:32		
Walking	0:17:03	00:24			00:24
Mount valve rear front axle	0:17:27	00:45	00:45		
Looking at what to do	0:18:12	00:23			00:23
Getting small parts from workbench	0:18:35	00:43		00:43	
Mount valve rear front axle	0:19:18	00:47	00:47		
Getting small parts from workbench	0:20:05	00:23		00:23	
Mount valve rear front axle	0:20:28	01:22	01:22		

Getting small parts from workbench + walking	0:21:50	02:05		02:05	
Mount valve rear front axle	0:23:55	02:26	02:26		
Gettting small parts from workbench	0:26:21	00:23		00:23	
Mount valve rear front axle	0:26:44	01:56	01:56		
Mount valve mid crossmember	0:28:40	00:20	00:20		
Laying out material, bolts etc (preparing, walking around)	0:29:00	00:30		00:30	
Mount valve mid crossmember	0:29:30	00:31	00:31		
Getting small parts from workbench + tool	0:30:01	00:19		00:19	
Mount valve mid crossmember	0:30:20	00:38	00:38		
Mount valve front rear axle	0:30:58	00:42	00:42		
Walking	0:31:40	00:38			00:38
Mount valve front rear axle	0:32:18	00:52	00:52		
Talking	0:33:10	02:17			02:17
Getting small parts from workbench	0:35:27	00:13		00:13	
Walking away	0:35:40	00:35			00:35
Mounting protection cushions on bars	0:36:15	00:29	00:29		
Getting parts from paint rack	**0:36:44**	**0:36:44**	**0:20:26**	**0:09:48**	**0:06:30**
Operator 2					
Clear coat VIN	0:06:50	00:14	00:14		
Work on other chassis	0:07:04	55:55			55:55
Using tugger to move chassis	1:02:59	02:04			02:04
Drinking	1:05:03	00:17			00:17
Walking away	1:05:20	05:57			05:57
Looking at what to do	1:11:17	01:23			01:23
Getting small parts from workbench + tools	1:12:40	01:50		01:50	
Putting bolts in rails	1:14:30	02:20	02:20		
Talking	1:16:50	00:44			00:44
Walking and looking	1:17:34	00:38			00:38

Idling	1:18:12	02:23			02:23
Getting tools from workbench	1:20:35	00:35		00:35	
Mount valves front axles	1:21:10	01:15	01:15		
Putting zip-ties in holders	1:22:25	00:51	00:51		
Moving to be idle	1:23:16	01:58			01:58
Talking about placement of valve	1:25:14	00:39			00:39
Using computer	1:25:53	04:09		04:09	
Clear coat VIN	1:30:02	01:41	01:41		
Work on other chassis	1:31:43	00:54			00:54
Moving chassis	1:32:37	02:18			02:18
Mount valves batt box	1:34:55	00:24	00:24		
Moving other chassis	1:35:19	01:16			01:16
Talking	1:36:35	00:56			00:56
Getting tools from workbench	1:37:31	00:20		00:20	
Mount valves batt box	1:37:51	00:29	00:29		
Leave tool + get small materials + new tool at workbench	1:38:20	00:47		00:47	
Mount valves batt box	1:39:07	03:08	03:08		
Idling	1:42:15	00:19			00:19
Walking away	1:42:34	08:46			08:46
Sub-assemble at workbench	1:51:20	01:16	01:16		
Looking at what to do	1:52:36	00:15			00:15
Getting small parts from workbench	1:52:51	00:28		00:28	
Mount valves rear front axle	1:53:19	00:28	00:28		
Leave tool	1:53:47	00:55		00:55	
Talking with Dave about placement of valves	1:54:42	02:08			02:08
Mount valves rear front axle	1:56:50	01:23	01:23		
Leave tools	**1:58:13**	**1:51:23**	**0:13:29**	**0:09:04**	**1:28:50**
Operator 3					

Looking at what to do	0:39:39	00:19			00:19
Getting small parts from workbench	0:39:58	00:51		00:51	
Mount valve rear end	0:40:49	01:31	01:31		
Putting zip-tie holders rear axles	0:42:20	01:42	01:42		
Putting zip-tie holders mid crossmember	0:44:02	01:13	01:13		
Putting zip-tie holders front axles	0:45:15	02:50	02:50		
Putting zip-tie holders mid crossmember	0:48:05	00:36	00:36		
Talking	0:48:41	01:44			01:44
Leaving material	0:50:25	00:36			00:36
Working on other chassis	0:51:01	02:44			02:44
Putting zip-tie holders front	0:53:45	00:21	00:21		
Putting zip-tie holders back	0:54:06	00:58	00:58		
Walking away	0:55:04	00:15			00:15
Putting zip-ties in holders	0:55:19	11:10	11:10		
Moving to valve sub-assembly area	1:06:29	00:27			00:27
Walking away	**1:06:56**	**0:27:17**	**0:20:21**	**0:00:51**	**0:06:05**
Operator 4					
Looking at what to do	0:44:40	00:10			00:10
Getting small parts from workbench	0:44:50	01:13		01:13	
Mount valves front	0:46:03	00:59	00:59		
Getting tool from workbench	0:47:02	00:19		00:19	
Mount valves front	0:47:21	01:19	01:19		
Working on other chassis	0:48:40	04:41			04:41
Mount valves front rear axle	0:53:21	01:05	01:05		
Getting small parts from workbench	0:54:26	01:14		01:14	
Mount valves rear axles	0:55:40	02:10	02:10		
Leaving tools	0:57:50	00:48		00:48	
Mount valves mid crossmember	0:58:38	01:34	01:34		

Working on other chassis	1:00:12	00:23			00:23
Leaving tools	1:00:35	01:10		01:10	
Walking away	1:01:45	01:02			01:02
Using tugger to move chassis	1:02:47	01:43			01:43
Taking out other chassis from oven	1:04:30	05:10			05:10
Looking at what to do	1:09:40	00:40			00:40
Applying protective tape	1:10:20	11:29	11:29		
Leaving tape	1:21:49	00:21		00:21	
Getting small parts from workbench	1:22:10	00:59		00:59	
Getting tool from workbench	1:23:09	02:05		02:05	
Talking about placement of valve	1:25:14	00:39			00:39
Talk with Dave about placement	1:25:53	02:10			02:10
Mount valves mid crossmember	1:28:03	03:57	03:57		
Talking	1:32:00	00:37			00:37
Moving chassis	1:32:37	02:04			02:04
Working on other chassis	**1:34:41**	**0:50:01**	**0:22:33**	**0:08:09**	**0:19:19**

Mack valve chassis 800973 (CSM64R)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Removing masking from axles	0:07:45	01:22	01:22		
Removing masking from other parts	0:09:07	03:03	03:03		
Moving other chassis	0:12:10	00:19			00:19
Removing masking from other parts	0:12:29	02:29	02:29		
Talking	0:14:58	00:32			00:32

Removing masking from other parts	0:15:30	00:10	00:10		
Talking + Using computer	0:15:40	01:03			01:03
Removing masking from other parts	0:16:43	01:10	01:10		
Break	0:17:53	20:57			
Getting kit-box	0:38:50	00:26		00:26	
Laying out valves (preparing)	0:39:16	00:45		00:45	
Putting valves on workbench	0:40:01	00:26			00:26
Mounting valves on the front of chassis	0:40:27	00:10	00:10		
Getting small parts from workbench	0:40:37	00:24		00:24	
Mounting valves front crossmember	0:41:01	00:09	00:09		
Getting small parts from workbench	0:41:10	00:15		00:15	
Mounting valve plate mid-crossmember	0:41:25	00:38	00:38		
Getting material from rack at workbench	0:42:03	00:52		00:52	
Mounting electrical box front rear axle	0:42:55	00:45	00:45		
Getting material	0:43:40	00:19		00:19	
Mounting valve front rear axle	0:43:59	00:32	00:32		
Getting material	0:44:31	00:32		00:32	
Mounting valve front crossmember	0:45:03	00:58	00:58		
Getting small parts from workbench	0:46:01	00:20		00:20	
Mounting valve rear end	0:46:21	00:20	00:20		
Checking computer	0:46:41	00:39			00:39
Getting small parts from workbench	0:47:20	00:40		00:40	
Laying out brake hoses	0:48:00	02:40		02:40	
Searching for material	0:50:40	01:27			01:27
Ordering small parts on computer	0:52:07	01:00			01:00
Laying out material (preparing)	0:53:07	00:53		00:53	
Mounting valve front crossmember	0:54:00	00:20	00:20		
Tightening valve plate mid-crossmember	0:54:20	00:20	00:20		
Walking + leaving tool	0:54:40	00:17		00:17	

Tightening valve front of chassis	0:54:57	01:07	01:07		
Getting small parts from workbench	0:56:04	01:03		01:03	
Moving chassis	0:57:07	02:07			02:07
Mounting brake hoses rear axle + fittings	0:59:14	08:36	08:36		
Talking	1:07:50	00:25			00:25
Getting small parts from workbench	1:08:15	00:49		00:49	
Mounting fittings + brake hoses rear axle	1:09:04	03:44	03:44		
Getting small parts from workbench	1:12:48	00:32		00:32	
Mounting fittings + brake hoses rear axle	1:13:20	02:50	02:50		
Talking to Dave	1:16:10	00:45			00:45
Getting small parts from workbench	1:16:55	00:52		00:52	
Mounting zip-tie holders	1:17:47	05:38	05:38		
Leave material	1:23:25	00:56			00:56
Ordering small parts on computer	1:24:21	00:39			00:39
Mounting valve front of chassis	1:25:00	00:33	00:33		
Putting zip-ties in holders	1:25:33	04:26	04:26		
Leave material	1:29:59	00:17			00:17
Putting on edge protection	1:30:16	00:39	00:39		
Leave tool + walk away	**1:30:55**	**1:23:10**	**0:39:59**	**0:11:39**	**0:10:35**
Operator 2					
Removing parts from chassis (bolts)	0:14:45	02:28			02:28
Walking to other chassis	0:17:13	00:40			00:40
Break	0:17:53	27:50			
Removing masking from axle	0:45:43	00:47	00:47		
Working on other chassis	0:46:30	00:26			00:26
Looking at chassis	0:46:56	00:08			00:08
Walking away	0:47:04	01:16			01:16
Removing protection	0:48:20	00:30	00:30		

Getting material	0:48:50	01:45		01:45	
Sub-assembling at workbench	0:50:35	01:50		01:50	
Mounting fittings for brakehoses front	0:52:25	00:52	00:52		
Moving to other chassis	0:53:17	03:29			03:29
Moving chassis	0:56:46	02:50			02:50
Getting small parts + sub-assembling at workbench	0:59:36	02:04		02:04	
Mounting valves at mid-crossmember	1:01:40	07:42	07:42		
Tightening valves front	1:09:22	00:29	00:29		
Getting small parts from workbench	1:09:51	00:24		00:24	
Mounting valves front	1:10:15	00:58	00:58		
Leaving tool	1:11:13	00:27		00:27	
Mounting brake hoses front	1:11:40	02:42	02:42		
Leaving tool	1:14:22	03:55		03:55	
Walking away	1:18:17	04:03			04:03
Mount valve front crossmember	1:22:20	00:28	00:28		
Getting small parts from workbench	1:22:48	01:33		01:33	
Ordering small parts on computer	1:24:21	01:23			01:23
Getting air-filter	1:25:44	00:22		00:22	
Mounting air-filter	1:26:06	00:44	00:44		
Getting small parts from workbench	1:26:50	00:22		00:22	
Tightening air-filter	1:27:12	00:13	00:13		
Leave tool + get tape	1:27:25	00:56		00:56	
Putting on protection tape	1:28:21	02:17	02:17		
Idle	1:30:38	00:51			00:51
Putting on protection tape	1:31:29	07:36	07:36		
Leave tape	1:39:05	01:46		01:46	
Start work on new chassis	**1:40:51**	**1:26:06**	**0:25:18**	**0:15:24**	**0:17:34**
Operator 3					

Looking at chassis	0:46:56	00:08			00:08
Moving away	0:47:04	22:33			22:33
Mounting valves mid-crossmember	1:09:37	00:49	00:49		
Mounting valve rear axle	1:10:26	00:19	00:19		
Leave + get tool	1:10:45	00:40		00:40	
Mounting valve front rear axle	1:11:25	02:15	02:15		
Getting small parts from workbench	1:13:40	00:56		00:56	
Walking away	1:14:36	01:34			01:34
Talking to Dave	1:16:10	00:48			00:48
Mounting valve rear axle	1:16:58	06:17	06:17		
Leave + get tool	1:23:15	00:59		00:59	
Mount brake hoses rear axle	1:24:14	04:59	04:59		
Idle	1:29:13	00:13			00:13
Tightening brake hoses rear axle	1:29:26	02:14	02:14		
Leave tool	1:31:40	00:43		00:43	
Mount clamps on brake hoses	1:32:23	02:02	02:02		
Idle	1:34:25	01:02			01:02
Get new chassis from oven	**1:35:27**	**0:48:31**	**0:18:55**	**0:03:18**	**0:26:18**

Mack valve chassis 800825 (CLX64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Remove masking from paint station	0:00:00	02:03	02:03		
Idle	0:02:03	00:19			00:19
Remove masking from paint station	0:02:22	02:08	02:08		

Throw away mask tape	0:04:30	00:12			00:12
Remove masking from paint station	0:04:42	02:18	02:18		
Throw away mask tape	0:07:00	00:15			00:15
Walk away	0:07:15	09:11			09:11
Checking white board and computer	0:16:26	01:00		01:00	
Idle	0:17:26	00:11			00:11
Fetching valve	0:17:37	00:18		00:18	
Looking for and preparing material	0:17:55	01:47		01:47	
Laying out brakehoses on axels	0:19:42	00:18		00:18	
Checking computer	0:20:00	00:20		00:20	
Assembling valve at workbench	0:20:20	00:56	00:56		
Laying out brakehoses on axels	0:21:16	00:45		00:45	
Getting small parts and electrical box	0:22:01	00:37		00:37	
Mounting electraical box	0:22:38	00:07	00:07		
Walking	0:22:45	00:35			00:35
Mounting valve front axle	0:23:20	00:43	00:43		
Getting small parts from workbench	0:24:03	00:17		00:17	
Mount valve mid-crossmember	0:24:20	00:22	00:22		
Getting small parts from workbench	0:24:42	00:14		00:14	
Mount valve rear-end of chassis	0:24:56	00:34	00:34		
Walk and get items from bluebox "kit"	0:25:30	00:44		00:44	
Prepare and layout all valves around the chassis	0:26:14	01:11		01:11	
Mount valve plate mid-crossmember	0:27:25	00:47	00:47		
Getting small parts from workbench	0:28:12	00:13		00:13	
Mounting valves	0:28:25	00:45	00:45		
Getting small parts from workbench	0:29:10	00:20		00:20	
Mount valve at front axle	0:29:30	01:15	01:15		
Getting small parts from workbench	0:30:45	00:15		00:15	
Mount valve at front axle	0:31:00	00:38	00:38		

