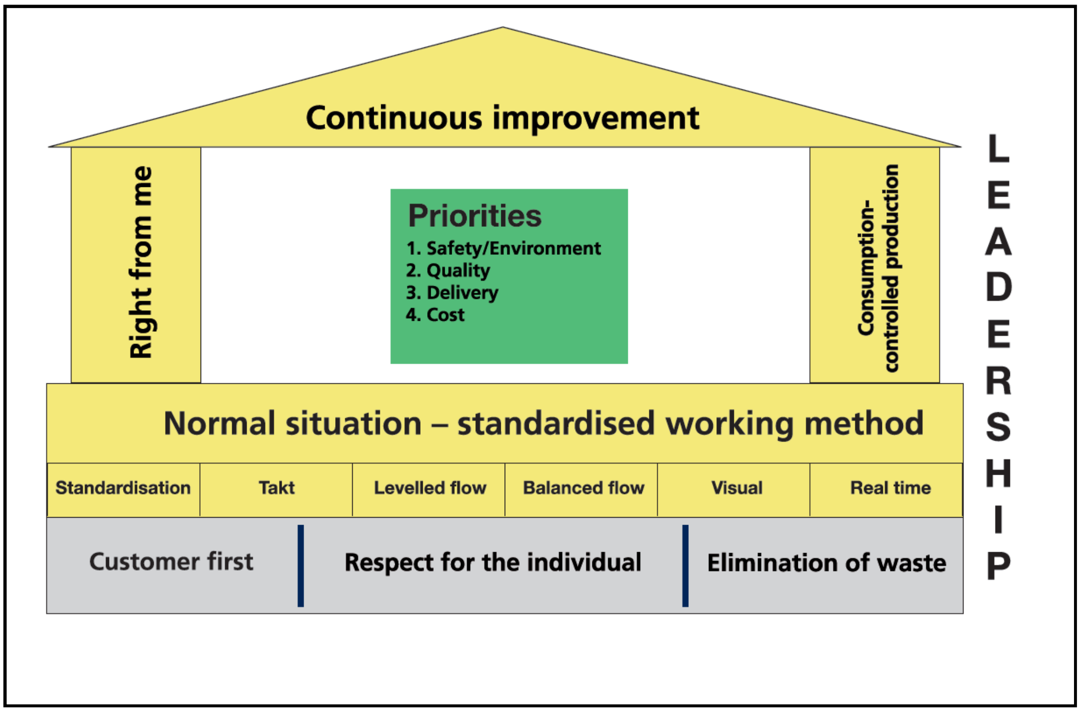

Linked flows of axles for truck assembly in Scania chassis production Södertälje

Master of Science Thesis in the Master Degree Programme, Supply Chain Management

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Abstract

This report is the result of a master thesis at Chalmers University of technology at the request of Scania CV AB chassis workshop in Södertälje. The transportation of axles to- and within the Scania chassis assembly plant is currently a flow in need of improvement. During transportation from the axle manufacturing plant a few hundred meters away, each axle is handled many times in several sorting and transporting operations. As the volumes are expected to increase, this flow needs to be analyzed and potential improvements and suggestions to handle the future volume increase are needed.

By using the tool of value stream mapping, the flow is analyzed beginning at the customer process, in this case represented by the axle pre-assembly within the plant, thru the buffers and operations until the origin of the axles at the axle manufacturing shipping department. The operations in the current system are analyzed and wastes and potential improvements are identified. These serve as a basis for a development of potential future state situations where the flow is modified to align better with the goals of minimizing forklift use and buffers as well as the Scania production system (SPS) and general lean production philosophies.

Two general solutions are presented, a single loop solution where the axles are transported directly from the axle plant to the pre-assembly using trains of several wagons, and a combination of different modes of transport using a double loop solution. The double loop solution, consisting of either trailers or trains for the outer loop to the chassis assembly plant, possibly combined with the use of wagons for the final stretch delivering the axles to the pre-assembly. These solutions present several ways of reducing handling and buffers throughout the process, in order to create a more levelled and visual flow with the capacity to handle the higher volumes.

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Contents

1 Introduction

This master thesis have been performed at Scania AB in Södertälje at the department MSLT during the spring of 2011 by Anders André and Jacob Wiklund, both students at the supply chain management masters programme at Chalmers University of technology in Gothenburg.

This thesis starts with a brief company description of Scania AB and the Chassis assembly plant in Södertälje, the purpose and research questions for the master thesis, a description of the method employed during the thesis, and a description of the problem to be analyzed. This is then followed by a review of relevant literature to support the subsequent analysis of the current state and the alternatives for the future.

1.1 Company description

Scania AB is a manufacturer in the automotive industry for commercial vehicles. Scania manufactures heavy trucks, buses and diesel engines for use in heavy vehicles, the marine segment and for general industrial applications.

Vabis (Vagnfabriksaktiebolaget i Södertelge) was founded in 1891 as a subsidiary to Surahammars bruk, manufacturing railway carriages. After a movement towards the automotive industry, Vabis merged in 1911 with the bicycle, car and truck manufacturer Scania from Malmö, creating Scania-Vabis, moving engine and car manufacturing to Södertälje (Scania AB, 2007).

The head office of Scania is still located in Södertälje, which also is the site of the chassis assembly plant in focus for this thesis. Additional manufacturing facilities are located in Sweden, France, Netherlands, Argentina, Brazil, Poland and Russia (Scania AB, 2010).

In Europe, the final assembly plants are located in Södertälje, Sweden, with an output of around 45 trucks and 14 bus chassis per day; Zwolle, the Netherlands, with an output of 120 trucks per day and Angers, France, with 55 trucks per day. These plants are supplied by Scania’s own main component manufacturers in Sweden and Scania’s paint shop for plastic parts in Meppel, the Netherlands.

Frame members are produced in Luleå; engines, gearboxes and front and rear axles are produced in Södertälje; cabs are produced in Oskarshamn and painted plastic cab parts are produced in Meppel, the Netherlands. Parallel to the European production, there is an assembly plant for trucks and busses in São Paolo, Brazil, of roughly the same size as the one in Södertälje. There are also production units for axles, engines, gearbox assembly and cabs in Brazil.

Figure 1: Scania Production sites worldwide (Scania AB, 2010)

The main market of Scania is Europe, constituting 39% of delivered trucks and busses during 2010, with Latin America at 28% and Asia at 19% (Scania AB, 2011). In Europe, this represents approximately 24 200 units, or 13,6% of the EU27+2 market, consisting of EU countries minus Greece and Malta, but including Switzerland and Norway.

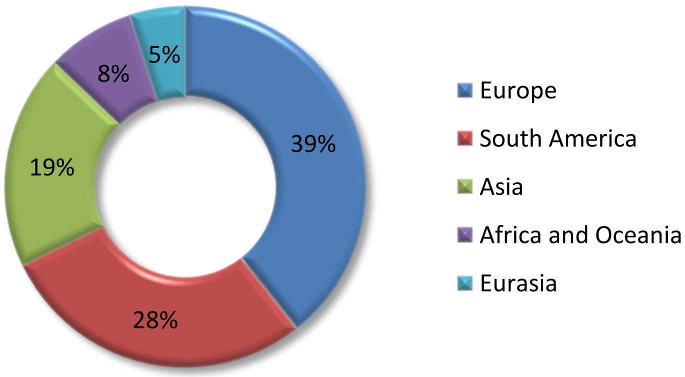

Figure 2: Scania markets worldwide (Scania AB, 2011)

Since 1970 Scania has been publicly noted at the Stockholm stock exchange, currently Volkswagen AG is the majority owner, controlling little over 70 percent of the votes and 45 percent of the capital of Scania (Scania AB, 2011).

1.1.1 Chassis assembly, Södertälje (MS)

With 41 400 m^2, the chassis assembly facility is the largest production unit (PRU) at Scania's Södertälje site. The PRU has around 950 employees, of which roughly 75% work at the assembly line. This is where all parts are mounted into a complete chassis. The production capacity of the main production line is ca 45 trucks and 14 bus chassis per day with a lead time of about eight hours. Additionally, 18 Knocked-Down (KD) chassis are prepared and packaged each day. These undergo final assembly locally in Malaysia, Taiwan, Thailand, Iran, South Africa or Russia. This is due to high custom fees for complete vehicles (Completely Built Up – CBU). The fees for disassembled vehicles are however not as high, which is why final assembly plants have been opened locally. (Scania AB, 2010)

The chassis assembly building, although large in itself, is pretty cramped. Little space is available for modification, and any available space is a scarce resource. Additionally, a large part of the plant is being used for storage of small sized inventory boxes as well as other storages and kitting lines using pallets. Parts of the line façade is currently undergoing a transformation, from using mostly high shelves with pallets and larger wooden boxes to utilizing lower shelves with smaller boxes.

Forklifts are heavily used for movements within the factory. This is partially being improved by the previously mentioned change towards higher small box utilization and a consequent reduction in pallet and forklift traffic. There are however still considerable problems with congestion and inefficiencies caused by an extensive use of forklifts.

Part logistics

Roughly 13 000 different part numbers are handled at the chassis assembly plant. Of these, about 80% are common to both trucks and buses. Each day, about 1750 units are delivered by an average of 48 trucks from 480 different suppliers. (One unit is for instance one pallet or one smallbox). In order to avoid unnecessary stock keeping at the plant, deliveries are supposed to arrive "Just-in-Time" i.e. at the earliest one day before the chassis is assembled. All vehicles are produced according to customer order and all components are labeled for a specific chassis.

When a delivery arrives by truck, it is unloaded by forklift into either an external storage building (low value- and low frequency goods), where it is broken down into smaller packaging, or transported directly into the in-house storage. In order to utilize available space as much as possible, the in-house storage is a floating storage, eliminating the need for designated storage places in the shelves. The assembly line is furnished by either forklifts or trains operating a route and restocking according to a kanban system using flags and empty boxes as signals.

Axles supply

All of Scania's production units in Europe are served by the axle production site in Södertälje, which was moved there from Falun, Sweden, in 2008. In total, about 600 axles, designated for around 250 vehicles, are produced each day. Axles are assembled from incoming components and painted before being shipped out to Scania's assembly units. Depending on the type of axles, they are placed in one of two types of racks; smaller ones for front axles, and larger racks for rear- and tag-axles. The racks are loaded into trailers and transported to the assembly plant.

Within DA, the axles are being produced in three separate lines; one for front-, one for rear-, and one for special axles. The axles are assembled in sequence, but as the flow has some sequence and balance limitations, the sequence cannot be upheld to one hundred percent. The flows of front and rear axles are then joined to one flow thru the paint shop, and are then separated again. As the axles reach the shipping area buffer, they are sorted in sequence by forklifts and placed in separate slots for each shipment, prepared for loading once the correct trailer arrives.

2 Problem background

The flow of axles for the chassis assembly in Södertälje in its current state presents a challenge to the logistics department.

Currently, the axles are transported by trailer to the goods reception, where they are unloaded and sorted into a buffer outside the main building. The axles are then picked in sequence and transported by forklift to a pre assembly buffer next to the assembly line and the axle pre-assembly.

Approximately 10 trucks worth of axles are stored at this buffer. The axles are then lifted into the pre assembly and are prepared for assembly onto the corresponding chassis.

As the axles are both large and heavy, the repeated forklift handling constitutes a problem in terms of congestion and safety issues in the crowded chassis workshop with its narrow aisles and dense traffic. It also implies waste in terms of multiple unnecessary movements, transports, and storage. The crowded workshop aisles also pose a capacity problem as increases in traffic would quickly become problematic.

These inefficiencies constitute a challenge, and as the truck production capacity in Södertälje is planned to increase with about 50% over the near future it will be necessary to improve the handling of axles. It is thus necessary to analyze and improve the process in question in preparation for such an increase.

2.1 Purpose

The main purpose of the thesis is to **analyze and improve the flow of truck axles** from the axle manufacturing plant to the axle pre assembly at the Scania chassis assembly in the Södertälje plant. This is to be done under existing structural conditions. A planned increase in output makes it necessary to improve the flow, since the current design, with an extensive use of forklifts, is less than satisfactory and pose a problem in terms of efficiency as well as production site safety due to an extensive use of forklifts. The main objectives of the thesis are as listed below.

- Analyze lead times, buffer storage levels, information flows, transport solutions and handling in the axle flow.
- Deliver suggestions of alternate solutions of flows between the axle manufacturing shipping department and the chassis manufacturing axle pre-assembly.
- Minimize and preferably eliminate the buffer of axles in the chassis assembly plant.
- Minimize and preferably eliminate the forklift handling of axles.
- The suggested solutions should take into consideration the impact on the flow of bus axles.

3 Method

This is a description of the different methods used during the thesis and the investigation and analysis. The basic methods of information collection used have been literature studies, interviews and empirical studies, which have made possible an understanding of the system and its potential.

3.1 Information collection

At the early stages of the thesis work, a basic understanding of the plant and the processes was achieved through first hand observations of on-site operations. Once sufficient insights into the flows and processes had been gained, a thorough literature review was performed. The literature consists mainly of textbooks in the field of production logistics and lean manufacturing as well as scientific articles published within the field. Further, empirical studies and interviews were performed at the plants in question as a ground for analysis.

The situation analysis is divided into two major parts. First, a description and analysis of the current state is performed in order to identify inefficiencies and wastes that currently exist. Secondly, as Scania intends to increase its output in the near future, suggestions and analysis of how the axle delivery will withstand an increased production rate, and hence a decreased takt time, is put forth.

3.2 Theoretical foundation

The foundation of the work has been based on the theories of lean production first presented by Womack, Jones and Roos, and the way that Scania has chosen to apply these theories to their production. The method used for evaluating the current system as well as future possibilities is value stream mapping, VSM, through which a schematic picture of the current operations, including buffer times, number of positions, total value added time etc is laid out. Similar maps have been done for the possible future states after suggested improvements, to visualize and quantify the implications of said proposals.

As a support for the development of the solutions and visualizations, a waste analysis has been performed, laying out the wastes in the system from a lean point of view. This has also been the basis when deciding upon what the requirements for the future state are. The VSMs and the waste analysis form the foundation on which argumentation for solutions are built.

3.3 Current state

To make sure that a complete picture of the processes involving the current flow of axels emerges, each aspect has been analyzed both quantitatively and qualitatively. This is represented by measurements/ time studies as well as general observations and interviews with key logistics personnel. Studies have been focused on the flow beginning at the supplier of axles (the production unit at the Södertälje plant) and ending at the axle pre-assembly, next to the main chassis assembly line.

3.3.1 *Quantitative analysis*

The quantitative measurements have been carried out through observations, calculations and time studies, providing a picture of how the flow looks like in its current state. This data have then been compiled into a value stream map (VSM), defining each step of the axle flow process. The VSM have then been used as a point of departure for discussions and analysis regarding bottle necks, unnecessary handling and other wastes. It also serves as a basis for discussion regarding potential improvements.

3.3.2 Qualitative analysis

To gain an understanding of the current situation of the flow of axles, a series of semi-structured interviews have been conducted with key logistics personnel involved in the flow. People of interest are for example fork lift drivers, production engineers, technicians, logistics managers, production coordinators etc. These interviews have provided an understanding of how the processes are perceived and what the major issues concerning the flow of axels are according to the people that know about it best.

Time has also been set aside for empirical studies and on-site observations in order to contribute to the overall understanding of the system. This has primarily been used during the first part of the project, but has provided support throughout the entire work process.

Combining this information with the quantitative results gained from measurements and time studies, a final analysis to come up with suggestions and ideas have been performed.

3.4 Future state

Based on the results from the current state analysis, conclusions and a waste analysis identifying any inefficiency and other drawbacks have been performed. This, in combination with interviews and observations, constitutes the basis of facts when considering how to tackle the planned increase in volume and the subsequent decreased takt time.

The result of this analysis is a number of alternative flow designs that have been analyzed and evaluated in regard to benefits and advantages and related to implications and problems in each solution. Each solution has also been analyzed from a cost perspective, investigating the profitability of each system in comparison to keeping the current layout. These solutions have also been combined into possible future state value stream maps illustrating the solution in a comprehensive way.

4 Delimitations

The report focuses on the flow of truck axles rather than incorporating bus axles, which utilizes a somewhat different route and handling within the chassis assembly plant. Any major alternative solutions will however consider the implication for the bus axle flow and discuss how to manage these implications.

Secondly, the report will concern only suggestions and improvements that can be implemented using an unchanged plant structure. That is, no changes to the general layout of the plant will be taken into consideration, nor will other solutions involving too large investments be recommended.

5 Literature review

In this chapter, a brief literature review will present relevant parts of the lean production philosophy, the lean principles, the Scania production system and the tool of value stream mapping used throughout this thesis.

5.1 Lean production

Since the early nineties, Scania has been working with a lean production system locally known as the Scania Production System (SPS). This lean production system is inspired by a similar system used, and originated, by Toyota. Toyota developed this way of producing after the Second World War, because they realized that they did not have the resources to build and operate large factories the way American companies did. The purpose of the Toyota Production System (TPS) was, and still is, to produce goods in a cheap, effective and quality assured manner. This is primarily achieved trough reduction of waste in the form of human effort, inventory, throughput time, manufacturing space, etcetera, with the goal of becoming highly responsive to customer demand and minimizing quality defects (Singh, Garg, Sharma, & Grewal, 2010). Since its introduction in 1947, the philosophies have spread throughout Japan and the rest of the world and are now an internationally recognized best practice of mass production of customer specified products.

The phrase “lean manufacturing” was coined by Womack, Jones and Roos (1990), when a large survey of the production processes at a number of large automotive manufacturers in Japan was presented. Even though lean production is based upon and to a large extent overlaps with the TPS, due to the fact that TPS is an automotive manifestation of the lean manufacturing principles, there are slight differences between the two. Since SPS can be said to be inspired by the TPS to a greater extent than by a strict interpretation of the basic lean principles, focus here will be put on explaining the TPS.