Talking with Dave (getting info on valves)	0:31:38	02:17			02:17
Getting small parts and assembling valve at workbench	0:33:55	02:11		02:11	
Mount valve back axles + hoses	0:36:06	09:54	09:54		
Changing workarea due to chassis move	0:46:00	01:30			01:30
Mounting valves front axle	0:47:30	01:12	01:12		
Talking (idle)	0:48:42	02:58			02:58
Fetching tool	0:51:40	00:30		00:30	
Bring out chassis from oven	0:52:10	10:30			10:30
Releasing air from back suspension	1:02:40	00:25			00:25
Working on other chassis	1:03:05	44:25			44:25
Mount valve rear axle	1:47:30	02:08	02:08		
Getting small parts from workbench	1:49:38	00:42		00:42	
Mount valve rear axle	1:50:20	02:23	02:23		
Leaving tools	1:52:43	00:17		00:17	
Moving chassis	1:53:00	00:20			00:20
Mount valve rear axle	1:53:20	02:10	02:10		
Working on other chassis	1:55:30	01:10			01:10
Mount zip-tie holder	1:56:40	02:34	02:34		
Idle	1:59:14	00:51			00:51
Break	2:00:05	21:27			
Return from break	**2:21:32**	**2:21:32**	**0:32:57**	**0:11:59**	**1:15:09**
Operator 2					
Using tugger to move chassis	0:45:30	02:39			02:39
Getting small parts from workbench	0:48:09	00:31		00:31	
Working on other chassis	0:48:40	14:40			14:40
Inspecting VIN number and using computer	1:03:20	02:10		02:10	
Walking away	1:05:30	01:13			01:13
Getting small parts from workbench	1:06:43	00:47		00:47	

Working on other chassis	1:07:30	08:00			08:00
Mounting	1:15:30	00:30	00:30		
Talking	1:16:00	00:29			00:29
Getting small parts from workbench	1:16:29	00:51		00:51	
Mount valve rear axles	1:17:20	00:20	00:20		
Idle	1:17:40	02:25			02:25
Talking with Dave	1:20:05	02:25			02:25
Mount valve rear axles	1:22:30	01:55	01:55		
Getting small parts from workbench + tool	1:24:25	00:38		00:38	
Mount valve rear axles	1:25:03	01:07	01:07		
Working on other chassis	1:26:10	01:20			01:20
Mount valve rear axles	1:27:30	00:53	00:53		
Getting small parts from workbench	1:28:23	00:37		00:37	
Walking away	1:29:00	01:00			01:00
Mount valve rear axles	1:30:00	04:12	04:12		
Getting small parts from workbench	1:34:12	00:53		00:53	
Working on other chassis	1:35:05	17:55			17:55
Moving chassis	1:53:00	01:15			01:15
Walking away	1:54:15	05:50			05:50
Break	2:00:05	21:27			
Returning from break	2:21:32	00:00			00:00
Talking with co-workers	2:21:32	01:31			01:31
Mount valve rear axles	2:23:03	00:09	00:09		
Getting small parts from workbench	2:23:12	00:18		00:18	
Fixing problem rear axle	2:23:30	00:32			00:32
Talking	2:24:02	02:03			02:03
Inspecting errors	2:26:05	00:18			00:18
Check computer + write on white board	2:26:23	03:05		03:05	
Getting small parts from workbench	2:29:28	00:41		00:41	

Mount valve rear axles	2:30:09	02:04	02:04		
Leave tool + get small parts + get new tool	2:32:13	01:07		01:07	
Mount valve rear axles	2:33:20	01:18	01:18		
Talk with Dave + get parts from other place	2:34:38	10:04			10:04
Working on other chassis	2:44:42	07:57			07:57
Moving chassis with Dave	2:52:39	01:50			01:50
Talk with Dave	2:54:29	01:13			01:13
Working on other chassis	2:55:42	32:16			32:16
Mount valve rear axles	3:27:58	01:54	01:54		
Leave tool	3:29:52	00:19		00:19	
Mount valve rear axles	3:30:11	01:04	01:04		
Leave tool	3:31:15	01:07		01:07	
Finish	**3:32:22**	**2:46:52**	**0:15:26**	**0:13:04**	**1:56:55**
Operator 3 (Palm oil)					
Removing parts from paint rack	0:36:18	00:12		00:12	
Mounting parts from paint rack	0:36:30	00:30	00:30		
Getting small parts from workbench + tools	0:37:00	00:40		00:40	
Mounting parts from paint rack	0:37:40	04:00	04:00		
Leave tools	0:41:40	00:25		00:25	
Removing parts from paint rack	0:42:05	02:20		02:20	
Walking away with empty rack	0:44:25	02:50			02:50
Getting small parts from workbench	0:47:15	00:45		00:45	
Mounting parts from paint rack	0:48:00	00:42	00:42		
Talking (idle)	0:48:42	02:34			02:34
Mounting valves	0:51:16	00:30	00:30		
Getting small parts from workbench	0:51:46	00:29		00:29	
Mount valves	0:52:15	00:45	00:45		
Walking away	0:53:00	00:50			00:50

Mount valves	0:53:50	02:10	02:10		
Walking away	**0:56:00**	**0:19:42**	**0:08:37**	**0:04:51**	**0:06:14**
Operator 4 Rear					
Tightening bolts	0:00:00	02:20	02:20		
Looking at chassis + getting tools	0:02:20	01:00		01:00	
Tightening bolts + Mounting	0:03:20	01:55	01:55		
Getting small parts from workbench	0:05:15	01:10		01:10	
Assembling valves at workbench	0:06:25	02:55	02:55		
Preparing and laying out material	0:09:20	00:30		00:30	
Talking	0:09:50	01:50			01:50
Assembling valves at workbench	0:11:40	08:40	08:40		
Leaving tools	0:20:20	00:30		00:30	
Talking	0:20:50	00:15			00:15
Mounting	0:21:05	00:30	00:30		
Getting small parts from workbench	0:21:35	01:25		01:25	
Mounting	0:23:00	00:45	00:45		
Getting small parts from workbench	0:23:45	00:40		00:40	
Mounting	0:24:25	00:35	00:35		
Getting small parts from workbench	0:25:00	00:15		00:15	
Mounting	0:25:15	01:55	01:55		
Getting small parts from workbench	0:27:10	00:20		00:20	
Mounting	0:27:30	00:50	00:50		
Looking at chassis	0:28:20	00:10			00:10
Mounting	0:28:30	01:00	01:00		
Leaving tools	0:29:30	00:25		00:25	
Getting small parts from workbench	0:29:55	00:55		00:55	
Mounting	0:30:50	03:45	03:45		
Break	0:34:35	22:48			

Mount valves rear axle	0:57:23	04:44	04:44		
Getting small parts from workbench	1:02:07	00:28		00:28	
Mount valves rear axle	1:02:35	03:25	03:25		
Apply tape	1:06:00	01:10	01:10		
Getting small parts from workbench	1:07:10	00:25		00:25	
Apply tape	1:07:35	03:20	03:20		
Getting small parts from workbench	1:10:55	00:45		00:45	
Tightening bolts	1:11:40	00:10	00:10		
Looking at chassis	1:11:50	00:35			00:35
Mounting zip-tie holders	1:12:25	00:45	00:45		
Getting zip-ties	1:13:10	01:00		01:00	
Putting zip-ties in holders	1:14:10	02:00	02:00		
Talking	1:16:10	00:35			00:35
Putting zip-ties in holders	1:16:45	00:20	00:20		
Talking	1:17:05	01:32			01:32
Putting zip-ties in holders	1:18:37	00:13	00:13		
Looking at chassis	1:18:50	00:30			00:30
Putting zip-ties in holders	1:19:20	00:40	00:40		
Talking	1:20:00	00:25			00:25
Working on other chassis	**1:20:25**	**1:20:25**	**0:41:57**	**0:09:48**	**0:05:52**
Operator 5 Front					
Tightening bolts	0:02:20	02:15	02:15		
Talking	0:04:35	00:35			00:35
Getting small parts from workbench	0:05:10	01:15		01:15	
Assembling valves at workbench	0:06:25	03:15	03:15		
Getting small parts from workbench	0:09:40	00:35		00:35	
Assembling valves at workbench	0:10:15	00:15	00:15		
Preparing and laying out material	0:10:30	00:20		00:20	

Mounting	0:10:50	08:10	08:10		
Talking	0:19:00	00:55			00:55
Getting small parts from workbench	0:19:55	00:15		00:15	
Mounting	0:20:10	00:30	00:30		
Getting small parts from workbench	0:20:40	00:40		00:40	
Mounting	0:21:20	00:10	00:10		
Getting small parts from workbench	0:21:30	00:35		00:35	
Mounting	0:22:05	00:25	00:25		
Getting small parts from workbench	0:22:30	01:05		01:05	
Mounting	0:23:35	02:40	02:40		
Getting small parts from workbench	0:26:15	00:15		00:15	
Mounting	0:26:30	00:15	00:15		
Getting small parts from workbench	0:26:45	02:55		02:55	
Mounting	0:29:40	01:20	01:20		
Getting small parts from workbench	0:31:00	00:23		00:23	
Mounting	0:31:23	00:17	00:17		
Getting small parts from workbench	0:31:40	01:25		01:25	
Mounting	0:33:05	03:07	03:07		
Getting small parts from workbench	0:36:12	01:48		01:48	
Talking	0:38:00	00:40			00:40
Getting small parts from workbench	0:38:40	01:00		01:00	
Assembling valves at workbench (front)	0:39:40	01:45	01:45		
Talking	0:41:25	01:20			01:20
Assembling valves at workbench (front)	0:42:45	05:15	05:15		
Moving chassis	0:48:00	00:30			00:30
Assembling valves at workbench (front)	0:48:30	01:20	01:20		
Getting small parts from workbench	0:49:50	00:45		00:45	
Apply tape	0:50:35	03:20	03:20		
Break	**0:53:55**	**0:51:35**	**0:34:19**	**0:13:16**	**0:04:00**

Volvo valve pre-assembly chassis 131514 (FM84R)

Activity	Elapsed time (h:mm:ss)	Element time (mm:ss)	Value adding time (mm:ss)	Supporting value adding time (mm:ss)	Non value adding time (mm:ss)
Operator 1					
Reading instructions	0:00:10	00:20		00:20	
Picking parts from rack or blue-box	0:00:30	00:15		00:15	
Talking	0:00:45	00:15			00:15
Picking parts from rack or blue-box	0:01:00	01:30		01:30	
Throwing away scrap	0:02:30	00:20			00:20
Moving cart	0:02:50	00:10			00:10
Throwing away scrap	0:03:00	00:10			00:10
Marking blue kit-box	0:03:10	01:45		01:45	
Picking parts from rack or blue-box	0:04:55	04:30		04:30	
Assembling valves	0:09:25	01:58	01:58		
Drop off parts at palm-oil bench	0:11:23	00:10			00:10
Talking	0:11:33	01:15			01:15
Drop off parts at palm-oil bench	0:12:48	00:10			00:10
Drop off parts at hose sub-assembly	0:12:58	02:00			02:00
Drop off parts at palm-oil bench	0:14:58	00:10			00:10
Assembling valves	0:15:08	24:12	24:12		
Drop off parts at hose sub-assembly	0:39:20	00:10			00:10
Assembling valves	0:39:30	02:00	02:00		
Drop off parts at palm-oil bench	0:41:30	00:10			00:10
Assembling valves	0:41:40	00:05	00:05		
Talking	0:41:45	01:15			01:15
Assembling valves	0:43:00	00:05	00:05		
Drop off parts at palm-oil bench	0:43:05	00:10			00:10

Talking	0:43:15	00:55			00:55
Assembling valves	0:44:10	02:35	02:35		
Drop off parts at palm-oil bench	0:46:45	00:10			00:10
Talking	0:46:55	03:15			03:15
Assembling valves	0:50:10	04:10	04:10		
Drop off parts at palm-oil bench	0:54:20	00:10			00:10
Assembling valves	0:54:30	03:00	03:00		
Talking	0:57:30	00:35			00:35
Assembling valves	0:58:05	01:55	01:55		
Reading instructions	1:00:00	00:30		00:30	
Assembling valves	1:00:30	00:40	00:40		
Putting items in plastic bag for blue kit-box	1:01:10	01:00	01:00		
Putting blue kit-box in rack	1:02:10	00:01		00:01	
Finishing	**1:02:11**	**1:02:01**	**0:41:40**	**0:08:51**	**0:11:30**

Volvo valve pre-assembly chassis 131531 (FH64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Begin new kit-box	1:03:15	00:25			00:25
Assembling valves	1:03:40	04:30	04:30		
Talking	1:08:10	01:15			01:15
Assembling valves	1:09:25	00:35	00:35		
Talking	1:10:00	01:20			01:20
Assembling valves	1:11:20	19:35	19:35		
Talking	1:30:55	00:35			00:35
Assembling valves	1:31:30	07:55	07:55		

Walking away	1:39:25	01:20			01:20
Returning after fetching small parts in pipe area	1:40:45	00:15		00:15	
Throwing away scrap	1:41:00	00:10			00:10
Assembling valves	1:41:10	00:10	00:10		
Checking computer	1:41:20	01:20		01:20	
Assembling valves	1:42:40	03:00	03:00		
Talking	1:45:40	00:05			00:05
Assembling valves	1:45:45	00:51	00:51		
Talking	1:46:36	00:19			00:19
Assembling valves	1:46:55	00:55	00:55		
Talking	1:47:50	01:25			01:25
Assembling valves	1:49:15	01:20	01:20		
Putting items in plastic bag for blue kit-box	1:50:35	00:15	00:15		
Talking	1:50:50	00:20			00:20
Picking parts	1:51:10	00:20		00:20	
Throwing away scrap	1:51:30	00:10			00:10
Fetching rack	1:51:40	00:40		00:40	
Sending over 2 blue-boxes	1:52:20	01:10		01:10	
Putting empty box in place	1:53:30	00:20		00:20	
Picking parts and mounting valves	**1:53:50**	**0:50:35**	**0:39:06**	**0:04:05**	**0:07:24**

Mack valve pre-assembly chassis 800846 (CSM84R)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Getting material	0:00:00	00:10		00:10	

Assembling valves	0:00:10	05:30	05:30		
Putting items in blue box and push it into rack	0:05:40	00:10		00:10	
Filling in note	0:05:50	00:40	00:40		
Cleaning a blue box and putting on nr	0:06:30	01:00		01:00	
Pushing in new box	0:07:30	00:15		00:15	
Gets a new kit	0:07:45	00:15		00:15	
Using computer	0:08:00	07:40		07:40	
Getting air filter	0:15:40	00:25		00:25	
Getting material	0:16:05	00:35		00:35	
Assembling valves	0:16:40	00:40	00:40		
Getting material	0:17:20	00:20		00:20	
Assembling valves	0:17:40	01:10	01:10		
Getting material	0:18:50	00:10		00:10	
Assembling valves	0:19:00	03:20	03:20		
Putting air filter in inventory	0:22:20	00:30		00:30	
Looking at chassis	0:22:50	00:30			00:30
Getting material	0:23:20	01:00		01:00	
Assembling valves	0:24:20	01:30	01:30		
Getting material	0:25:50	00:10		00:10	
Assembling valves	0:26:00	02:20	02:20		
Getting material	0:28:20	00:25		00:25	
Assembling valves	0:28:45	03:25	03:25		
Putting part in blue box + getting material	0:32:10	00:45		00:45	
Assembling valves	0:32:55	01:30	01:30		
Getting material	0:34:25	01:00		01:00	
Assembling valves	0:35:25	05:45	05:45		
Putting parts in blue box	0:41:10	00:10		00:10	
Assembling valves	0:41:20	00:40	00:40		
Putting parts in blue box	0:42:00	00:10		00:10	

Filling in note	0:42:10	00:15		00:15	
Cleaning a blue box and putting on nr	0:42:25	02:00		02:00	
Personal time	0:44:25	00:35			00:35
Computer	**0:45:00**	**0:45:00**	**0:26:30**	**0:17:25**	**0:01:05**