The TPS was pioneered by Taiichi Ohno, who had the responsibility to make Toyota’s production as efficient as possible. With the customer as the starting point and focus, he developed the base of the TPS which is today a set of 14 principles serving the common purpose of producing cars to customer order, rapidly and with a minimized number of defects. A selection of these principles will be examined closer later. A bearing idea behind the 14 principles is the reduction of waste. That is cutting off anything that doesn´t produce actual value for the end customer. When analyzing a production system, it is not unusual to find that actual value added time ranges from tenths or even hundreds of a percent to a few percent of total operating time. Liker (2004) gives an example in which a company’s management, who believe they are efficient, finds out that their value added time is below 3 percent. The reason for this is the traditional way of producing, where local savings and buffers to take up fluctuations causes the entire value chain to slow down.

Russel and Taylor (1999) define waste (non-value adding activities/processes) as anything other than the minimum amount of equipment, materials, effort, parts, space and time that are essential to add value to the product. The waste (or muda) is popularly categorized into seven subsections, each representing actions or phenomena that don’t add to the value of the product from a customer point of view. The seven wastes are overproduction, waiting, unnecessary transport or conveyance, over processing or incorrect processing, excess inventory, unnecessary movement and finally defects. An additional form of waste, unused employee creativity, is sometimes added to the list (Liker, 2004). Scania likes to add this waste when defining their key waste reduction goals. (Scania, 2007)

5.1.1 7 + 1 wastes

Overproduction occurs when a production unit or a process is producing more goods than is demanded by the market. This results in finished- or WIP (Work-In-Progress)-goods stocks, which is a facilitator for other wastes. For example, when finished goods (or any type of goods) are stored, it will take a lot of time before potential defects are spotted, resulting in a risk that a lot of defective products will come off the line before the defect is found and corrected. Also, the extra time makes it harder to find the root cause of the problem. Overproduction also incurs extra cost in the form of excess personnel required and extra transports to storage. But perhaps the most important consequence of overproducing and building stocks is that it hides other wastes. That is, it will be hard to make continuous improvements, a bearing idea of lean and TPS, if no difference is noticed because all improvements are just leading to a more efficient stacking of products in buffer storage. Because this waste incurs so many of the other wastes, it is generally regarded as the most important one to eliminate. (Liker, 2004)

Waiting entails workers just standing around waiting for the next step of the process to begin or for material or equipment to be fed to the process (Liker, 2004). Having personnel in place without anything to do can be likened with the +1 waste since the unused time could be spent improving standards, or organizing the workplace.

Unnecessary transport or conveyance means all transporting of goods between, to and from stations in and around the production. In addition to constituting a form of excess inventory, transportation also presents a risk of damaging the goods or personnel as the risk of accidents increases with a higher amount of traffic in the factory. Also, distances correlate to time in the sense that there is a risk that feedback of poor quality may be delayed with a greater transportation distance. (Hines & Rich, 1997)

Over processing or unnecessary processing is work performed that changes the product, but that in the end does not amount to any extra value to the end customer. A common example of this is using overly complex methods or tools to perform simple tasks (Liker, 2004). Hines and Rich (1997) argues that this may require a poor production floor layout as well as encourage over production in order to make use of- and pay for the equipment. Another way unnecessary processing might occur is if processes are not quality assured enough to prevent faulty products from being manufactured (Hines & Rich, 1997).

Excess inventory is considered a waste because it ties up capital and, more importantly, hides other wastes and makes it hard to react rapidly to discrepancies in the production flow (Liker, 2004). It is important to note that not all inventories are considered a waste, only *excess* inventory. Baudin (2004) emphasizes that inventories are necessary when there is a mismatch in incoming and outgoing quantities. This is a situation arising for example when differently sized batches are coming in versus going out or when fixed rate production has to supply a fluctuating demand. If a reduction of inventory is not accompanied by elimination of other problems, the buffer reduction will sooner or later result in difficulties to deliver, because the safety net has been removed. (Baudin, 2004)

Unnecessary movements are all movements a worker has to do that isn´t adding any direct value. Examples are reaching for tools, looking for, sorting or stacking parts. This waste can be tiring or unhealthy for workers as well as potentially increasing the risk of defects. (Hines & Rich, 1997)

Defects lead to unnecessary work and cost due to scrapping, reworking, inspection and handling. Hines and Rich (1997) refer to this as the bottom-line waste, as this is the only waste that incurs direct cost. Many of the TPS philosophies, like continuous improvement, stopping the line at faults and fool proofing are entirely or partially aimed at reducing the number of defects.

Unused employee creativity will slow down the continuous improvement process and therefore the progress of the entire production process. Scania adds this extra waste to the list when describing the wastes they are working to minimize.

5.1.2 Necessary wastes

When applying TPS, the first question should always be "What does the customer want from this process?" All activities and processes can be divided into one of three sub-categories depending on their relation to the actual value creation for the end customer. An activity can be value adding, not value adding or not value adding but necessary (Liker, 2004). The previously described wastes all represent clear examples of non value adding activities, i.e. they are all candidates for elimination. Hines and Rich (1997) describe the third category; value adding activities that are necessary. These are activities that don't in actuality produce any real value to the customer, but that under current structure are still necessary for the production or the quality record to work out. Examples include moving the product between stations and unpacking deliveries. These are wastes that require extensive investments or reworking the production system or layout of the shop floor in order to be reduced or eliminated.

5.2 The Lean principles

From a production perspective, focusing on the flow of products and operations, some of the guiding principles and tools of the TPS need further explanation and a more thorough review. These principles will be described in the following chapter. However, the principles do not represent lean thinking in its entirety, as believed by many companies. They merely represent the operations aspect of lean thinking, and are just tools that in order to be fully effective need to be supported by a companywide long term philosophy (Liker, 2004).

5.2.1 Create a continuous flow to bring problems to the surface

In the traditional mass production way of thinking, similar machines and similarly skilled people are grouped together in departments specialized in certain types of operations. By doing this, economies of scale can be maximized and production capacity can be utilized to its highest potential leading to the lowest possible capital cost per unit. This will maximize productivity of personnel as they can specialize within a certain field. Producing in this way will cause batch sizes to grow in order to minimize changeover times and to maximize efficiency in the processes. (Liker, 2004)

From a lean perspective this way of thinking will only create a lot of work-in-progress (WIP) inventory caused by the most fundamental waste: overproduction. A mass production system will guarantee overproduction in large batches which leads to inventory buildup, requiring storage space and more importantly, hiding problems in the processes (Liker, 2004). By eliminating this inventory, problems are forced out into the open, forcing people to deal with them and solve the causes of these problems that previously were not even known to exist. A common lean metaphor is to liken this reduction of WIP inventory to lowering the water level of a lake, thus exposing the problems in the form of rocks in the water, forcing you to act, or risk sinking. Unless the problems are handled, the processes will shut down. Hence everyone concerned will be motivated to solve the problems that surface (Liker, 2004).

In an ideal continuous flow, processes are physically lined up in sequence to produce the customer's order in the shortest time using the lean ideal batch size: one. Instead of optimizing the utilization of machines and people, the flow of materials is optimized to run as fast as possible thru the factory. By having a continuous flow between the processes and not allowing any inventory to build up between the processes, nobody is building anything that is not needed immediately, thus preventing overproduction and unnecessary inventory. A continuous flow also tends to force implementation of a lot of the other lean tools and philosophies such as preventive maintenance and built in quality as these are required in order to keep the flow running. The creation of a flow thus initiates and facilitates a number of improvement activities in different areas that will eliminate waste in the system. (Liker, 2004)

Built in quality is facilitated by a continuous flow as every operator acts as an inspector and will work to fix any problems before passing on the product. Defects that are passed on will soon be discovered so that causes and problems can be detected and corrected instantly. (Liker, 2004)

Flexibility is increased and as the lead time is very short the possibility to adapt to what the customer wants increases as there is no need to wait for large batches and queues to be completed before changing to another order with changed specification. (Liker, 2004; Womack & Withers, 2006)

As productivity no longer is measured by a department's utilization of people and machinery, the true productivity of the processes will increase as overproduction and inventory handling is eliminated. In a one piece flow, non-value-adding activities such as moving inventory around are minimized and it becomes a lot easier to calculate the true need for capacity and people, as excess is clearly visualized (Liker, 2004).

Naturally, the reduction of inventory this leads to frees up floor space and reduces costs for tied up capital in inventory, which also reduces the risk of inventory obsolescence.

5.2.2 Use pull systems to avoid overproduction

The classical way of scheduling production according to forecasts based on projected customer demand will always lead to either overproduction or deficiencies as projections and forecasts never are completely correct and demand can change very quickly. This will inevitably lead to waste of different kinds (Liker, 2004). To make sure processes aren't overproducing and creating unnecessary inventory, but rather produce only what is needed, pull systems should be used wherever it is not possible to have a pure one-piece-flow. A pull based system is governed by consumption and is in its ideal state a perfect just-in-time- system, delivering exactly what is requested at the right quantities precisely when it is needed without any unnecessary storing or buffers. In reality, a pull system is most often achieved through a kanban system, which uses the inventory levels at the receiving end as an indicator to signal a need for replenishment.