Volvo brake hoses chassis 131505 (FM84R)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Looking at what to do	0:00:00	01:11			01:11
Talking	0:01:11	00:09			00:09
Checking computer	0:01:20	00:36		00:36	
Fetching hoses	0:01:56	00:16		00:16	
Getting small parts from brake hoses bench	0:02:12	00:18		00:18	
Talking + Walking	0:02:30	00:35			00:35
Looking at chassis and talking with Franky	0:03:05	00:25			00:25
Getting small parts from brake hoses bench	0:03:30	00:33		00:33	
Sorting material at hoses workbench	0:04:03	00:34			00:34
Get bucket	0:04:37	00:13		00:13	
Fetching tool	0:04:50	00:20		00:20	
Fitting hoses	0:05:10	00:47	00:47		
Getting small parts from brake hoses bench	0:05:57	00:26		00:26	
Fitting hoses	0:06:23	00:47	00:47		
Getting small parts from brake hoses bench + sorting material (zip-ties) + talking to Dave	0:07:10	04:15		04:15	
Checking computer	0:11:25	03:19		03:19	

Getting material	0:14:44	00:57		00:57	
Walking to Valves	0:15:41	01:31			01:31
Talking to Franky	0:17:12	00:18			00:18
Getting small parts from brake hoses bench + materials handling	0:17:30	04:40		04:40	
Mounting fittings front	0:22:10	02:16	02:16		
Moving chassis	0:24:26	01:02			01:02
Mounting fittings front	0:25:28	01:02	01:02		
Checking computer and writing down pick	0:26:30	01:38		01:38	
Getting small parts from hoses bench	0:28:08	00:16		00:16	
Checking computer	0:28:24	01:36		01:36	
Mounting fittings front	0:30:00	03:26	03:26		
Getting small parts from hoses bench	0:33:26	01:24		01:24	
Mounting fittings front	0:34:50	03:21	03:21		
Tightening fittings	0:38:11	05:17	05:17		
Moving chassis	0:43:28	00:50			00:50
Getting small parts from hoses bench	0:44:18	02:39		02:39	
Walking to Valves sub-assembly	0:46:57	02:38			02:38
Getting small parts from hoses bench	0:49:35	00:13		00:13	
Mounting fittings rear	0:49:48	01:58	01:58		
Getting small parts from hoses bench + tool	0:51:46	01:10		01:10	
Mounting fittings rear	0:52:56	06:16	06:16		
Tightening fittings	0:59:12	00:48	00:48		
Getting material	1:00:00	01:08		01:08	
Talking	1:01:08	00:55			00:55
Getting material + cutting pipes	1:02:03	01:15		01:15	
Checking computer	1:03:18	00:16		00:16	
Talking	1:03:34	00:50			00:50
Checking computer and writing down pick	1:04:24	02:19		02:19	

Laying out hoses (preparing)	1:06:43	02:24		02:24	
Checking computer	1:09:07	01:08		01:08	
Mounting hoses	1:10:15	04:55	04:55		
Talking	1:15:10	00:30			00:30
Mounting hoses	1:15:40	03:10	03:10		
Marking hoses	1:18:50	00:50	00:50		
Walking to piping area	1:19:40	00:35			00:35
Getting small parts from hoses bench	1:20:15	00:43		00:43	
Walking to other chassis	1:20:58	00:52			00:52
Tightening hoses other chassis	1:21:50	04:22			04:22
Mounting fittings + tightening other chassis	1:26:12	05:28			05:28
Getting small parts from hoses bench	1:31:40	00:39		00:39	
Mouning fittings + tightening other chassis	1:32:19	02:31			02:31
Mounting zip-ties + cable to brakes	1:34:50	07:09	07:09		
Checking computer for next chassis	**1:41:59**	**1:41:59**	**0:42:02**	**0:34:41**	**0:25:16**

Volvo brake hoses chassis 131523 (FM64R)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Checking computer	0:00:00	00:12		00:12	
Getting bucket	0:00:12	00:12		00:12	
Looking at chassis	0:00:24	00:26			00:26
Throwing scrap	0:00:50	00:36		00:36	
Getting material	0:01:26	01:44		01:44	
Mounting fittings rear axles	0:03:10	01:27	01:27		

Mounting fittings front rear axle	0:04:37	04:43	04:43		
Leaving tools	0:09:20	00:22		00:22	
Checking VIN number	0:09:42	00:20			00:20
Getting material	0:10:02	01:25		01:25	
Checking instruction	0:11:27	01:31		01:31	
Laying out hoses and preparing + checking instructions	0:12:58	03:24		03:24	
Mounting hoses to boosters front	0:16:22	02:30	02:30		
Tightening booster fittings front	0:18:52	00:58	00:58		
Looking at other chassis brake hoses	0:19:50	01:24			01:24
Mounting hoses to chassis in front	0:21:14	00:46	00:46		
Tightening fittings of hose on chassis	0:22:00	01:34	01:34		
Move one chassis	0:23:34	01:15			01:15
Move one chassis	0:24:49	01:52			01:52
Looking at other chassis brake hoses + getting material	0:26:41	03:19		03:19	
Talking to Franky + walking	0:30:00	00:50			00:50
Mounting hoses to boosters in front	0:30:50	01:46	01:46		
Mounting hoses rear axles	0:32:36	00:50	00:50		
Walking to valve area	0:33:26	01:50			01:50
Getting small parts from bench	0:35:16	00:17		00:17	
Mounting fittings front boosters	0:35:33	00:59	00:59		
Mounting fittings + hoses at rear axles	0:36:32	01:44	01:44		
Mounting hoses + tightening front brake boosters	0:38:16	01:14	01:14		
Getting tool	0:39:30	00:08		00:08	
Tightening hoses front brake booster	0:39:38	00:59	00:59		
Mounting/dismounting hoses at front, unsure of what hose where	0:40:37	02:03			02:03
Asking for help + getting help	0:42:40	02:42			02:42
Tightening hoses to chassis front	0:45:22	02:08	02:08		
Mounting cables to brakes front	0:47:30	02:36	02:36		
Inspecting other chassis	0:50:06	00:43			00:43

Mounting cables to brakes front	0:50:49	02:13	02:13		
Routing cables inside rail + securing	0:53:02	02:19	02:19		
Idle + walking	0:55:21	01:21			01:21
Fetching pipe	0:56:42	00:48		00:48	
Mounting brake pipe at rear axles	0:57:30	00:43	00:43		
Starting new chassis	**0:58:13**	**0:58:13**	**0:29:29**	**0:13:58**	**0:14:46**

Volvo brake hoses chassis 131526 (FH64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Looking at chassis	0:58:13	01:03			01:03
Getting material	0:59:16	01:19		01:19	
Mounting fittings back rear axle	1:00:35	02:57	02:57		
Mounting fittings front rear axle	1:03:32	01:36	01:36		
Mounting fittings back rear axle	1:05:08	02:55	02:55		
Mounting pipe on other chassis	1:08:03	01:02			01:02
Idle + talking	1:09:05	00:38			00:38
Mounting fittings front rear axle	1:09:43	01:38	01:38		
Mounting fittings front axle right side	1:11:21	01:15	01:15		
Mounting fittings front axle left side	1:12:36	01:23	01:23		
Checking computer	1:13:59	00:41		00:41	
Getting material	1:14:40	00:42		00:42	
Laying out and preparing hoses	1:15:22	00:58		00:58	
Getting material	1:16:20	00:49		00:49	
Laying out and preparing hoses	1:17:09	00:55		00:55	

Mounting hoses front axle left side + tightening + mounting cables to brakes	1:18:04	07:07	07:07		
Securing cables inside rails	1:25:11	01:14	01:14		
Walking away	1:26:25	02:01			02:01
Mounting hoses front axle right side + tightening + mouting cables to brakes	1:28:26	06:18	06:18		
Break	1:34:44	21:18			
Mounting hoses front axle right side + tightening + mouting cables to brakes	1:56:02	05:53	05:53		
Securing cables inside rails	2:01:55	09:57	09:57		
Checking cables + leaving and getting material	2:11:52	01:23		01:23	
Idle	2:13:15	00:21			00:21
Checking computer	2:13:36	01:18		01:18	
Starting new chassis	**2:14:54**	**1:16:41**	**0:42:13**	**0:08:05**	**0:05:05**

Volvo harnesses chassis 131524 (FH64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Getting material	0:00:00	04:45		04:45	
Adjusting radio	0:04:45	01:05			01:05
Laying out harness cables	0:05:50	02:30	02:30		
Using computer	0:08:20	00:10		00:10	
Talking	0:08:30	01:50			01:50
Teaching other harnesser	0:10:20	01:00			01:00
Eating fruit	0:11:20	02:10			02:10
Getting material	0:13:30	00:30		00:30	
Talking	0:14:00	02:30			02:30
Teaching other harnesser	0:16:30	00:30			00:30

Mounting	0:17:00	01:45	01:45		
Talking	0:18:45	00:25			00:25
Harnessing	0:19:10	01:15	01:15		
Talking	0:20:25	00:55			00:55
Drinking	0:21:20	01:10			01:10
Talking	0:22:30	04:10			04:10
Harnessing	0:26:40	00:55	00:55		
Looking	0:27:35	00:55			00:55
Harnessing	0:28:30	03:20	03:20		
Talking	0:31:50	00:20			00:20
Getting material	0:32:10	00:30		00:30	
Harnessing	0:32:40	17:40	17:40		
Idle	0:50:20	00:30			00:30
Harnessing	0:50:50	01:20	01:20		
Talking	0:52:10	01:00			01:00
Harnessing	0:53:10	01:30	01:30		
Fiddling with tool	0:54:40	00:40			00:40
Talking	0:55:20	00:10			00:10
Harnessing	0:55:30	01:32	01:32		
Idle	0:57:02	00:43			00:43
Harnessing	0:57:45	00:17	00:17		
Idle	0:58:02	00:08			00:08
Harnessing	0:58:10	01:30	01:30		
Idle	0:59:40	00:45			00:45
Move one chassis	1:00:25	01:15			01:15
Lunch	1:01:40	34:40			
Harnessing	1:36:20	00:40	00:40		
Eating	1:37:00	00:35			00:35
Harnessing	1:37:35	07:45	07:45		

Move one chassis	1:45:20	01:10			01:10
Idle	1:46:30	02:30			02:30
Looking at other chassis	1:49:00	01:00			01:00
Brooming	1:50:00	00:50		00:50	
Using computer	1:50:50	00:45		00:45	
Brooming	1:51:35	00:15		00:15	
Talking	1:51:50	02:15			02:15
Brooming	1:54:05	00:50		00:50	
Drinking + Talking	1:54:55	01:25			01:25
Working with other things	**1:56:20**	**1:56:20**	**0:41:59**	**0:08:35**	**0:31:06**
Operator 2					
Using computer	0:00:00	04:40		04:40	
Laying out harness cables	0:04:40	04:50	04:50		
Harnessing	0:09:30	15:10	15:10		
Talking	0:24:40	01:40			01:40
Harnessing	0:26:20	08:00	08:00		
Talking	0:34:20	00:30			00:30
Harnessing	0:34:50	01:15	01:15		
Getting material	0:36:05	00:25		00:25	
Harnessing	0:36:30	04:40	04:40		
Looking	0:41:10	00:20			00:20
Harnessing	0:41:30	10:40	10:40		
Talking	0:52:10	02:05			02:05
Harnessing	0:54:15	03:47	03:47		
Idle	0:58:02	00:08			00:08
Harnessing	0:58:10	02:15	02:15		
Move one chassis	1:00:25	01:15			01:15
Lunch	1:01:40	34:20			

Harnessing	1:36:00	09:20	09:20		
Move one chassis	1:45:20	01:00			01:00
Harnessing	1:46:20	02:00	02:00		
Idle	1:48:20	00:40			00:40
Looking at other chassis	1:49:00	01:20			01:20
Using computer	1:50:20	01:45		01:45	
Looking at other chassis	1:52:05	00:55			00:55
Using computer	1:53:00	06:30		06:30	
Working with other things	1:59:30	07:00			07:00
Harnessing	2:06:30	00:35	00:35		
Getting material	2:07:05	01:25		01:25	
Harnessing	2:08:30	01:30	01:30		
Getting material	2:10:00	00:20		00:20	
Working with other things	**2:10:20**	**2:10:20**	**1:04:02**	**0:15:05**	**0:16:53**

Volvo harnesses chassis 131503 (FM84R)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Talking	0:00:00	00:30			00:30
Laying out harness	0:00:30	00:09	00:09		
Talking	0:00:39	01:11			01:11
Routing cables in rail	0:01:50	15:00	15:00		
Refilling blue-box	0:16:50	00:15			00:15
Talking	0:17:05	01:25			01:25
Harnessing	0:18:30	12:20	12:20		

Talking	0:30:50	01:20			01:20
Harnessing	0:32:10	02:20	02:20		
Talking	0:34:30	02:20			02:20
Move chassis	0:36:50	01:10			01:10
Harnessing	0:38:00	01:00	01:00		
Talking	0:39:00	04:05			04:05
Harnessing	0:43:05	13:35	13:35		
Getting material	0:56:40	02:30		02:30	
Talking	0:59:10	02:20			02:20
Mounting brackets	1:01:30	00:50	00:50		
Getting material	1:02:20	01:00		01:00	
Harnessing	1:03:20	05:40	05:40		
Walk away to get cable	1:09:00	28:50			28:50
Harnessing	1:37:50	01:40	01:40		
Getting material	1:39:30	00:45		00:45	
Harnessing	1:40:15	06:15	06:15		
Getting material	1:46:30	00:10		00:10	
Harnessing	1:46:40	00:35	00:35		
Getting material	1:47:15	00:20		00:20	
Harnessing	1:47:35	00:35	00:35		
Getting material	1:48:10	00:45		00:45	
Harnessing	1:48:55	10:05	10:05		
Move chassis	1:59:00	02:00			02:00
Harnessing	2:01:00	00:20	00:20		
Talking	2:01:20	00:38			00:38
Harnessing	2:01:58	02:37	02:37		
Getting material	2:04:35	01:00		01:00	
Harnessing	2:05:35	00:45	00:45		
Getting material	2:06:20	00:20		00:20	

Harnessing	2:06:40	00:20	00:20		
Talking	2:07:00	02:15			02:15
Harnessing	2:09:15	01:45	01:45		
Getting material	2:11:00	00:40		00:40	
Looking at other chassis	2:11:40	00:30			00:30
Getting material	2:12:10	00:10		00:10	
Talking	2:12:20	00:30			00:30
Getting material	2:12:50	00:20		00:20	
Harnessing	2:13:10	01:00	01:00		
Talking	2:14:10	04:40			04:40
Getting material	2:18:50	00:30		00:30	
Talking	2:19:20	00:20			00:20
Getting material	2:19:40	00:50		00:50	
Talking	2:20:30	01:50			01:50
Harnessing	2:22:20	01:00	01:00		
Getting material	2:23:20	00:30		00:30	
Harnessing	2:23:50	10:10	10:10		
Getting material	2:34:00	00:40		00:40	
Harnessing	2:34:40	03:20	03:20		
Idle	2:38:00	00:30			00:30
Harnessing	2:38:30	09:24	09:24		
Break	2:47:54	32:06			
Harnessing	3:20:00	17:00	17:00		
Move chassis	3:37:00	01:40			01:40
Harnessing	3:38:40	09:10	09:10		
Talking	3:47:50	00:10			00:10
Harnessing	3:48:00	02:40	02:40		
Drinking	3:50:40	00:30			00:30
Getting material	3:51:10	02:45		02:45	