5.2.3 Level scheduling, Heijunka

When building to order, no production is commenced before the customer order for that exact product is collected. The problem with this though, is that demand will be uneven, which will require the factory to produce different quantities at different times. This unevenness (Mura) implies a risk that the producer will be left with lots of waste in the form of either over- or under capacity depending on the rate of incoming orders. The idea of heijunka is to produce goods at a constant rate, allowing all operations to execute continuously and predictably. In a heijunka system, product types aren't produced in batches, but rater in a constant stream of different products evenly spread out over the available production time. This is achieved through accumulating orders over time and leveling the work schedule, thus enabling a predictable production with reduced lead time. The main benefits of leveling and predictability include reduced need for large stocks as well as the ability to put an even work load on the factory and its employees, thus reducing wastes of different sorts. (Liker, 2004)

5.3 Scania Production System

During the eighties, Scania was not doing very well and was suffering from a high employee turnover rate. This meant that it was very hard to keep the competence within the company. Apart from this, quality wasn't at all as prioritized as it is today, forcing the production to work with high levels of inventories to handle the defects. All together, this led to lots of waste and increasing costs. In order to stop this development, Scania started a benchmarking cooperation with Toyota and commenced a strive to become lean – the project that would later become the Scania Production System (SPS).

The SPS is a local adaptation of the Toyota production system (TPS) that is based on three basic principles; customer first, respect for the individual and elimination of waste. All the basic building blocks are the same as in the TPS, such as one-piece flow, pull production, stopping the line when defects arise, kanban signals for replenishment, leveling of the production flow, etc. In the beginning though, the transition to SPS wasn't entirely problem free. This was largely due to the fact that the change wasn't completely anchored throughout the entire organization, and many of the employees didn't realize how the changes would affect the value for the customer. In short, a lean culture was yet to permeate all levels of the company.

An important factor of lean manufacturing is this culture and the fact that everybody within the company knows about the concept and realizes why it is done and what is expected of each individual for the efforts to be successful (Liker, 2004). Over time, the culture of lean has grown throughout the organization of Scania and the lean principles have been embraced as the backbone of SPS.

In order to keep a thurough understanding of SPS and it's principles and to propagate the system through all levels of the company, all new employees at Scania attend courses on SPS and how it impacts the organization and their daily work.

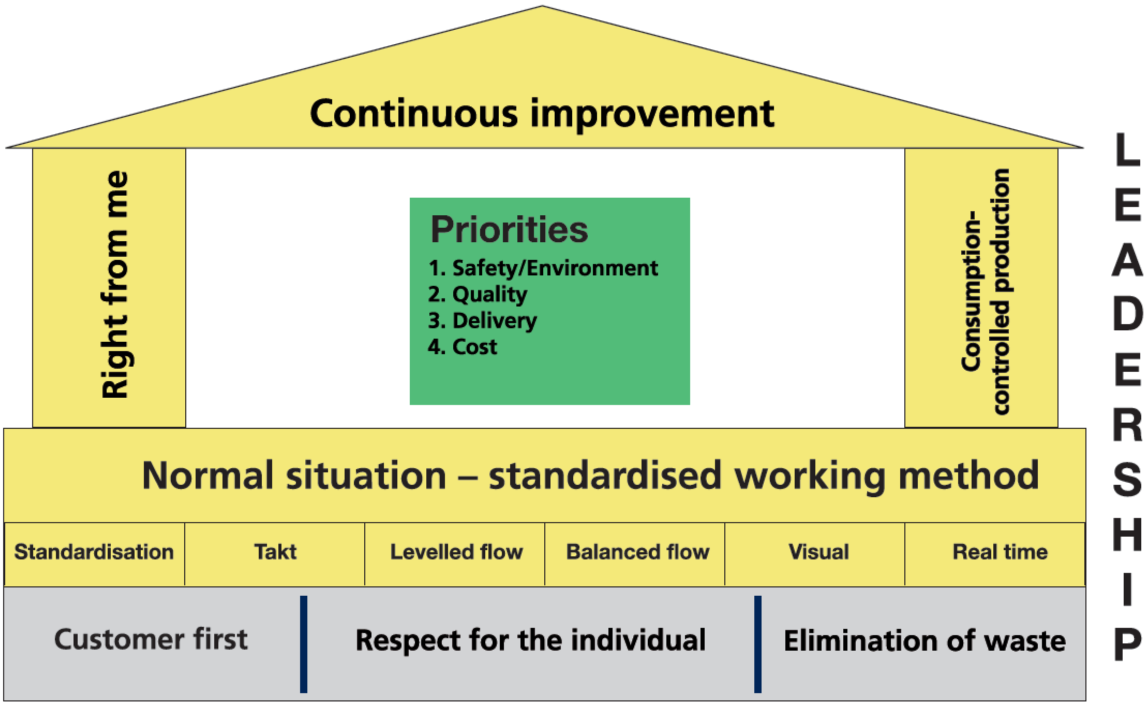

Figure 3: The Scania Production System

5.3.1 SPS at the chassis assembly

Taking the chassis assembly as an example, one piece flow has long since been implemented. Along the assembly line, 5S practices have ensured a tidy and organized workplace and standardization makes sure everyone knows exactly what to do and when to do it. Should anything go wrong anyway, a backup operator (andon) can be called upon to help fix the problem/delay before it is passed on, which hopefully prevents a stop of the entire line. Around the shop floor, sign boards are placed indicating what operations is to be performed at each station and how much of the work time that is value added work versus non value added. Kanban systems are used as indicators for when to replenish the line-side stocks, of which some are kitted and some not, depending on the complexity of the part. Trains performing in-house milk runs are used to some extent, but forklifts are still a common sight within the factory. In addition to this, management and employees can be seen walking around the floor, looking, learning and discussing potential improvements in true lean and TPS spirit.

As mentioned, forklifts are used quite a lot within the facility and the in-house storages, thus material facades are adapted to this form of transportation. High pallet shelves around the factory and near the main transportation routes incur congestion and unnecessary stops for all kinds of transport modes, which diminishes the ability to use a perfectly smooth flow.

5.4 Value stream mapping

An example of a value stream map is shown in the below figure. The mapping method in itself is described and explained in this chapter.

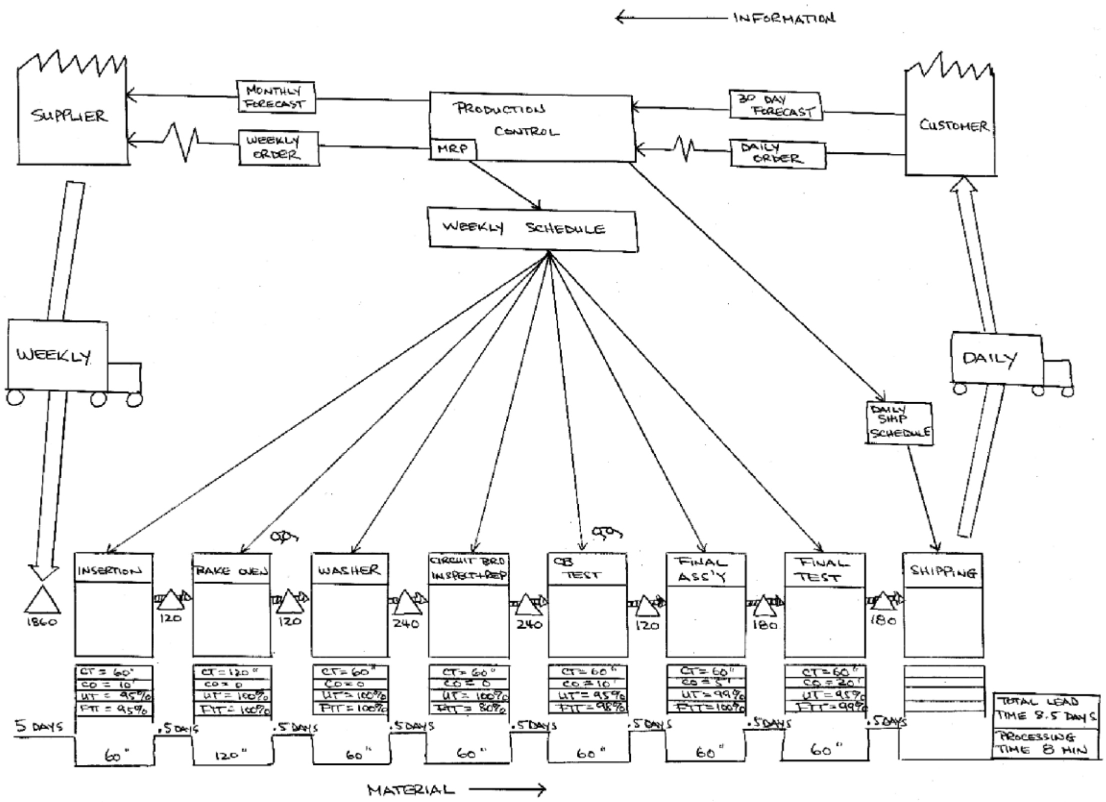

Figure 4: Example of a value stream map by Womack and Withers (2006)

5.4.1 Introduction

The Lean enterprise institute, founded by Jim Womack in 1997 with the intention to spread the lean ideas and methods across companies, have established and made popular many of the methods used in companies working with the lean concept (Lean Enterprise Institute Inc., 2009). One of the methods this institute have developed and presented is the tool of Value Stream Mapping (VSM) thru Rother and Shook (1998) as a functional method aimed at reorganizing production systems with a lean perspective. One reason for this was to provide a structured method for managers and companies to be able to map the total value stream in all of their product families, which is presented as one of the most vital steps in the lean transformation process by Womack and Jones (1996). This step in the process was often overlooked and because of this, improvement efforts were often misdirected and the value adding flow ended up in “a quagmire of buffers and downstream detours in the way to the next process step” (Rother & Shook, 1998). Thus, Value Stream Mapping was presented as a tool in order to accomplish more sustainable success in the fight against waste in the industry.