Talking	3:53:55	00:10			00:10
Harnessing	3:54:05	06:05	06:05		
Talking	4:00:10	00:40			00:40
Harnessing	4:00:50	02:00	02:00		
Getting material	4:02:50	00:40		00:40	
Harnessing	4:03:30	03:00	03:00		
Getting material	4:06:30	05:55		05:55	
Mounting batt box cables	4:12:25	02:11	02:11		
Getting material	4:14:36	01:22		01:22	
Mounting batt box cables	4:15:58	01:17	01:17		
Checking cables at the rear	4:17:15	01:05		01:05	
Getting material	4:18:20	02:10		02:10	
Harnessing	4:20:30	04:00	04:00		
Finish	**4:24:30**	**4:24:30**	**2:28:08**	**0:24:27**	**0:59:49**
Operator 2					
Getting material	1:40:30	00:50		00:50	
Harnessing	1:41:20	18:30	18:30		
Move chassis	1:59:50	00:40			00:40
Harnessing	2:00:30	00:40	00:40		
Getting material	2:01:10	00:20		00:20	
Harnessing	2:01:30	06:50	06:50		
Getting material	2:08:20	05:40		05:40	
Harnessing	2:14:00	02:05	02:05		
Getting material	2:16:05	00:10		00:10	
Harnessing	2:16:15	02:25	02:25		
Idle	2:18:40	01:00			01:00
Harnessing	2:19:40	00:50	00:50		
Idle	2:20:30	03:20			03:20

Harnessing	2:23:50	03:10	03:10		
Idle	2:27:00	00:50			00:50
Harnessing	2:27:50	03:40	03:40		
Idle	**2:31:30**	**0:51:00**	**0:38:10**	**0:07:00**	**0:05:50**

Mack harnesses chassis 800928 (CMM64T)

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Fetching harness and laying out	0:00:00	02:39		02:39	
Talking	0:02:39	00:49			00:49
Working on other chassis	0:03:28	00:13			00:13
Fetching bucket	0:03:41	00:13		00:13	
Sorting harnesses and routing	0:03:54	11:35	11:35		
Idle	0:15:29	01:36			01:36
Mounting edge protection	0:17:05	00:26	00:26		
Securing harnesses	0:17:31	14:13	14:13		
Getting material	0:31:44	01:03		01:03	
Mounting and securing harnesses	0:32:47	04:01	04:01		
Moving to get material (zip-ties)	0:36:48	00:44		00:44	
Idle	0:37:32	00:57			00:57
Securing harnesses	0:38:29	01:28	01:28		
Idle + walking	0:39:57	00:30			00:30
Securing harnesses	0:40:27	01:27	01:27		
Idle	0:41:54	01:03			01:03
Securing harnesses	0:42:57	00:34	00:34		

Idle	**0:43:31**	**0:43:31**	**0:33:44**	**0:04:39**	**0:05:08**
Operator 2					
Sorting harnesses and routing	0:03:54	02:45	02:45		
Walking to valves workbench to get edge protection	0:06:39	01:56		01:56	
Mounting edge protection	0:08:35	00:41	00:41		
Routing harnesses	0:09:16	03:47	03:47		
Looking for tool	0:13:03	00:53			00:53
Routing harnesses	0:13:56	04:37	04:37		
Idle	0:18:33	00:09			00:09
Routing and securing harnesses	0:18:42	19:00	19:00		
Materials handling (opening bags with cables)	0:37:42	00:47			00:47
Securing harnesses	0:38:29	05:58	05:58		
Idle	0:44:27	00:58			00:58
Securing harnesses	0:45:25	00:12	00:12		
Idle	**0:45:37**	**0:41:43**	**0:37:00**	**0:01:56**	**0:02:47**
Operator 3					
Mounting harnesses	0:14:48	01:41	01:41		
Leaving tools	0:16:29	00:51		00:51	
Mounting harnesses	0:17:20	00:28	00:28		
Walking away to work on other chassis	0:17:48	02:14			02:14
Mounting harnesses	0:20:02	01:01	01:01		
Walking away to get tool	0:21:03	01:31		01:31	
Idle	0:22:34	02:17			02:17
Mounting harnesses at rear end	0:24:51	00:30	00:30		
Talking to Franky + walk away	0:25:21	15:10			15:10
Idle	0:40:31	01:20			01:20
Securing harnesses	0:41:51	01:09	01:09		

Idle	0:43:00	00:56			00:56
Securing harnesses	0:43:56	01:34	01:34		
Idle	**0:45:30**	**0:30:42**	**0:06:23**	**0:02:22**	**0:21:57**

Mack power steering

Activity	**Elapsed time (h:mm:ss)**	**Element time (mm:ss)**	**Value adding time (mm:ss)**	**Supporting value adding time (mm:ss)**	**Non value adding time (mm:ss)**
Operator 1					
Walks away after reading instructions	0:00:00	00:20			00:20
Discussing chassis and looking	0:00:20	01:00			01:00
Walks back to station	0:01:20	00:20			00:20
Reading instructions	0:01:40	01:20		01:20	
Walks away to get instructions	0:03:00	00:50			00:50
Returns to station	0:03:50	00:05			00:05
Walks to chassis 1	0:03:55	00:05			00:05
Mounting fittings on chassis 1	0:04:00	03:00	03:00		
Getting material and small parts	0:07:00	00:40		00:40	
Talking to Dave	0:07:40	00:20			00:20
Looking for cable	0:08:00	00:30			00:30
Cutting cable	0:08:30	00:30		00:30	
Discussing with Dave	0:09:00	00:40			00:40
Mounting fittings on hoses	0:09:40	01:15	01:15		
Giving two hoses to operator	0:10:55	00:35			00:35
Looking at chassis 1	0:11:30	00:05			00:05
Getting material	0:11:35	00:25		00:25	
Mounting fittings	0:12:00	00:55	00:55		

Chassis
1: 983
2: 908
3: 990
4: 919
5: 982
6: 974
7: 963
8: 008

Gets interrupted to check chassis 2	0:12:55	00:25			00:25
Moves back to station to read instructions	0:13:20	00:40			00:40
Cutting hose	0:14:00	00:20		00:20	
Mounting fitting on hose	0:14:20	00:45	00:45		
Talking	0:15:05	00:45			00:45
Mounting fitting on hose	0:15:50	01:40	01:40		
Interrupted to discuss other hose	0:17:30	01:30			01:30
Cutting hose	0:19:00	00:20		00:20	
Mounting fitting	0:19:20	01:00	01:00		
Mounting fitting using big machine	0:20:20	00:30	00:30		
Giving last hose to person who interrupted	0:20:50	00:10			00:10
Giving next to last hose to person who interrupted before	0:21:00	00:25			00:25
Discussing chassis 2	0:21:25	01:35			01:35
Walks to chassis 3 with one hose	0:23:00	01:00			01:00
Mounting fittings on chassis 1	0:24:00	02:35	02:35		
Getting material	0:26:35	00:30		00:30	
Discussing with Franky	0:27:05	01:55			01:55
Discussing with PE	0:29:00	02:30			02:30
Walks to chassis 1	0:31:30	00:10			00:10
Mounting fittings on chassis 1	0:31:40	03:30	03:30		
Interrupted by PE	0:35:10	00:45			00:45
Mounting hoses chassis 1	0:35:55	00:45	00:45		
Getting tools	0:36:40	00:25		00:25	
Mounting hoses chassis 1	0:37:05	04:35	04:35		
Break	0:41:40	19:40			
Mounting hoses chassis 1	1:01:20	01:15	01:15		
Getting small parts (zip-ties)	1:02:35	00:25		00:25	
Mounting hose uising zip-ties	1:03:00	00:40	00:40		
Talking	1:03:40	00:20			00:20

Sorting and laying out hoses	1:04:00	01:20		01:20	
Mounting hoses chassis 1	1:05:20	01:20	01:20		
Discussing routing of hose	1:06:40	01:15			01:15
Mounting hoses	1:07:55	01:55	01:55		
Checking computer	1:09:50	00:20		00:20	
Walks and looks at chassis 1	1:10:10	00:15			00:15
Checking computer	1:10:25	01:35		01:35	
Interrupted to help Franky	1:12:00	00:40			00:40
Checking computer	1:12:40	02:20		02:20	
Interrupted to help other person	1:15:00	00:20			00:20
Checking computer	1:15:20	00:25		00:25	
Helping Franky	1:15:45	01:15			01:15
Getting equipment for chassis 1	1:17:00	00:40		00:40	
Mounting hoses using zip-ties	1:17:40	01:15	01:15		
Interrupted and moves to chassis 3	1:18:55	02:05			02:05
Preparing moving of chassis	1:21:00	00:50			00:50
Getting material	1:21:50	01:15		01:15	
Waiting for chassis move	1:23:05	01:45			01:45
Talking	1:24:50	02:05			02:05
Mounting fittings chassis 1	1:26:55	00:30	00:30		
Fetching material	1:27:25	01:00		01:00	
Climbing inside chassis	1:28:25	00:20		00:20	
Mounting fittings and hoses	1:28:45	16:00	16:00		
Climbing out from chassis	1:44:45	00:00		00:00	
Collecting material and moving to next chassis	**1:44:45**	**1:44:45**	**0:43:25**	**0:14:10**	**0:27:30**
Operator 1					
Walks to chassis 4 with material	1:45:05	00:15		00:15	
Checking computer	1:45:20	04:40		04:40	

Walks to chassis 4	1:50:00	00:10			00:10
Preparing working place	1:50:10	00:20		00:20	
Walks to chassis 7 to discuss	1:50:30	00:55			00:55
Walks to station to read instructions	1:51:25	02:15			02:15
Cutting hoses	1:53:40	00:30		00:30	
Looking for something	1:54:10	00:15			00:15
Cutting hoses	1:54:25	00:35		00:35	
Walks to check chassis 1	1:55:00	02:15			02:15
Looking for something	1:57:15	00:50			00:50
Cutting hoses and marking	1:58:05	01:45		01:45	
Reading instructions	1:59:50	00:15		00:15	
Cutting hoses and marking	2:00:05	09:45		09:45	
Walks to chassis 7 to discuss	2:09:50	01:10			01:10
Cutting hoses	2:11:00	04:30		04:30	
Looking for something	2:15:30	00:15			00:15
Reading instructions	2:15:45	00:20		00:20	
Mounting fittings	2:16:05	00:15	00:15		
Reading instructions	2:16:20	01:20		01:20	
Mounting fittings	2:17:40	04:00	04:00		
Thinking	2:21:40	00:30			00:30
Marking	2:22:10	00:20	00:20		
Mounting fittings on hoses	2:22:30	02:40	02:40		
Thinking	2:25:10	00:10			00:10
Opening a new roll	2:25:20	00:50		00:50	
Cutting hoses	2:26:10	00:25		00:25	
Marking	2:26:35	00:25	00:25		
Reading instructions	2:27:00	00:50		00:50	
Mounting fittings	2:27:50	00:20	00:20		
Mounting fittings using large machine	2:28:10	00:25	00:25		

Reading instructions	2:28:35	00:10		00:10	
Mounting fittings	2:28:45	00:55	00:55		
Reading instructions	2:29:40	00:25		00:25	
Marking	2:30:05	00:15	00:15		
Walks away to make phone call	2:30:20	00:50			00:50
Investigates problem	2:31:10	00:55			00:55
Discussing with Franky	2:32:05	03:35			03:35
Mounting fittings on chassis 4	2:35:40	01:05	01:05		
Looking at chassis 6 and 8	2:36:45	02:35			02:35
Getting material	2:39:20	00:30		00:30	
Securing fittings on chassis 4	2:39:50	02:05	02:05		
Getting material	2:41:55	01:00		01:00	
Mounting fittings chassis 4	2:42:55	04:40	04:40		
Interrupted discussing	2:47:35	00:20			00:20
Walks away to help the person who interrupted	2:47:55	02:15			02:15
Back at station	2:50:10	00:10			00:10
Preparing working place	2:50:20	01:05		01:05	
Mounting hoses	2:51:25	01:35	01:35		
Walks away to look for parts	2:53:00	01:05			01:05
Looking at chassis 4	2:54:05	00:05			00:05
Walks to computer	2:54:10	00:20			00:20
Checking computer	2:54:30	01:00		01:00	
Walks to get instruction and reads it	2:55:30	03:10		03:10	
Looking for something	2:58:40	01:30			01:30
Reading instructions	3:00:10	00:40		00:40	
Walks to computer	3:00:50	00:45			00:45
Checking computer	3:01:35	02:05		02:05	
Walks back to station	3:03:40	00:10			00:10
Fetching tools	3:03:50	00:45		00:45	

Interrupted discussing	3:04:35	01:25			01:25
Reading instructions	3:06:00	00:35		00:35	
Discussing with Franky	3:06:35	01:00			01:00
Walks to chassis 1 to help the person who interrupted	3:07:35	02:55			02:55
Getting hoses from chassis 4	3:10:30	00:15		00:15	
Checking computer	3:10:45	01:30		01:30	
Walks to station to read instructions	3:12:15	02:35		02:35	
Walks to computer	3:14:50	00:10			00:10
Checking computer	3:15:00	01:05		01:05	
Discussing with Franky	3:16:05	03:30			03:30
Walks to chassis 4	3:19:35	00:20			00:20
Securing fittings on chassis 4	3:19:55	01:55	01:55		
Discussing with Dan	3:21:50	00:15			00:15
Mounting hoses	3:22:05	05:25	05:25		
Talking to PE	3:27:30	00:35			00:35
Mounting hoses	3:28:05	02:55	02:55		
Discussing with Franky	3:31:00	01:35			01:35
Walks to chassis 4	3:32:35	00:40			00:40
Routing cables	3:33:15	01:15	01:15		
Mounting hoses	3:34:30	01:25	01:25		
Climbing inside chassis	3:35:55	00:05		00:05	
Securing hoses using zip-ties	3:36:00	07:00	07:00		
Talking	3:43:00	00:15			00:15
Securing hoses using zip-ties	3:43:15	00:25	00:25		
Talking	3:43:40	00:15			00:15
Securing hoses using zip-ties	3:43:55	00:25	00:25		
Climbing out from chassis	3:44:20	00:10		00:10	
Securing fittings	3:44:30	03:50	03:50		
Securing using zip-ties and marking	3:48:20	01:20	01:20		

Collecting material and moves to next chassis	**3:49:40**	**2:04:35**	**0:44:55**	**0:43:25**	**0:36:15**
Operator 1					
Walks to chassis 5 and puts down tools	3:51:00	00:05		00:05	
Break	3:51:05	30:55			
Preparing working place	4:22:00	01:20		01:20	
Fetching blue box to station	4:23:20	00:55		00:55	
Reading instructions	4:24:15	00:15		00:15	
Mounting fittings on hoses	4:24:30	01:40	01:40		
Reading instructions	4:26:10	00:40		00:40	
Getting help	4:26:50	00:20			00:20
Marking	4:27:10	00:15	00:15		
Reading instructions	4:27:25	00:10		00:10	
Marking	4:27:35	00:20	00:20		
Reading instructions	4:27:55	00:55		00:55	
Marking	4:28:50	00:30	00:30		
Interrupted, discussing	4:29:20	00:45			00:45
Marking	4:30:05	01:00	01:00		
Thinking	4:31:05	00:10			00:10
Discussing	4:31:15	00:50			00:50
Mounting fittings using big machine	4:32:05	01:15	01:15		
Marking	4:33:20	00:30	00:30		
Mounting fittings using big machine	4:33:50	01:55	01:55		
Reading instructions	4:35:45	00:25		00:25	
Marking	4:36:10	01:00	01:00		
Reading instructions	4:37:10	00:30		00:30	
Thinking	4:37:40	00:35			00:35
Discussing	4:38:15	01:45			01:45
Marking	4:40:00	00:20	00:20		