5.4.2 Method description

Value stream mapping is focused on analysis and improvement of manufacturing environments with disconnected flow lines and revolves a lot around linking processes together and creating continuous flow (Rother & Shook, 2004). The purpose of the method is to clarify more than individual processes and to create an image of the flow in its entirety. This visual representation of the flow enables the user to identify causes of the different types of wastes, and creates a language for better understanding and transferring knowledge and experiences in regard to manufacturing processes. This commonality and standardized way of analyzing the value stream of a product and its corresponding processes is a way to incorporate several of the lean concepts in a way, such that flaws in the system become more apparent. It also creates a way of quantifying a process that encourages and eases discussions and analysis of the value stream and the consequences of changes in the flow (Rother & Shook, 2004; Lasa, Laburu, & de Castro Vila, 2008).

As the flow becomes visualized, this puts focus on the flow of value and should be used as a foundation for a vision of an ideal state and create a stepping stone for further improvement. Rother and Shook (2004) makes the comparison that starting lean improvement initiatives without a proper understanding of the complete flow is "…like building a house without a blueprint" (Rother & Shook, 2004, p. 2). However, the mapping in itself bares little value and is not a way of becoming faster or leaner. It is just the tool used in order to realize the potential in the system and to create the vision of the improved future state. The value stream mapping tool also puts focus on the information flow between the different processes and the different agents in the value stream in a way that is often overlooked by other methods, as these tend to focus on the visible physical flow of products within the workshop (Rother & Shook, 2004). In the lean point of view, the flow of information is equally important to the physical flow, as it is the flow of information that initiates processes and steers the production in the desired direction and pace. Rother and Shook (2004) argues that the information flow and the material flow are just two sides of the same coin and both of these sides need to be mapped thoroughly in order to fully understand the value creation processes within a company.

As many companies move towards being more lean, they often try to do this by implementing different lean tools, such as just in time principles, set up time reduction programs, 5S initiatives, Total Productive Maintenance (TPM), etc. By using VSM, the interdependence of different functions and departments are more clearly visualized and understood, and a holistic view can be obtained about a situation which is hard to analyze using the more conventional industrial engineering tools (Singh, Garg, Sharma, & Grewal, 2010).

The VSM process in itself is based around five phases that with the help of a team of key personnel in the value stream can clarify the flow and its potential and later facilitate the realization of this potential. These phases are as described below.

Selection of a product family

In the lean spirit of putting customers first, an important step of the value stream mapping is to choose a product family based on the journey this particular product travels thru the company's processes. Customers of the company have no interest in averages and aggregates of all of the produced products, but are only interested in their particular product. Product families should thus be defined from the customer's perspective on commonalities in processing steps and machines used

(Womack & Withers, 2006). Only mapping one product family at a time also reduces the complexity of the map and makes it possible to comprehend and analyze in a good way. (Rother & Shook, 2004)

Mapping of the current state

As mentioned earlier, to have any hope of improving the entire value stream, the current state need to be mapped carefully. This is done by starting as far downstream in the company as possible, i.e. as close to the customer as possible. The products are then followed upstream, noting and counting any buffers or storing of the products and any processes that work on the product on the way from the goods entering the company. For each process, details such as cycle time, change over time, uptime, available working time and number of operators are noted.

After mapping the physical flow, the information flow needs to be mapped and analyzed. This is what differentiates VSM from other traditional mapping efforts which only focus on the physical flow of materials (Womack & Withers, 2006). The most important question in this phase is to ask each process how it knows what to do next, as this influences the flow and initiates any physical processes and movements. This can also be a big cause of waste in the flow, as faulty information can drive overproduction and result in a lot of waiting products. Just as for the physical flow, the information flow is analyzed downstream to upstream, from the receiving of customer orders and forecasts via in-house planning- and MRP-systems to placed orders and delivered forecasts to suppliers. Within the company, the information provided for each process indicates whether the flow is initiated on a planned schedule and thus pushes the products forward in the flow, with a high risk of causing overproduction and large unnecessary stock and buffers, or whether it is initiated on the consumption of products downstream, thus pulling products only when they are needed, avoiding overproduction and unnecessary storage. (Rother & Shook, 2004; Womack & Withers, 2006)

When both the physical and the information flow have been mapped, a timeline can be created illustrating the ratio between active value adding time on each product in each process and the total lead time from materials entering the system from the supplier until delivery to the customer.

Creating the future state map

When the current state map is created, this map should be used to create a vision of the desired future state, where wastes have been reduced and a better flow have been achieved. In order to create a future lean value stream, some basic guidelines are presented by Rother and Shook (2004) to assist users of the VSM tools to think and base their vision on the lean principles and create a lean and customer oriented value flow.

The most important issue is to determine the takt time of the product. Takt time should be set by dividing the rate of customer requirements per unit of time (often day or shift) by the available working time per unit of time (Womack & Withers, 2006). If production is run faster than the takt, for instance because of a use of high speed machines with large batches, this will result in building inventory, which in turn requires extra personnel, floor space, and equipment for moving and storing the inventory. If production is run slower than takt time, then customer demand can’t be met and potential sales are missed.

A continuous flow should be used wherever possible in the flow. By having a flow of products in a steady continuous stream, the most cost effective and customer responsive production can be obtained (Womack & Withers, 2006). This will eliminate the need for buffers and other forms of waste between the processes. However, continuous flow can only be introduced when production technologies can be scaled to run at takt time and a series of processing steps have a high availability and are highly repeatable (Womack & Withers, 2006). Processes that do not meet these criteria can induce increased lead times and stop-times at the other processes if connected to them in a continuous flow. In these cases it is better to use a pulled First-In-First-Out (FIFO)- or a supermarket-system until the reliability can be increased and set up times reduced (Rother & Shook, 2004).

By using a pull-based system wherever a continuous flow is not possible between the different work centers one can achieve the next best thing. A pull system in the form of a supermarket is not a standard stagnant inventory, but is controlled by a pull signal from downstream processes instead of push orders from upstream (Womack & Withers, 2006). As articles are withdrawn from the front of the buffer, a signal is sent to the upstream process to replenish the supermarket with the same amount that was just withdrawn. In this way, the supermarket with its pull signals prevents any overproduction by the processes upstream and at the same time replaces costly and inaccurate MRP scheduling systems. Instead, the usage of materials in downstream processes will govern what, when and in which quantities the processes upstream produce anything. (Womack & Withers, 2006; Rother & Shook, 2004)

The processes and the flow do however need to be planned somewhere, and this is done at the so called pacemaker process. How the production is done at this process sets the pace for the value stream and is linked to processes upstream and downstream by two simple rules. Every activity upstream from the pacemaker produce only to a direct replenishment signal from the next downstream process, and every activity downstream from the pacemaker are linked in a FIFO sequence in a continuous flow. Therefore, the pacemaker receives the production schedule and every other process falls in line. (Rother & Shook, 2004; Womack & Withers, 2006; Lasa, Laburu, & de Castro Vila, 2008)

In the pacemaker process, the production should be as level as possible, having an even product mix and stable volume, which is in accordance with the Lean concept of Heijunka explained earlier (Liker, 2004). The traditional way of having an MRP system create a production schedule with large batches and as few changeovers as possible will strive to maximize the use of the available production time and to keep a high utilization rate. However, this will inevitably lead to huge inventories and longer lead times in order to keep what the customer needs in stock at all times until next large batch is run. The more leveled the volume and even the product mix can be kept in the pacemaker process, the better the production will correspond to changes in customer demand. The lead time will be shorter and only a small stock of finished goods needs to be kept. (Womack & Withers, 2006; Rother & Shook, 2004; Liker, 2004).

Defining and achieving a working plan

In these final steps of the VSM process, the map of the future state is used to define what improvement measures are needed to realize this. Naturally, this depends greatly on the processes involved and the vision created in the future state map. It is thus necessary to analyze how the changes will contribute to improving the value stream in a way that affects the customer positively. A lot of improvement efforts are undertaken without making sure the changes are in accordance with the overall future state vision. Nash and Poling (2008) emphasizes that the VSM team must not get stuck trying to create the perfect plan and use a quote from General George S. Patton to illustrate why: “A good plan, violently executed now, is better than a perfect plan next week” (Nash & Poling, 2008, s. 221). It is thus better to get started with the implementation as things will change as soon as the plan is put into action either way (Nash & Poling, 2008).

5.4.3 The map itself

A value stream map can be divided into three sections: communication or information flow, process or production flow, and finally timelines and travel distances. An example of a Value Stream Map made by Womack and Withers (2006) is shown in Figure 4, the three sections of which will be discribed below.