Talking	4:40:20	03:25			03:25
Walks away to look at chassis 7	4:43:45	01:55			01:55
Getting help to read and understand instructions	4:45:40	02:05			02:05
Re-marking	4:47:45	04:30			04:30
Walks and leaves the re-marked hoses at chassis 7	4:52:15	00:35			00:35
Securing fittings	4:52:50	01:50	01:50		
Getting help	4:54:40	01:10			01:10
Marking	4:55:50	01:00	01:00		
Securing fittings	4:56:50	01:50	01:50		
Leaving hose	4:58:40	00:50		00:50	
Walks to chassis 5	4:59:30	00:15			00:15
Preparing working place	4:59:45	00:55		00:55	
Walks to station to get parts	5:00:40	01:20		01:20	
Mounting brackets	5:02:00	00:30	00:30		
Mounting fittings	5:02:30	01:45	01:45		
Laying out hoses	5:04:15	01:40		01:40	
Mounting hoses	5:05:55	01:40	01:40		
Climbing inside chassis	5:07:35	00:05		00:05	
Mounting hoses	5:07:40	00:05	00:05		
Getting tools	5:07:45	00:25		00:25	
Mounting hoses + brackets	5:08:10	08:20	08:20		
Climbing out from chassis	5:16:30	00:05		00:05	
Collects material	5:16:35	00:35		00:35	
Securing fittings + hoses and marking	5:17:10	00:35	00:35		
Move to next chassis	**5:17:45**	**1:26:45**	**0:26:20**	**0:11:10**	**0:18:20**
Operator 1					
Moving tools and equipment to chassis 6	5:17:45	00:30		00:30	
Planning work, fetching equipment	5:18:15	00:25		00:25	

Talking	5:18:40	00:30			00:30
Mounting fittings	5:19:10	00:30	00:30		
Walks to chassis 8	5:19:40	00:35			00:35
Walks to station	5:20:15	00:05			00:05
Cutting hoses	5:20:20	03:15		03:15	
Reading instructions	5:23:35	00:15		00:15	
Mounting fittings	5:23:50	01:50	01:50		
Reading instructions	5:25:40	00:15		00:15	
Mounting fittings using big machine	5:25:55	00:20	00:20		
Marking	5:26:15	00:30	00:30		
Mounting fittings using big machine	5:26:45	02:00	02:00		
Leaving hose at chassis 7	5:28:45	00:45			00:45
Talking	5:29:30	00:55			00:55
Walks away	5:30:25	03:35			03:35
Reading instructions	5:34:00	00:50		00:50	
Cutting hoses	5:34:50	00:25		00:25	
Marking	5:35:15	00:50	00:50		
Cutting hoses	5:36:05	02:40		02:40	
Mounting fittings	5:38:45	03:00	03:00		
Discussing	5:41:45	01:05		01:05	
Mounting fittings using big machine	5:42:50	00:45	00:45		
Talking	5:43:35	00:25			00:25
Mounting fittings using big machine	5:44:00	02:05	02:05		
Talking	5:46:05	00:45			00:45
Mounting fittings using big machine	5:46:50	00:50	00:50		
Marking	5:47:40	01:30	01:30		
Materials handling	5:49:10	01:05		01:05	
Walks to chassis 8	5:50:15	00:30			00:30
Fetching notebook and walks to check chassisnumber	5:50:45	01:55			01:55

Talking	5:52:40	03:15			03:15
Walks to chassis 6	5:55:55	00:05			00:05
Securing fittings	5:56:00	00:50	00:50		
Getting tools	5:56:50	02:00		02:00	
Checking chassis 6	5:58:50	00:10			00:10
Securing fittings	5:59:00	02:00	02:00		
Fetching material + tools	6:01:00	02:00		02:00	
Mounting fittings at chassis	6:03:00	02:10	02:10		
Fetching material + tools	6:05:10	01:15		01:15	
Mounting fittings	6:06:25	02:25	02:25		
Fetching material + tools	6:08:50	00:40		00:40	
Mounting fittings	6:09:30	01:00	01:00		
Thinking	6:10:30	00:05			00:05
Fetching material + tools	6:10:35	01:40		01:40	
Mounting fittings	6:12:15	00:45	00:45		
Laying out hoses	6:13:00	00:50		00:50	
Mounting hoses	6:13:50	00:45	00:45		
Talking	6:14:35	01:00			01:00
Mounting hoses	6:15:35	00:40	00:40		
Talking	6:16:15	00:20			00:20
Collecting material and moves to next chassis	**6:16:35**	**0:58:50**	**0:24:45**	**0:19:10**	**0:14:55**
Operator 1					
Cutting hoses	6:17:22	00:13		00:13	
Mounting fittings	6:17:35	00:20	00:20		
Marking	6:17:55	00:25	00:25		
Mounting fittings using large machine	6:18:20	00:45	00:45		
Interrupted	6:19:05	00:35			00:35
Mounting fittings using large machine	6:19:40	01:50	01:50		

Marking	6:21:30	01:10	01:10		
Hanging cable on stand	6:22:40	00:10			00:10
Mounting fittings using large machine + marking	6:22:50	01:30	01:30		
Hanging hose on stand	6:24:20	00:10			00:10
Marking	6:24:30	00:40	00:40		
Mounting fitting	6:25:10	01:50	01:50		
Mounting fittings using large machine	6:27:00	01:00	01:00		
Marking	6:28:00	01:05	01:05		
Hanging cable on stand	6:29:05	00:05			00:05
Mounting fitting	6:29:10	01:40	01:40		
Mounting fittings using large machine	6:30:50	00:35	00:35		
Marking	6:31:25	00:20	00:20		
Hanging hose on stand	6:31:45	00:15			00:15
Mounting fittings	6:32:00	00:55	00:55		
Mounting fittings using large machine	6:32:55	00:20	00:20		
Marking	6:33:15	01:00	01:00		
Reading instructions	6:34:15	00:25		00:25	
Mounting fittings	6:34:40	00:20	00:20		
Mounting fittings using large machine	6:35:00	00:20	00:20		
Marking	6:35:20	01:50	01:50		
Interrupted	6:37:10	00:50			00:50
Mounting fittings using large machine	6:38:00	01:55	01:55		
Marking	6:39:55	00:20	00:20		
Material handling	6:40:15	00:05		00:05	
Interrupted	6:40:20	00:20			00:20
Hanging hose on stand	6:40:40	00:45			00:45
Reading instructions	6:41:25	00:10		00:10	
Walks to leave hoses on trolley	6:41:35	00:45			00:45
Idle	6:42:20	00:15			00:15

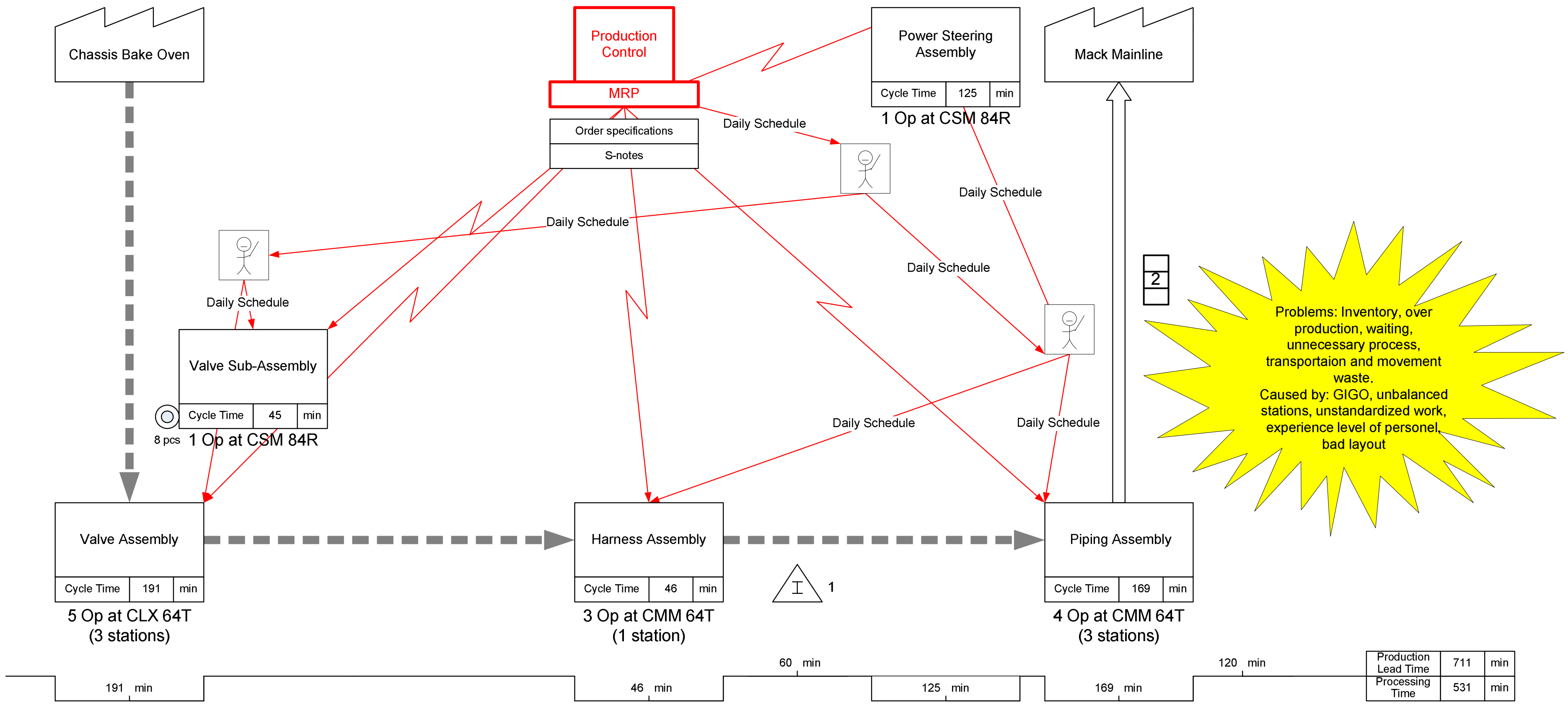
Fetching new roll	6:42:35	00:10		00:10	
Reading instructions	6:42:45	00:35		00:35	
Material handling	6:43:20	00:30		00:30	
Marking finished hose	6:43:50	01:20	01:20		
Material handling	6:45:10	01:00		01:00	
Reading instructions	6:46:10	00:45		00:45	
Hanging hose on stand	6:46:55	00:20			00:20
Reading instructions	6:47:15	00:35		00:35	
Cutting hoses	6:47:50	00:50		00:50	
Marking	6:48:40	00:10	00:10		
Interrupted	6:48:50	00:15			00:15
Marking	6:49:05	00:15	00:15		
Interrupted	6:49:20	00:10			00:10
Mounting fittings using large machine	6:49:30	01:05	01:05		
Material handling	6:50:35	00:25		00:25	
Reading instructions	6:51:00	00:10		00:10	
Cutting hoses	6:51:10	00:20		00:20	
Mounting fittings	6:51:30	00:20	00:20		
Cutting hoses	6:51:50	01:00		01:00	
Mounting fittings using large machine	6:52:50	00:50	00:50		
Interrupted	6:53:40	02:00			02:00
Cutting hoses	6:55:40	00:45		00:45	
Mounting fittings using large machine	6:56:25	01:30	01:30		
Marking	6:57:55	01:20	01:20		
Interrupted to check other chassis	**6:59:15**	**0:41:53**	**0:27:00**	**0:07:58**	**0:06:55**

Sub-cutting station (STN120)

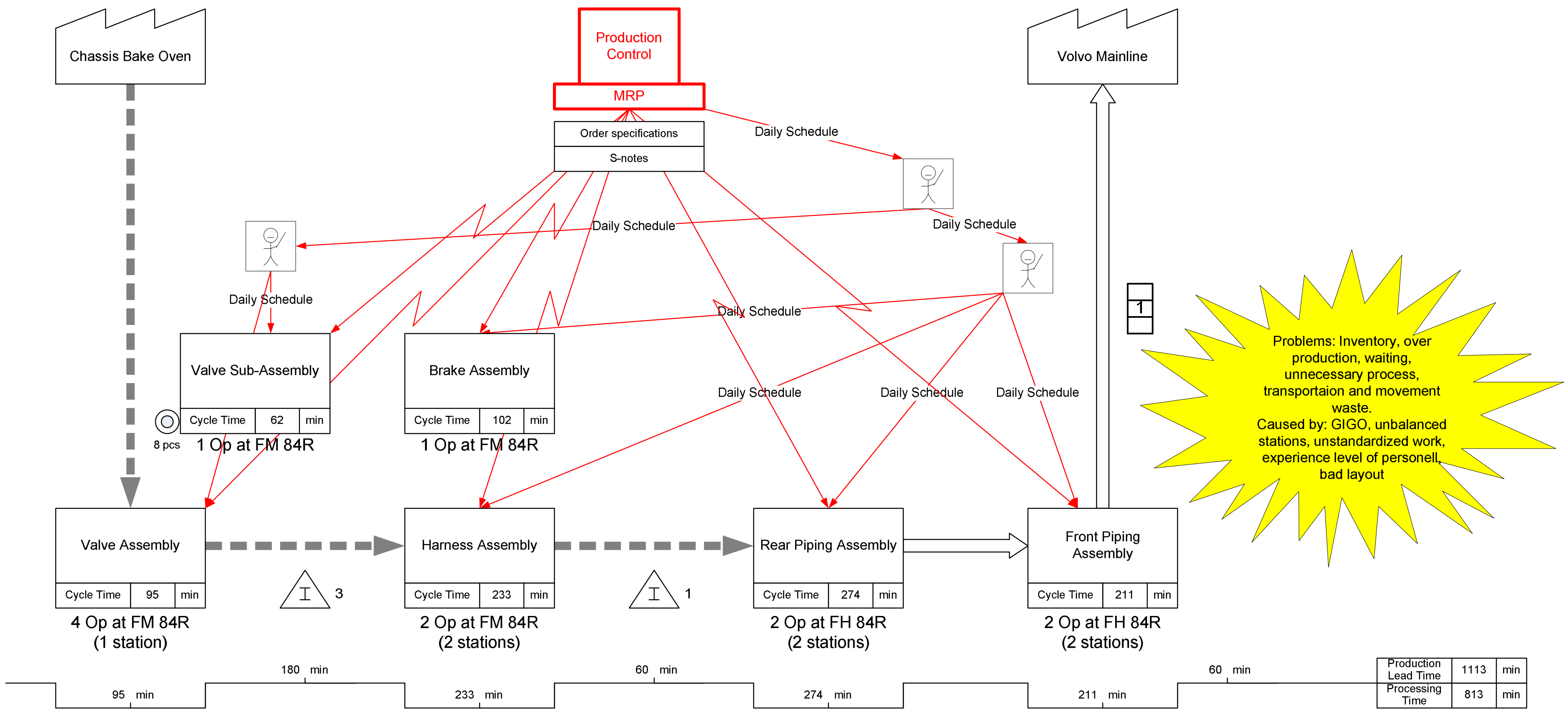
Date	Starttime (h:mm)	End time (h:mm)	Element time (mm)	Brand
9/03/2009	11:00	12:00	1:00	Mack
10/03/2009	07:25	08:00	0:35	Mack
11/03/2009	06:15	08:20	2:05	Mack
12/03/2009	08:20	14:57	6:47	Volvo
13/03/2009	06:00	11:00	4:40	Volvo
16/03/2009	06:00	08:30		Volvo
16/03/2009	11:30	14:57	5:27	Volvo
17/03/2009	08:00	10:45	2:25	Volvo
18/03/2009	10:00	11:30	1:30	Volvo
19/03/2009	06:00	07:00	1:00	Mack
Brand	Volvo	Mack		
Mean time spent in this station each day (h:mm)	4:09	1:10		
Mean time spent in this station each day (%)	51.83%	14.52%		

Appendix F – Value stream mapping

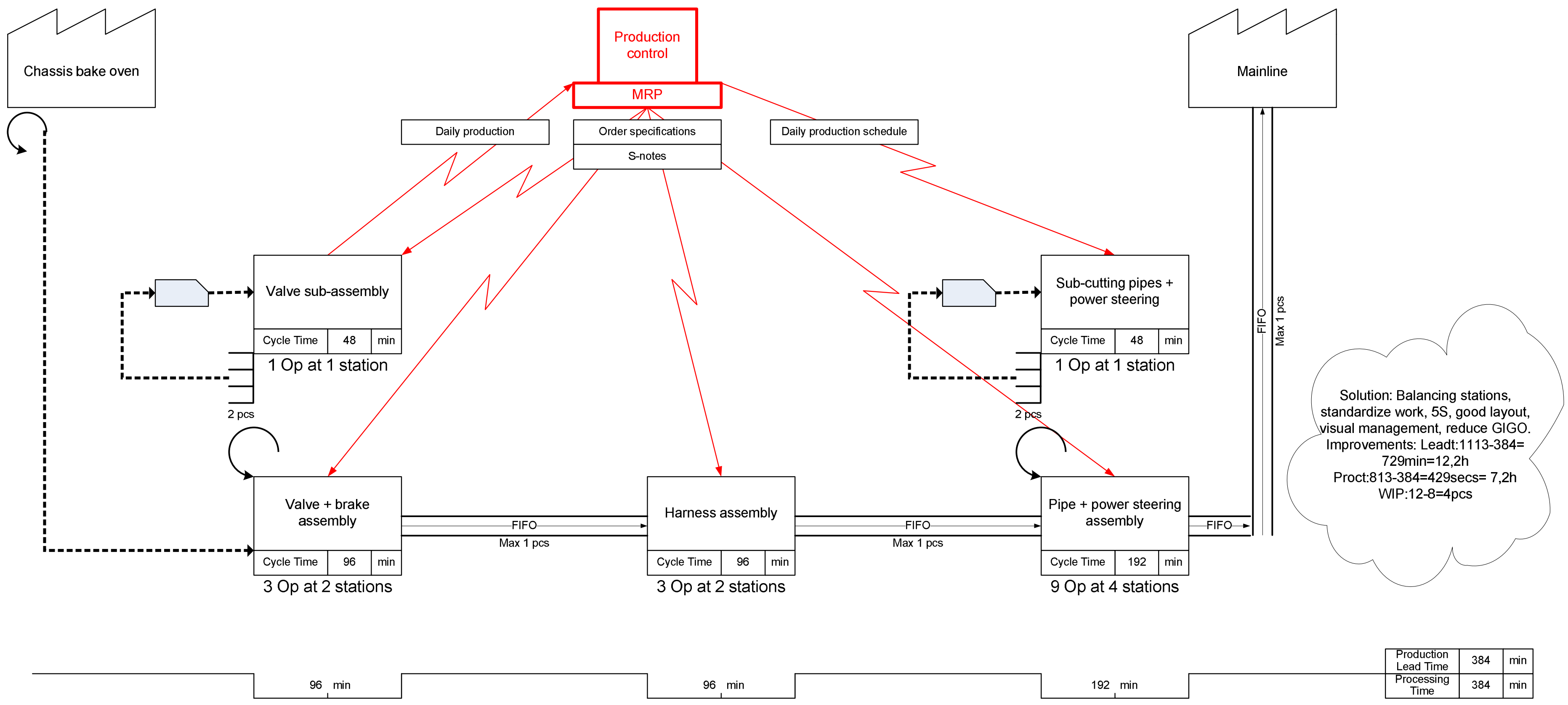
Mack current state value stream map



Volvo current state value stream map



Valve and pipe area ideal future state value stream map



Appendix G – Transcription of interviews

Operator 1

The VSM from Appendix F – Value stream mapping was presented to the interviewee in order to verify its correctness. The current situation was agreed upon. For the future however the operator expressed a need for more information to be passed on and exchanged between the supervisors of the chassis line and the valve area in order to catch errors and faults faster. Previously the chassis line supplied the valve assembly area with a piece of paper each day that stated what changes had been made to different chassis, this way of working was however stopped a long time ago. The WBS that can be seen in 5.2 - Work breakdown structure was also presented. The only comment was that the taping has to be done as the final step and in the last few minutes before the chassis is moved, this in order to ensure that the paint is not getting stuck and ripped when the tape is removed.

The operator finds the process to be working well. The only downside is that the skill level is low at the moment. In normal cases it should be sufficient with two operators on the Volvo side and three operators on the Mack side. At the moment there are on average four operators in the area due to the previously mentioned low skill level. Regarding the process, the valves are made in daily batches. The conception of the operator is however that only valve's for two chassis should be made at a time to ensure higher productivity. The chassis should cool off for 10-20 minutes after leaving the oven. However the masking tape is easier to remove straight after the chassis leave the oven since the paint is not entirely dry. Currently the operators mounting the valves are sub-assembling the trailer bar and the rear brake fittings for the Mack trucks. The rear brake fittings should be possible to sub-assemble before the chassis arrive. For the Volvos no sub-assembly is carried out by the valve mounting operators.

To deal with the problem of bad S-notes, it is suggested that when a problem arises it is directly passed on to 3P to be able to take care of the issue immediately and reduce the lead time. Currently all problems has to first go through PE, which takes about 30 minutes. After that PE passes it on to 3P which investigates the problem by themselves for about 30 minutes. They give an answer to PE which passes it on to production. Currently the process takes, in good cases, around two hours which is causing a lot of grievances in the production. What is requested is that 3P has one person that can directly come out in to the production and look at the issues. 9 times out of 10 the chassis line is producing according the assembly instructions in the computer; therefore if a problem occurs it can often be related to design issues.

When shown the spaghetti diagrams a suggested solution from the operator is to use a trolley containing all necessary small parts, valves and tools in order to minimize the walking distance needed. One workbench is needed since the trailer bar cannot be assembled at the chassis as it weighs too much. Previously the work was arranged in such a way that one operator mounted all the valves and a second operator followed to tighten all the bolts. This way of working has however deteriorated because of the low skill level. It is also suggested that the sub-assembly area should be reduced to only one workbench. With the introduction of global fittings both valve sub-assembly and piping ought to be easier. With the current situation it is also mentioned that moving the mounting of the Volvo brake hoses to the valve mounting area shouldn't be an issue. The Volvo air-dryer takes about 5-6 minutes to assemble and the Mack one takes a little bit longer.

Operator 2

The operator is pleased with his working environment on a general scale. It is more a case of following the flow within the area. The only problem expressed is if there is not enough labour. When there are three operators working in the area and a new chassis is coming out of the oven, one of the operators has to pull that chassis out of the oven, meaning there are two operators left to finish previous chassis. If one of the operators is missing it creates a lot of pressure on the remaining ones. Another problem is that trucks often come in to the valve area incomplete, meaning that holes are missing where valves are supposed to be mounted, or bolts are missing which are supposed to be used to mount valves. It is mentioned that the Mack Titan and any of the tri-axles are the most time consuming ones, also with the introduction of global fittings there will be some initial problems until everyone is used to the new working method. But all models are generally pretty much the same.

The WBS from 5.2 - Work breakdown structure was presented and the operator agreed that it reflects what is being done in the area. It is also explained that the time for applying the tape can vary a lot depending on the length of the rails and the number of cross-members. There are also no real dependencies in the WBS apart from the fact that the tape has to be applied as the final step. As it is now, one operator is doing the front while the other two does the middle and the back. One problem with the Mack is that the brake hoses that are fitted at the valve mounting station are not standardized like on the Volvo. Depending on where the cross-members are located the brake hoses needs to be fitted in different places all the time; this is seen as a problem as it is hard to know what brake hose is supposed to go where since they are always different in length.

The winch used to move the chassis out of the oven is seen as something that should be kept in the area. Other than that the towing buggies are something that needs to be looked at. They are three or four years old and has not been serviced with the result that the tires are worn out meaning you have to push the chassis anyway since they are just slipping on the floor otherwise.

When shown the spaghetti diagram from Appendix B – Spaghetti diagrams the operator thinks that one possible solution is to have all the tools, nuts and bolts in a toolbox that can be brought to the chassis to eliminate much of the movement to the workbench. It is said that you mainly need 12 and 13 spanners, 18 and 21 for big bolts and nuts, half inch and 3/8 inch gun together with 12 and 13 sockets. The problem is though that many of the tools gets borrowed and is never returned which is causing time delays as the operators needs to run around in other areas to find the correct tools. Previously there were three trolleys used containing all the tools and small parts needed, however these have since been removed and substituted for large blue cabinets that are too big and heavy to move close to the chassis.

Operator 3

The VSM from Appendix F – Value stream mapping was presented in order to verify the correctness. The current state map was deemed to reflect the situation as it is at the moment. It is mentioned that the production schedule rarely matches what is actually produced. This causes problems with the supply of material as the warehouse follows the production schedule when doing their picks. The underlying reason is unknown to the interviewee but some possible reasons mentioned is that the chassis line is dropping chassis when for instance punch holes are missing, also the paint shop is sometimes rearranging the order to save time cleaning their equipment if they can paint several chassis of the same colour. This has the effect that the piping area has to rearrange the order again because otherwise the mainline will not have the correct material when the chassis is coming through. It is mentioned that sequence changes should only be made by supervisors or people higher up, not by the line workers. There are also no real assembly instructions for the pipers, most of the information they get is from the order specification or from the S-notes. The same thing applies to the harnessing although they have access to some more information.

In regard to the WBS from 5.2 - Work breakdown structure it is mentioned that the harnessing has to be done first together with brake hoses. The only thing that can be done beforehand is the fittings for the brake hoses. On Mack they can be done simultaneously but on Volvo the harnessing needs to be done first. This is because the pipes are later closed in and secured using the harnesses to create a good unison bundle.

One of the things that shouldn’t have been changed from previous setups is according to the interviewee how the trucks were parked. Previously the chassis where parked perpendicular to the way they are parked now. A few years back however the idea of station based piping was introduced in order to create a better flow through the system, however the stations where never implemented meaning that the process is still the same as before but additionally they have to move all the chassis each time the main line needs a new one. Furthermore it is clear that the interviewee is very open to changes and thinks that basically every aspect needs to be looked at, such as manning and layout.

When shown the spaghetti diagrams it is suggested that pipe reels needs to be available closer to the chassis and the actual piping to get rid of the excess movement that is currently present. Additional computers are needed, together with toolboxes for all the workers. Ideally a good piper should be teamed up with someone who does all the running for him, for instance getting pipes and small parts, so that the focus can be on the actual piping. Pre-cutting is mentioned as something that will be hard to implement since all the trucks are so different. It will create problems with storage since there is constraints on how much pipe that can be ordered to the station per day.

The problem related to bad S-notes is often because the people in production have to work through the middle man. Production raises the problem to PE which goes to 3P, who in turn says it is not a problem; PE relays the information back to production that still has a problem. This cycle repeats itself while the chassis needs to move further through the process often loosing several hours of assembly time.

Operator 4

When asked about the working environment, the operator feels that the biggest problem is that there is always something wrong, it is never a smooth operation. In general the working environment is considered to not so good; however the work in itself is something that is seen as satisfying. The WBS from 5.2 - Work breakdown structure was considered accurate and reflects the general overview of what is being carried out in the particular area. Regarding the actual work the harnesses have to be mounted before the battery cables since there are isolation switch connections and voltage regulators that go to the electrical distribution board that has to be mounted before the battery cables. The reason that some of the Mack harnessing is made after the piping just prior to the main line is thought to be because those cables are made more to measure depending on cab and chassis length, whereas the harnesses are of standard length.

The interviewee feels that there is nothing in particular regarding the way they are working that should be kept within the harnessing. However it is mentioned that the old way of parking the chassis perpendicular to the current layout is something that was better than it is today because of all the movement of chassis that is currently slowing the process down. The current placement of the material for the harnessing station is something that is mentioned as a problem.

When shown the spaghetti diagram it is yet again emphasized that the material for harnessing is placed at the wrong spot. The general idea is also that there is too much work for two operators to carry out the harnessing. Also the variation in trucks is causing the cycle time to fluctuate significantly, from a 6x4 that takes roughly an hour to an 8x4 rigid with battery-box that takes several hours. Therefore if the truck mix is wrong the harnessing might end up struggling to meet production demand. As it is now they are trying to distribute the work in such a way that one operator does the left hand side and the other one does the right hand side. But since the workload differs from side to side they end up helping each other once the first operator is finished. It is also clear that the Mack is much easier to harness than the Volvo since they only have one harness and not so many valves.

Operator 5

When asked about the working environment the operator generally enjoys his work but quite naturally it has its ups and downs. Currently it is a bit annoying to work on the Volvo piping because the floor has not been painted for a long time which is causing a lot of dust to accumulate. Also additional fans are something that would be considered good as it tends to get hot at times. The water cooler station is appreciated. Furthermore the operator feels that there is too much material scattered around the working place, for instance several picks that are delivered while the trucks are not coming out as they should. This has not always been the case, and there was a time when the right material was supplied at the right time.

The WBS from 5.2 - Work breakdown structure was presented, it was deemed correct. Some general comments were that the Volvo piping is much harder than the Mack piping since they are much more complex with more valves and more tanks. Also the Volvo has more variations in the actual pipe-routing, there will inevitably come a truck that no one has ever seen and this is where the experience of the operators plays a big role. What the operator finds annoying is the moving of the chassis which is causing a lot of time to be lost. In regard to dependencies within the WBS it doesn't matter if the rear pipes are mounted before the front pipes and vice versa. But it depends to some extent on the truck, if it is for instance an 8x4 rigid the rear pipers should ideally route and mount their pipes to the battery-box which will then be a part of the front pipers work. The most important thing however is that there is no overlaying of work, if there are crossovers from the rear to the front or the other way around it might happen that the front or rear piper has to redo the other operators work since he has secured the pipes in the way of the other.

The normal way of doing the piping is that the operator doing the actual routing of the pipes stays in the truck while the other operator of the team is cutting all the pipes and fetching all the material. As an example, the operator cutting will cut all the pipes needed for the left hand side, give that to the operator piping who will route and secure those pipes to a certain degree. Meanwhile the other operator starts cutting all the pipes needed for the right hand side. The operator inside the chassis will, once the right hand side is cut, start routing and securing the pipes on the right hand side. The other operator will then help with securing the pipes on the left hand side and then finally on the right hand side. In which order this is carried out differs from team to team and even between different operators. Ideally there should only be two people at the same time working on the chassis, meaning two guys piping and two guys fetching material and cutting pipes.

The moving of chassis is again mentioned as something that disturbs the normal way of working. Once the chassis needs to be moved you have to collect all the pipes and hang them on the truck in order to be able to move it, after that you also have to clean the area where truck was placed to make room for the new one. The operators also needs to get out from inside the chassis, move the truck, and then climb back inside. If there would be another way of doing this it would be good. In regard to the introduction of global fittings it is seen as something that will create an easier working environment over time as the operators learn how to work with them. There are however some worries that certain variation of trucks will be hard to do with global fittings as they are much bulkier than the old fittings.

The spaghetti diagrams was shown to the operator and the first comment was that with the new station layout and the buffer before the mainline there is a lot of more walking required in order to get to the pipe reels when piping the Volvos. Since the vips fittings are faced out with the introduction of the global fittings the only thing that the pipers really need is easy access to the pipes. When asked if it would be easier to do the Volvo piping the same way as for the Mack with the pipes on moveable reels it was mentioned that the Mack pipes are coloured and the Volvo pipes are black, so you still need to mark the pipes on the Volvo with tape. Also the Volvo pipe rolls are much bigger and heavier which would mean that the pipe reel would get to heavy to move around. It would maybe be good if they could split it in to smaller batches but then there is a problem with how much pipe that can be ordered and stored at the station at the same time.