The process or production flow at the bottom half of the map is the part of the map most often associated with traditional flowcharting as this part of the flow normally receives the most attention. This flow illustrate the physical movements from left to right and should as described above be drawn from right to left originating at the downstream processes and climb upstream towards suppliers. (Nash & Poling, 2008; Womack & Withers, 2006)

The information processes illustrated at the top half of the map is what separates the VSM process from traditional process-mapping techniques such as flowcharting (Nash & Poling, 2008). This illustration of communication in the system, both formal and informal, provides an image of the information channels, enabling analysis and evaluation of these channels. According to Nash and Pooling (2008), much of the chaos and confusion that often appear in a value stream can be traced back to faulty or unnecessary communication which add no value to the final processes.

At the bottom of the map, the timeline summarizes much of the time information that can be extracted from the physical flow and communicates this information clearly to the audience in order to establish focus and to highlight the importance of these figures. By documenting the process lead time in this graph, the map will illustrate the total time for products to move thru the system from incoming goods to complete shipped products. The amount of stock or buffer inventory between each process is documented as cover time in the top half of this graph. The bottom half is constituted of the cycle times observed at each process and thus constitutes the active part of the processes. This part of the map is also often used to show the traveled distances thru the processes of physical products of physical movement by people or machinery.

6 Current state flow

Scania strives to perform all aspects of its operations in a lean manner. This is not something that can be achieved overnight though, but rather it requires an extended period of continuous improvements. (Liker, 2004) As the axle manufacturing plant (DA) is a fairly recent addition to the Södertälje manufacturing site, there still hasn't been enough time to perfect a lean flow. This can for example be seen in the fairly large buffer storages and the frequent use of forklifts. Continuous efforts are being made though with the intent to make the flow leaner at DA, at MS and of course in the interface between the two. The following is a description of the flow from the axle sorting/shipping area at DA to the line-side axle pre-assembly at MS.

6.1 Current state VSM

The analysis of the current state has resulted in the value stream map illustrated in Figure 5 shown below.

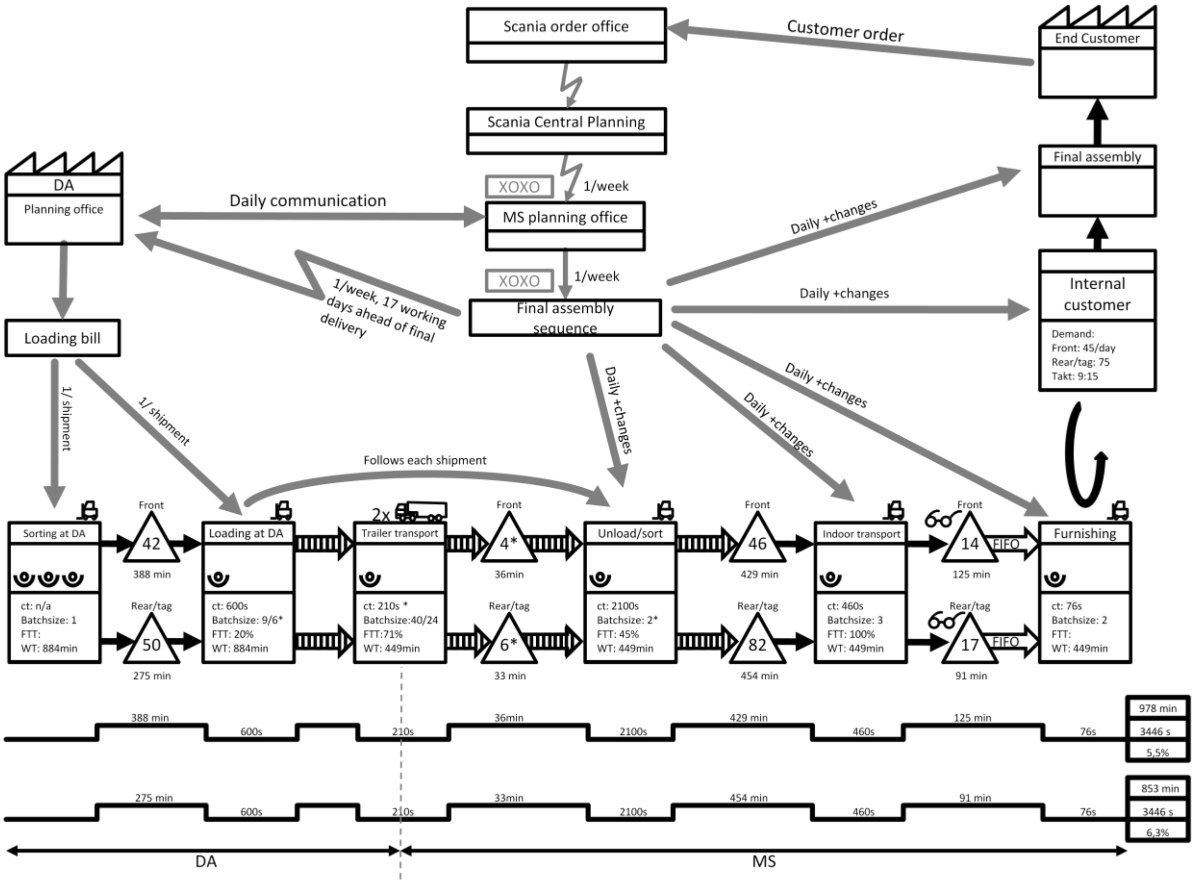

Figure 5: Current state value stream map

The different parts of this value stream will be described further in the rest of chapter 6 with the relevant parts of the map highlighted in conjunction with their description. An analysis identifying wastes and improvement potentials will be described in chapter 7.

6.2 The physical flow

Starting from the end of the flow, the axles are loaded into a conveyor system that leads the axles to the pre-assembly, which in this case is seen as the customer.

6.2.1 Buffer handling at pre-assembly

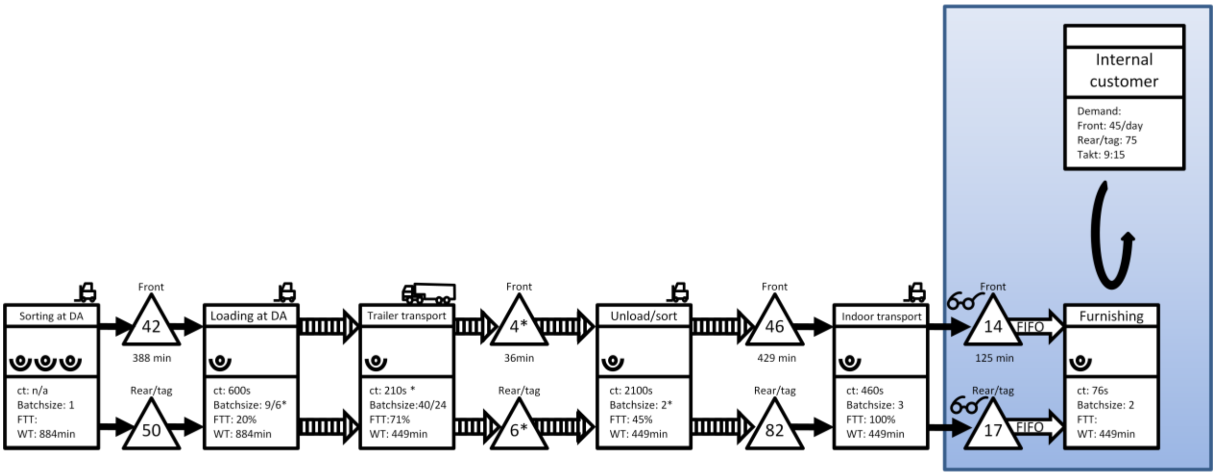

Figure 6: Physical flow, Furnishing

Two separate conveyors are used, one for front axles and one for rear/tag axles. The axles are loaded into the conveyor one by one as per a form of kanban system by which a light on top of the conveyor system comes on whenever it is time for another axle to be loaded. A single forklift (Pre-Assembly Forklift, PAF) performs the work of loading the axles into the conveyor system. Before being loaded, the axles are stored in a buffer that holds approximately 10 trucks, or 92,5 minutes worth of axles with the current takt time of 9 minutes 15 seconds, on the floor just beside the pre assembly. This buffer time is to some extent justified by the need to warm up the axles before entering the pre assembly. This is motivated during cold winter conditions, but the buffer stays the same all year around. The axles are stored in racks that hold a single axle each and in this buffer they are placed in two rows, each two axles in height. One row is for front axles, which mostly uses smaller racks, and the other row is for rear and tag axles, which use larger racks. Here, the axles are stored in a FIFO sequence so that, under normal conditions, the PAF doesn't have to rearrange the buffer in order to replenish the pre-assembly. The PAF does have other tasks around the pre-assembly area as well, but a majority of its time is dedicated to the loading of axles.

6.2.2 In-plant transportation

The pre-assembly buffer, is replenished by another, larger, forklift (Transporting Forklift, TF).