Another problem that is highlighted is that if the trucks would be complete once they enter the piping area it would be much easier to finish the job on time. As it is now there are brackets and other parts constantly missing which is slowing the process down considerably, sometimes for hours. The different stages of information exchange is mentioned as an issue when a problem arises, production reports to PE which reports to 3P, decision is fed back to PE which talks to production, all the while the truck has to move on.

Another problem at the moment is the skill level. It takes approximately 4-6 months to learn Volvo piping at a basic level, meaning the most common variants. The problem now is that there is a constant shift between Mack and Volvo in the production with the alternating line which means that there is no continuity in the training and learning of the Volvo piping. It is also mentioned that piping is one of the least popular jobs in the factory so many of the operators feel unmotivated as they don't really want to be doing what they are doing, and there is no incentive to stay in piping. The idea to pre-cut the pipes is considered hard to implement, it may work for standard 6x4 trucks. Another problem related to this is that there is no standardized way of routing the pipes which means that it differs between operators how much pipe is going to be needed.

Operator 6

The operator generally finds his working environment to be good although stressful at times. The transition to Volvo piping is seen as difficult and troublesome since the Volvo trucks are pretty much all different whilst the Mack trucks are pretty much the same. Also the constant change between Mack and Volvo doesn't give the operators enough time to get accustomed to the Volvo trucks. In between the changes they tend to forget what they have learned from the previous run of Volvos.

The WBS was deemed correct. It is explained that they are trying to figure out the fastest and best way to route the pipes through the Mack and currently the fastest way they have found is if they start in the front and run them straight through. One man should do the front of the piping on the Mack and two guys should work out the rear part of the piping. The coloured pipes are seen as something that makes the routing easier, and this is something that should if possible be implemented in the Volvo piping. There are no real dependencies in the piping, except that the harnesses need to go in first.

A few problems that are mentioned are that brackets are often missing and slow the process down, also there are pretty often issues with holes missing in the chassis rails which means certain valves cannot be mounted and hence makes the piping impossible. This problem is deemed to only cause issues on the Mack side. Pre cutting of the pipes is something that has existed in the past but was removed due to an unknown reason. Trolleys with toolboxes have also been used in the past, but were removed as they were visually not good.

Appendix H – WIP cost calculation of chassis

Volvo

	Direct		Overhead		Total
	Materiel	Labour	Variable	Fixed	
Jan	4,557,886.98	183,582.30	217,477.69	145,083.04	5,104,030.00
Feb	6,763,726.97	282,882.47	319,970.12	252,570.45	7,619,150.00
Mar	7,046,586.62	303,986.09	343,840.56	271,412.73	7,965,826.00
Total	18,368,200.56	770,450.86	881,288.36	669,066.22	20,689,006.00
Average	**129,353.53**	**5,425.71**	**6,206.26**	**4,711.73**	**145,697.23**

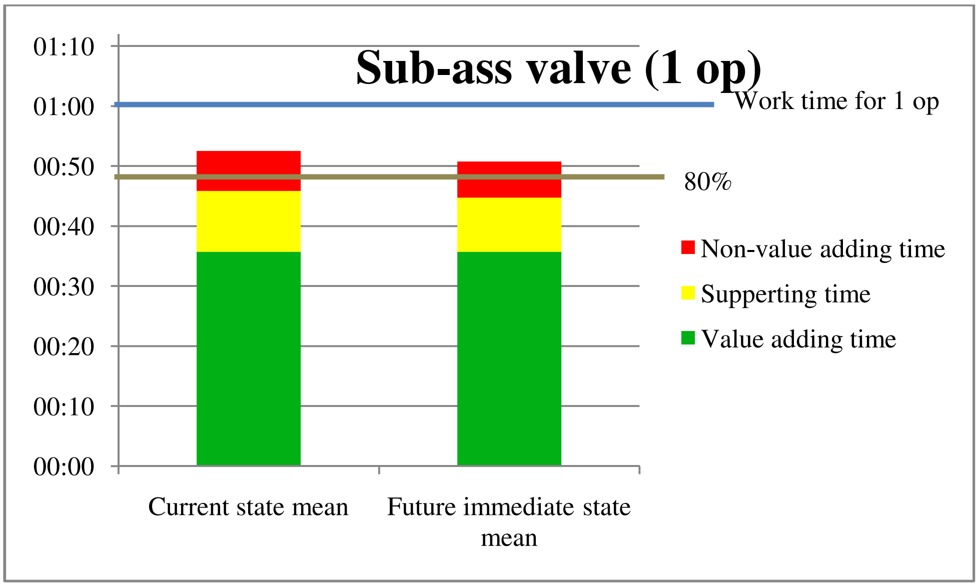
No. of Trucks 142
Based on production report Jan-March 2009

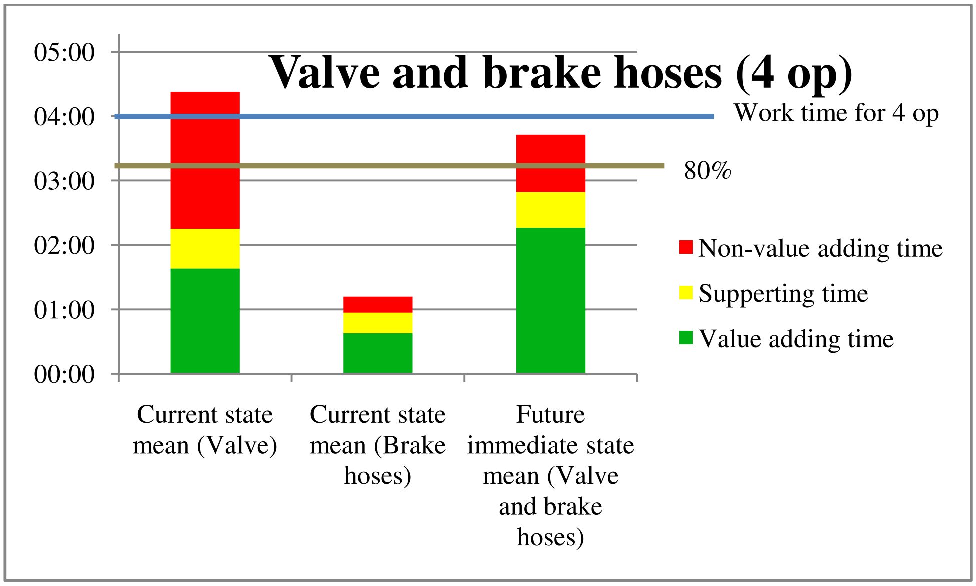
Mack

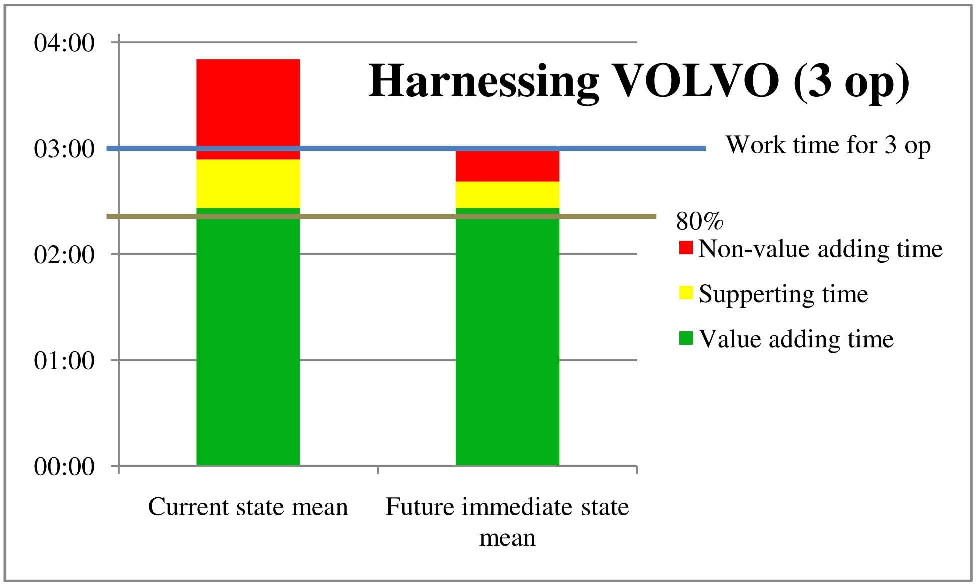
	Direct		Overhead		Total
	Materiel	Labour	Varbiable	Fixed	
Jan	**5,697,991.08**	**287,772.78**	**361,553.84**	**110,253.29**	6,457,571.00
Feb	6,599,202.77	328,570.50	354,044.29	271,720.45	7,553,538.00
Mar	9,514,859.61	472,040.86	508,637.79	390,367.23	10,885,905.50
Total	21,812,053.46	1,088,384.14	1,224,235.92	772,340.97	24,897,014.50
Average	**123,932.12**	**6,184.00**	**6,955.89**	**4,388.30**	**141,460.31**

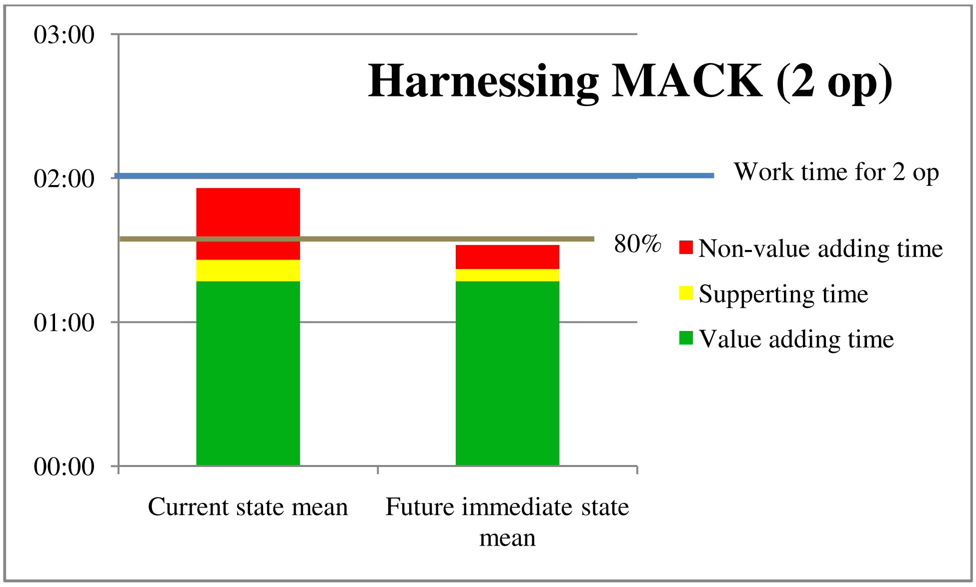
No. of Trucks 176
Based on production report Jan-March 2009

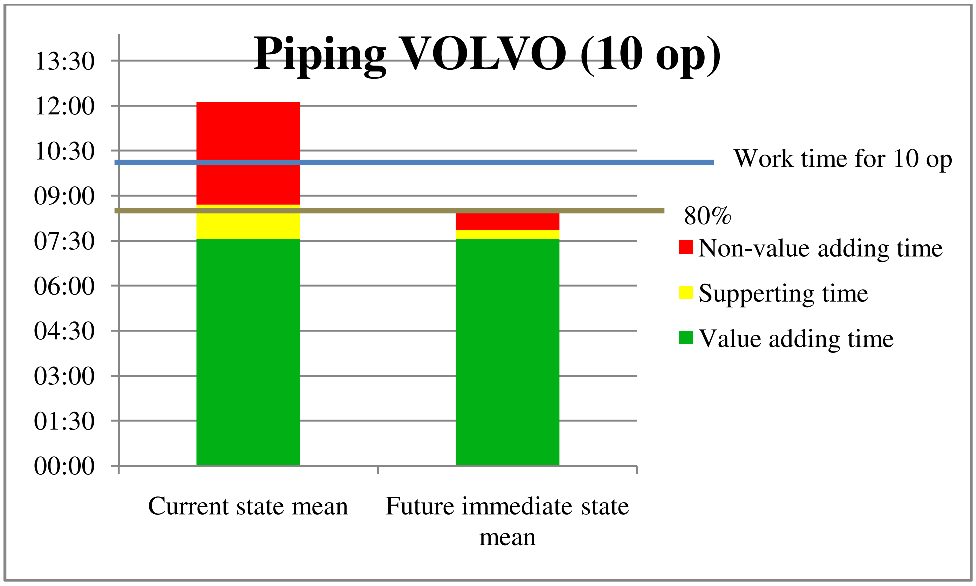
Appendix I – Station balancing diagrams for immediate state

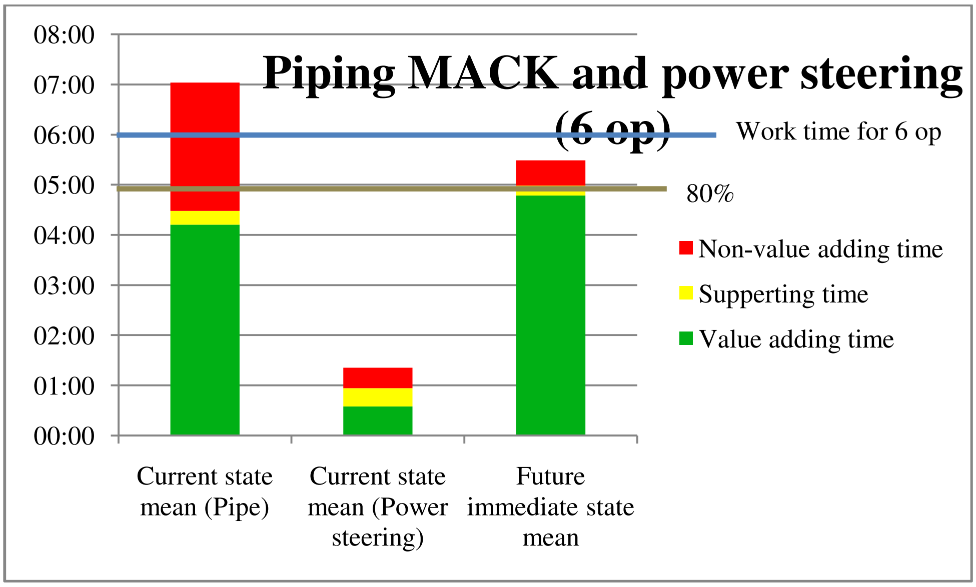


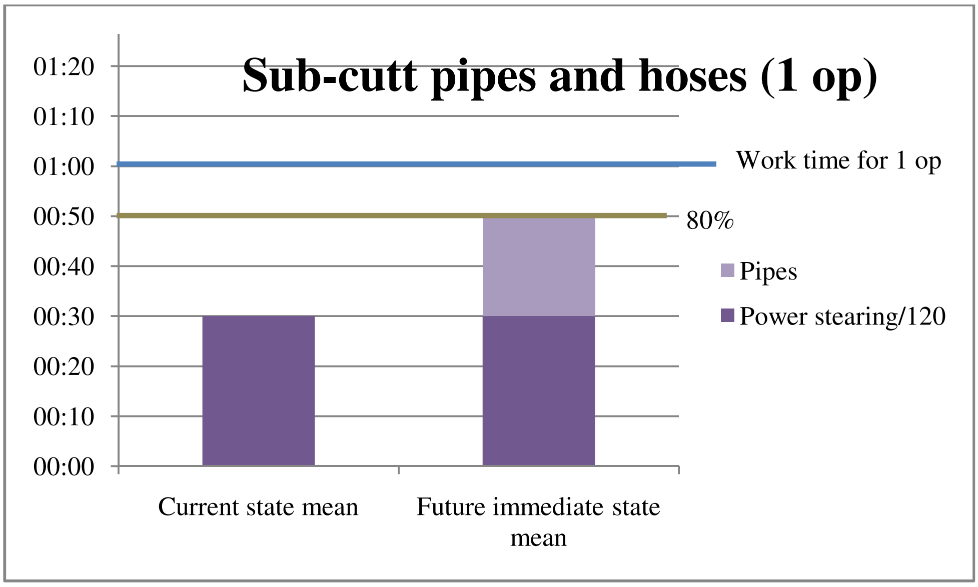



Harnessing VOLVO (3 op)
04:00
03:00
02:00
01:00
00:00
Work time for 3 op
80%
Non-value adding time
Supperting time
Value adding time
Current state mean
Future immediate state mean