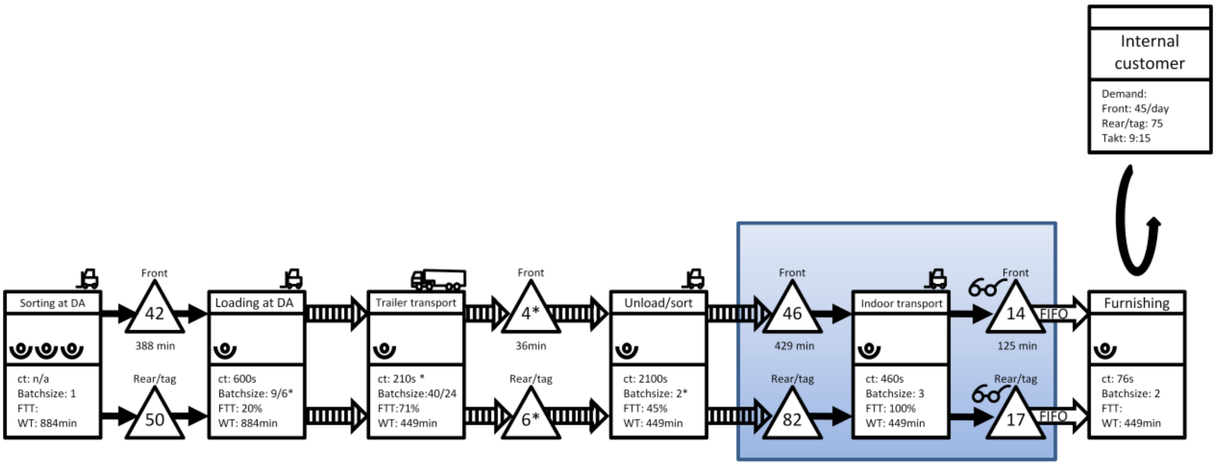

Figure 7: Physical flow, Indoor transport

The driver of the TF use visual control to see when the buffer is running low on either front- or rear axles and thus commence picking axles from a pre-sorted buffer just outside the production facility. The TF is dedicated solely to the transportation of axles and conveys either front- or rear axles only in cycle times of approximately thirty minutes before switching to the opposite type of axle. The axles are picked from the outside buffer and transported in batches of maximum four axles, but often less, to the inside buffer. The route used for transportation is a congested one, resulting in the TF having to stop and wait because of other vehicles during approximately 40% of the transports. Since the TF is significantly wider when carrying the axles, and because of the desire to align the flow thru the factory as unidirectional as possible, an alternate route is used when returning to the outside buffer axle-free. When returning to the outside buffer, empty racks in batches of three in height are most often brought along from the pre-assembly buffer and loaded into the waiting unloaded trailer. The cycle time for replenishment is just over seven and a half minutes. This TF is dedicated solely to the handling of axles.

In addition to this handling, certain axles that require more time in pre-assembly are specifically called upon by the PAF operator. These are then delivered by the TF, but put to the side of the conveyor systems and later manually brought into pre-assembly.

6.2.3 Unloading at MS

Looking at the outside buffer storage, it is fed by trailers coming in five times per day, twice with front axles only and three times with rear- and tag axles. Before being put into the buffer, they have to be sorted into sequence.

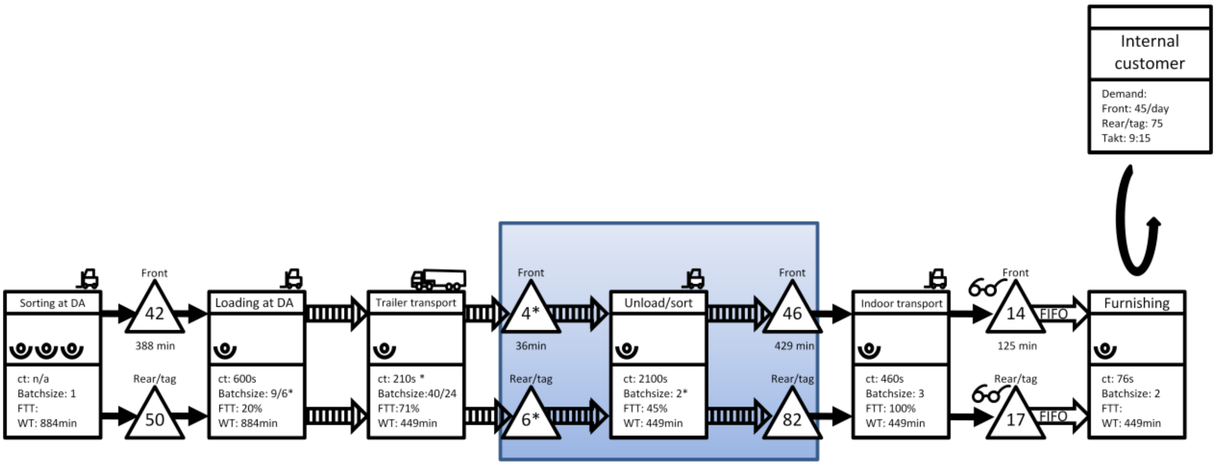

Figure 8: Physical flow, Unload/sort

This is performed by the same forklift that unloads the trailers (Unloading/sorting Forklift, UF). Specifically, the axles are taken off the trailer and placed into sequence on the ground beside it, before being transported 50 odd meters to the buffer. This operation takes about 40 minutes per trailer, totaling the axle handling time of the UF to almost five hours daily, the rest of which is dedicated to handling engines and prop shafts. Most of the axles are for trucks, as opposed to bus, making truck axles responsible for 45% of total work time. Here, the axles are stacked four in height, enabling the TF to lift them two in height at a time without restacking, for further delivery to the ensuing buffer, thus facilitating the picking of four axles at a time. The outside buffer consist of about 80 rear- and tag axles and 50 front axles at any given moment, translating into about 47 complete trucks or a little over one day's worth of production.

6.2.4 Trailer transport

A single side-loaded trailer is, as mentioned, loaded with either front axles or rear- and tag axles. These can carry a maximum of 30 axles a piece, which are sorted in such a way that rear- and tag axles, although arriving on the same trailer, are loaded in separate stacks. Each of the two types is stacked in sequence though, with the ones that will be used in production first loaded on the inside of the trailer and then stacked further out in the outside buffer for easier picking.

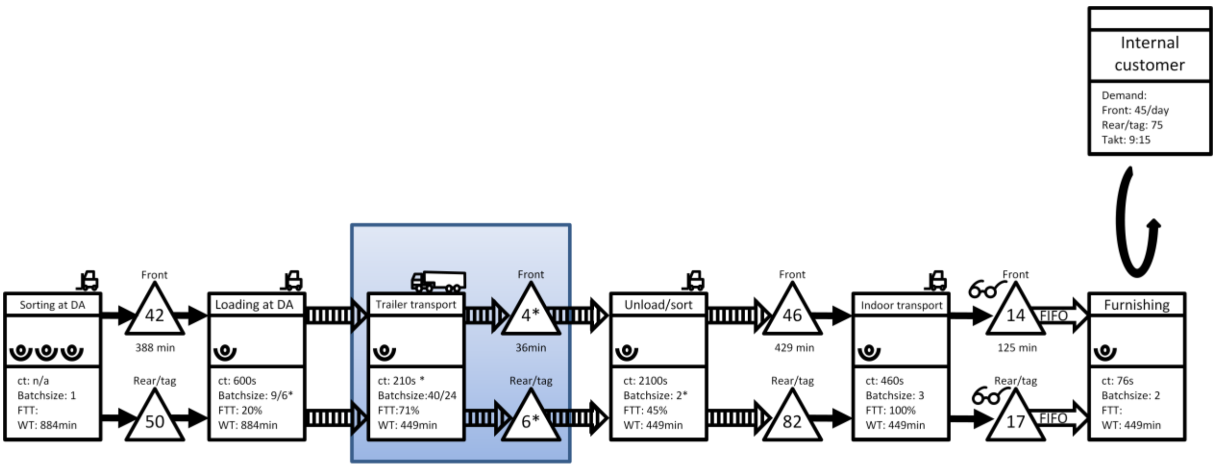

Figure 9: Physical flow, Trailer transport

The trailers arrive from the axle production facility (DA), which is located about 500 meters from the MS axle unloading zone. One roundtrip from MS including loading at DA takes approximately 30 minutes, resulting in a lowest possible cycle time including loading and unloading of 30+40=70 minutes. The 30 minutes is comprised of connecting the trailer to the truck (~3:00 min), return to DA (~3:30 min), unloading of racks (~4:30 min), loading (~10:00 min) transport to MS (~ 3:30 min) and disconnecting of the trailer (~5 min). On the way back to DA the trailers are used for the return flow of empty racks for later loading of new axles. At DA, the loading slots are divided between trailers going to Scania's facilities in Anger, Zwolle and Södertälje, meaning the trailer going to MS will sometimes have to wait to be loaded. In order to make transportations more efficient, the truck switches between two trailers, so that unloading and carriage can be performed simultaneously.