Harnessing MACK (2 op)
03:00
02:00
01:00
00:00
Work time for 2 op
80%
Non-value adding time
Supperting time
Value adding time
Current state mean
Future immediate state mean


Piping VOLVO (10 op)
13:30
12:00
10:30
09:00
07:30
06:00
04:30
03:00
01:30
00:00
Work time for 10 op
80%
Non-value adding time
Supperting time
Value adding time
Current state mean
Future immediate state mean


Piping MACK and power steering (6 op)
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Work time for 6 op
80%
Non-value adding time
Supperting time
Value adding time
Current state mean (Pipe)
Current state mean (Power steering)
Future immediate state mean


Sub-cutt pipes and hoses (1 op)
01:20
01:10
01:00
00:50
00:40
00:30
00:20
00:10
00:00
Work time for 1 op
80%
Pipes
Power stearing/120
Current state mean
Future immediate state mean

Appendix J – MPU calculation

Calculation for the Method value

Data from Selected work sampling categories

Activity	Time of day		
	Current state	Immediate state	Ideal state
	Valve area		
Assembly	02:40	02:40	02:40
Handling tools	00:15	00:15	00:15
Materials handling	01:00	01:00	00:45
Moving chassis	00:10	00:05	00:05
Administrative work	00:54	00:50	00:45
Located in piping area	00:09	00:00	00:00
Cleaning	00:03	00:03	00:03
~~Unrelated talking~~			
Moving	01:22	00:40	00:30
~~Personal time~~			
~~Idle~~			
~~Other~~			
Total	06:35	05:34	05:03
	Pipe area		
Assembly	02:43	02:43	02:43
Handling tools	00:22	00:22	00:22
Materials handling	00:42	00:10	00:10
Moving chassis	00:15	00:05	00:05
Administrative work	00:18	00:18	00:18
~~Help eachother~~			
Cleaning	00:08	00:08	00:08
~~Unrelated talking~~			
Moving	01:07	00:35	00:20
~~Personal time~~			
~~Idle~~			
~~Other~~			
Total	05:39	04:22	04:06
Change in Method			
Total avarage value for the whole area	06:07	04:58	04:34
Value of change		1,23	1,34

Calculation for the Performance value

	Current state	Immediate state	Ideal state
Pace	100%	100%	100%
	70%	72%	85%
Change in Performance			
Value of change		1,03	1,21

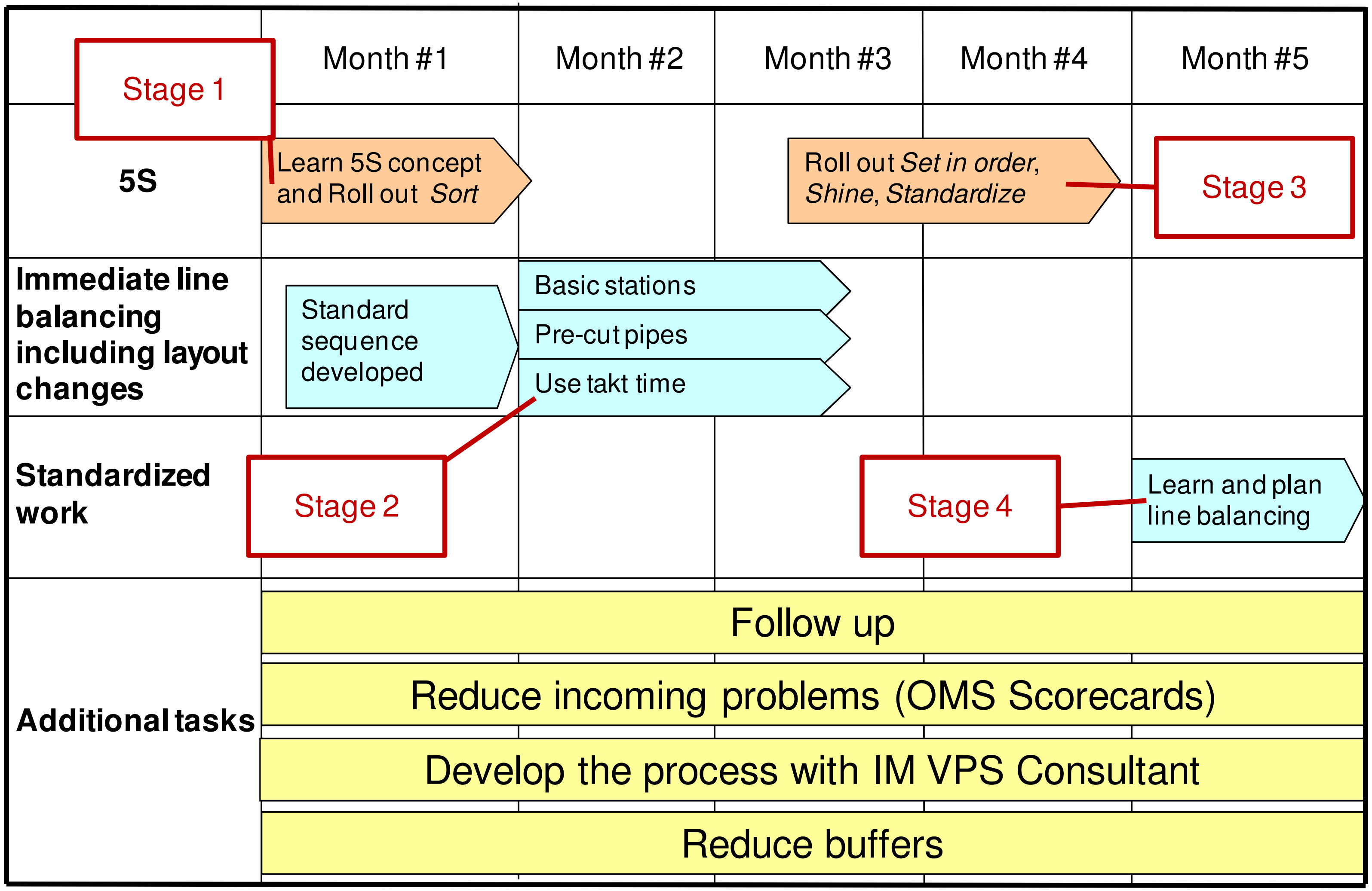
Calculation for the Utilisation value

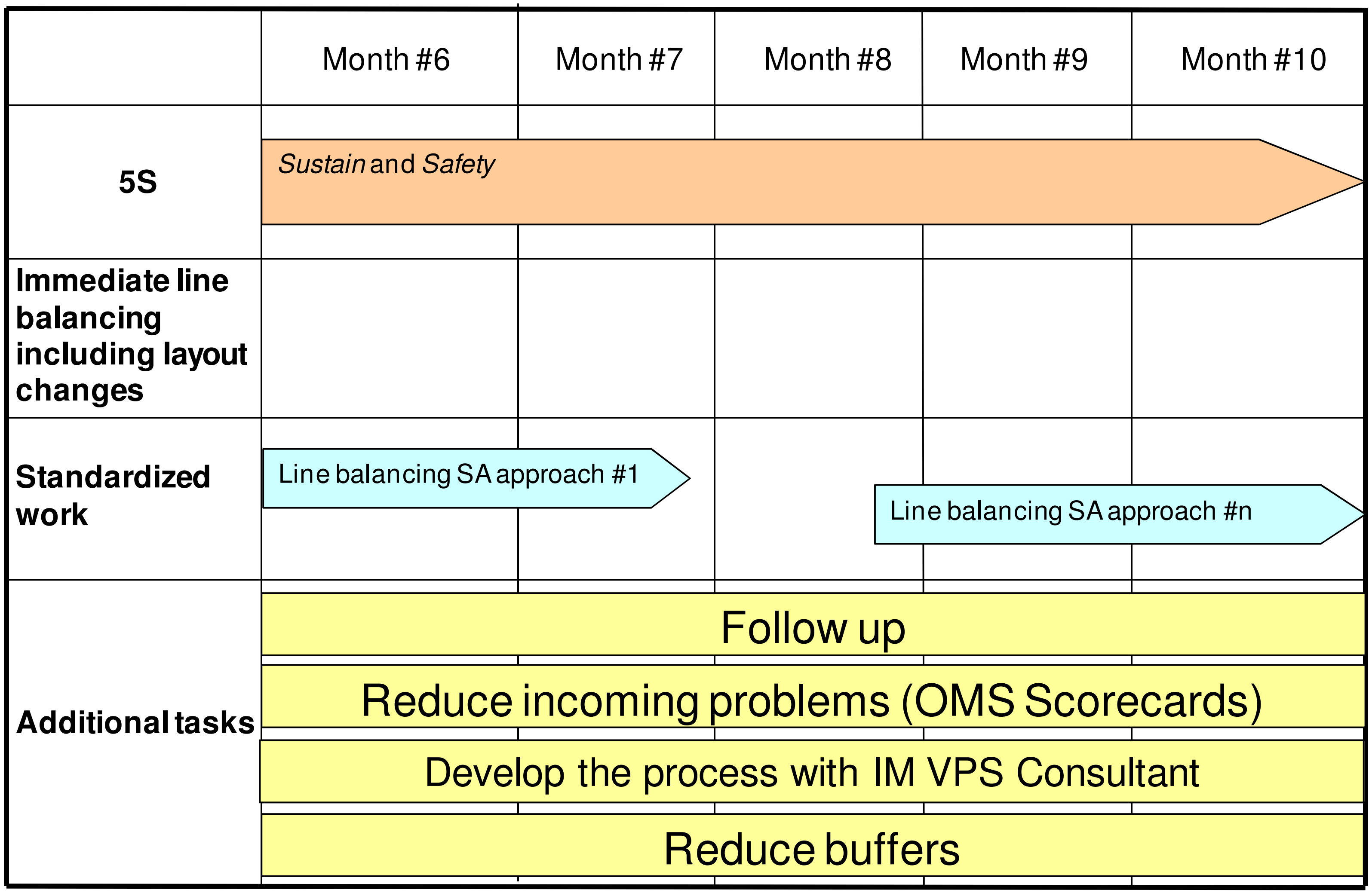
Activity	%		
	Current state	Immediate state	Ideal state
	Valve area		
~~Assembly~~	~~02:40~~		
Handling tools	00:15	00:15	00:15
Materials handling	01:00	01:00	00:45
Moving chassis	00:10	00:05	00:05
Administrative work	00:54	00:50	00:45
Located in piping area	00:09	00:00	00:00
Cleaning	00:03	00:03	00:03
Unrelated talking	00:34	00:25	00:15
Moving	01:22	00:40	00:30
Personal time	00:10	00:10	00:10
Idle	00:22	00:15	00:10
Other	00:18	00:18	00:13
Total	05:21	04:01	03:11
	Pipe area		
~~Assembly~~	~~02:43~~		
Handling tools	00:22	00:22	00:22
Materials handling	00:42	00:10	00:10
Moving chassis	00:15	00:05	00:05
Administrative work	00:18	00:18	00:18
Help eachother	00:12	00:10	00:00
Cleaning	00:08	00:08	00:08
Unrelated talking	00:35	00:25	00:20
Moving	01:07	00:35	00:20
Personal time	00:12	00:12	00:12
Idle	00:48	00:30	00:20
Other	00:33	00:33	00:20
Total	05:18	03:28	02:35
Total work day	08:02	08:02	08:02
Total avarage value for the whole area	05:19	03:45	02:53
Time of change for all exept assembly		01:34	02:26
30% of the time change added to the assembly time gives the Utilization time	02:42	03:10	03:26
Utilization [Assembly/Total work time]	33,6%	39,5%	42,8%
Improvement of U		1,18	1,27

Calculation for the productivity increase

	Current to Immediate state	Current to Ideal state
M	1,23	1,34
P	1,03	1,21
U	1,18	1,27
Productivity change	49,0%	106,6%

Appendix K – Implementation time plan




Month #6
Month #7
Month #8
Month #9
Month #10
5S
Sustain and Safety
Immediate line balancing including layout changes
Standardized work
Line balancing SA approach #1
Line balancing SA approach #n
Additional tasks
Follow up
Reduce incoming problems (OMS Scorecards)
Develop the process with IM VPS Consultant
Reduce buffers

Appendix L – Implementation risk analysis

Risk description	Probability	Consequence	Risk value	Preventive actions to be taken	Consequence actions to be taken
Incoming problems to the area not reduced causing large variations in the cycle times which will have a negative impact on the station layout	**4**	**4**	**16**	Present the details of the described problems in the diagram for involved departments and keep log of all showstoppers	Intensify the dialog with involved departments or stop the production when showstoppers are entering the area
Current project team handover to a working group and the following up phase fades out without any result	**3**	**4**	**12**	Setup a strong plan for the implementation and point out one responsible for the following up phase	
Experience level of operators to low to make the suggestion work	**3**	**4**	**12**		
Additional risks that have been overlooked having an impact on the outcome	**3**	**3**	**9**	Continuously work with the risk analysis	Replan
Interference with other projects	**3**	**3**	**9**	Keep ongoing projects updated of the implementation process	Replan
Management and involved departments do not offer enough support to PE and production	**3**	**3**	**9**	The dialog of objectives and purposes should be both down and up in the hierarchy	Intensify the dialog with involved parties
Conflict with parallel 5S program	**4**	**2**	**8**	Include the expert for 5S in the planning of this project	Replan without starting with 5S or delay the whole implementation

Standardization is a change of mindset that might be neglected which would have a negative impact on the result	**2**	**4**	**8**	Everyone involved should learn that this will take time and is a mindset change	Go back one step in the plan
Lack of money for investments	**2**	**3**	**6**		Delay implementation
Lack of knowledge within the program group	**2**	**3**	**6**	Use Matheus as a program coach	Gather additional information
Variations of workload to large to make station layout work	**2**	**3**	**6**	Implement more waiting waste for operators at critical station and one buffer for the immediate state	Use S-note guys or implement parallel materiel flow with one flow of more operators with heavier variations
Not all people involved have had the chance to understand the changes and their purposes	**3**	**2**	**6**	Be clear with the purposes and use everyone to participate when generating the objectives	Replan by letting everyone participate in the process
Changes not accepted by blue collars	**2**	**2**	**4**	Inform and gather opinion	Implement gradually
Changes not accepted by the union	**1**	**3**	**3**	Inform union in case of major changes	Rework future state
Changes not accepted due to logistical problems	**1**	**3**	**3**	Inform logistics department continuously	Work out compromises with logistical department
Production will not accept to balance their own work	**1**	**3**	**3**	Inform about the purpose and PE and production is setting the objectives together	Replan and come up with a common plan
Inadequate equipment to implement changes	**1**	**2**	**2**	Investigate what equipment is available	Rework future state
Program manager get sick for a longer time	**1**	**2**	**2**	Assign backup PM	The backup PM will take over