6.2.5 Loading and buffer handling at DA

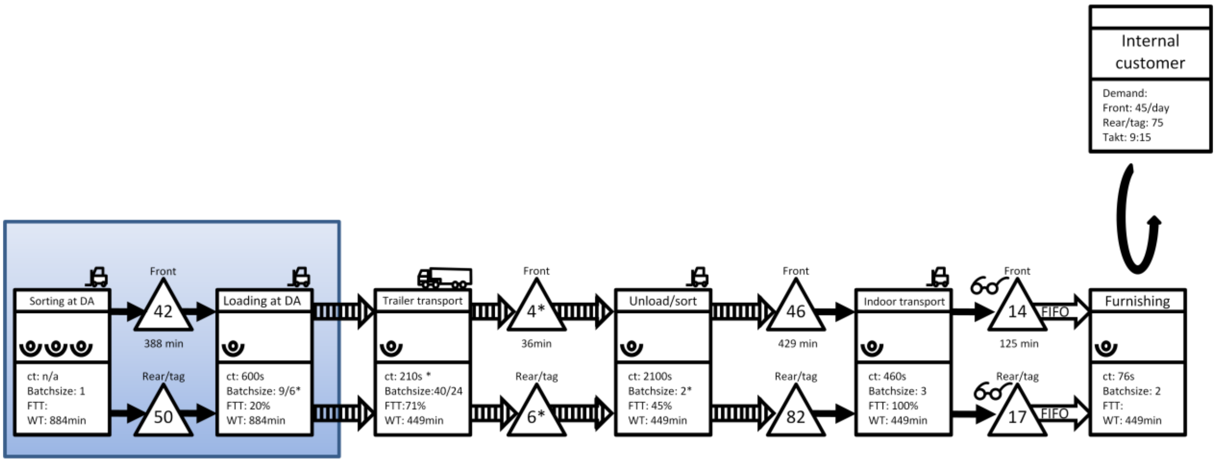

Figure 10: Physical flow, Sorting and loading at DA

At DA, axles are accumulated in 34 sorting spaces. These are necessary largely because production and loading is not performed in a straight sequence to the final assembly of trucks and busses. Axles coming out of production are accumulated in storage spaces that, when all axles for one shipment have arrived, are sorted into sequence so that loading onto the trailer is facilitated. After sorting and sequencing, the axles are transported to MS for the previously described unloading and sorting. The forklifts used at DA are larger and able to load the trailer more rapidly than is possible for unloading at MS. Here, five forklifts are used in total, two for unloading finished axles, sorting them into lanes destined for the same trailer, one for sorting the axles and relocate them to another lane in the correct loading sequence, one forklift for loading empty racks from the trailers that arrive before they are loaded into the axle conveyors, and finally a larger forklift, able to lift 6-9 axles depending on rack size, for loading of the trailers.

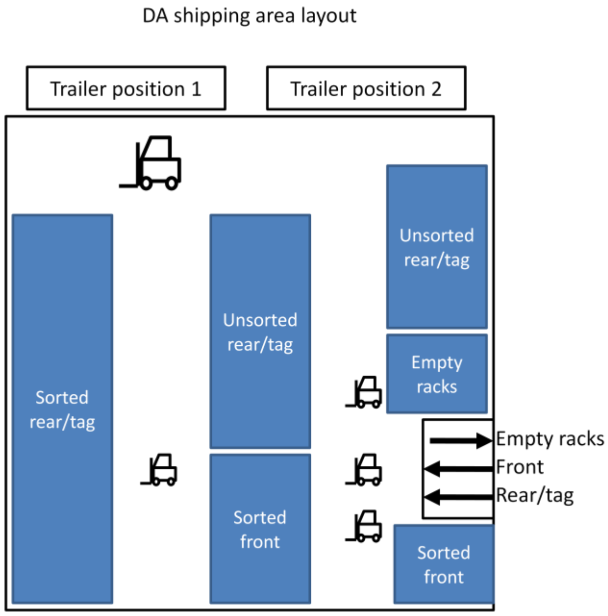

Figure 11: Layout of DA shipping area

6.2.6 Axle and rack dimensions

As previously mentioned, the axles are transported using either large or small racks. The dimensions of the different rack types can be seen in the figure below. The arrow indicating the front on the images represent which end that should enter the axle pre assembly conveyor first.

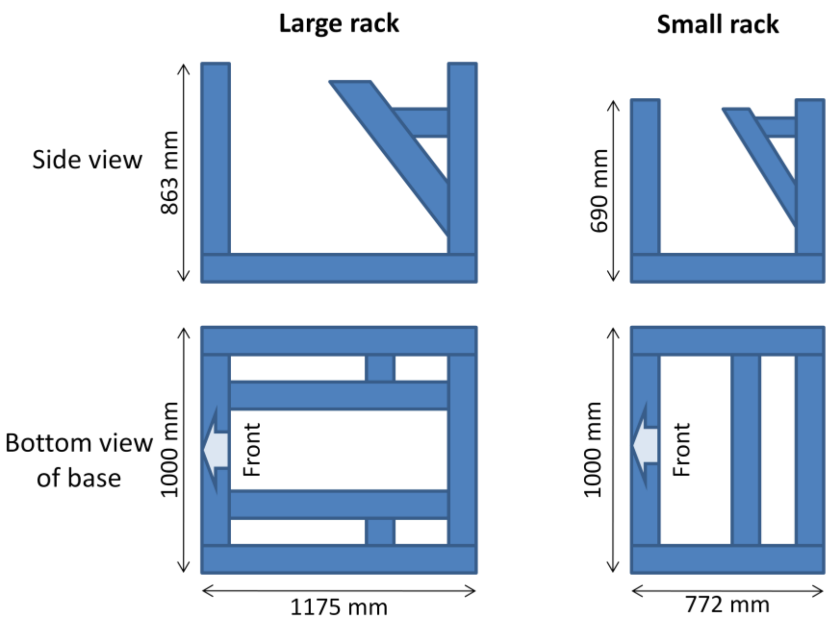

Figure 12: Rack design

The axles themselves are approximately 2,5 m wide and range in weight from around 700 kg for a simple front axle and up to 1200 kg for the heaviest rear axles.

6.3 Information flow

In accordance with one of the main pillars of the Scania Production System, as described in chapter 5.3, the production at Scania should be controlled by the consumption of downstream processes. At the chassis assembly plant in Södertälje (MS) and the other Scania PRU:s, this means that the production at the main assembly line is governed by customer orders, and the sequence of production sets the material need for the different processes and suppliers upstream from the final assembly.

As each chassis is built to customer order and specification, the planning of production sequences and the handling of sequence changes are an important factor to consider when analyzing the information flow in the system.

6.3.1 Planning process and supplier communication

Once a week, the Scania central planning release a batch of production orders (called status 1 sequence) to the production planning office at MS.

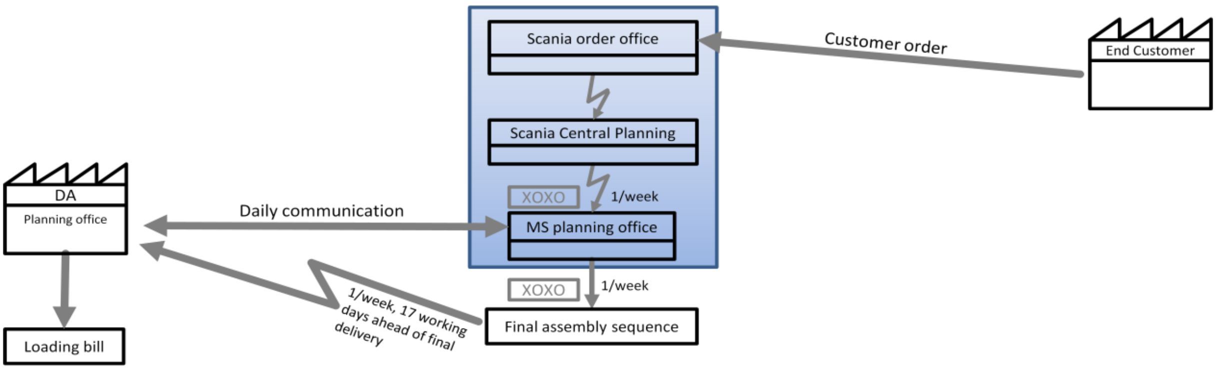

Figure 13: Information Flow, MS planning office

The content of this batch is then to be assembled in the coming unplanned planning period where each planning period is four to six days long. These batches are based on incoming customer orders handled by the order office and divided by the central planning among the different production units (PRU:s) depending on available volumes and vehicle type and split into different periods depending on the delivery date. This division is also dependent on a number of high level mixing rules and restrictions for the final assembly, such as limitations in handling large numbers of trucks with many tag axles etc.

The batch from the central planning is then broken down once a week by the local production planning to a production sequence for the final assembly line for the days in the relevant part period. This sequence, called status 2, is based on a further broken down, plant specific set of mixing rules and restrictions. These rules range from restrictions that if broken will stop the final assembly line, to rules that can be handled by the assembly line operators, many of which cause higher time pressure and thus increase the risk of errors, both in the assembly line and in the supply of materials. One example of a line stopping rule is a restriction in the combinations of drive axles and tag axles for the sequence of trucks. As the axle pre-assembly can only prepare a fixed number of axles at a time, they cannot manage several heavy vehicles in a row.

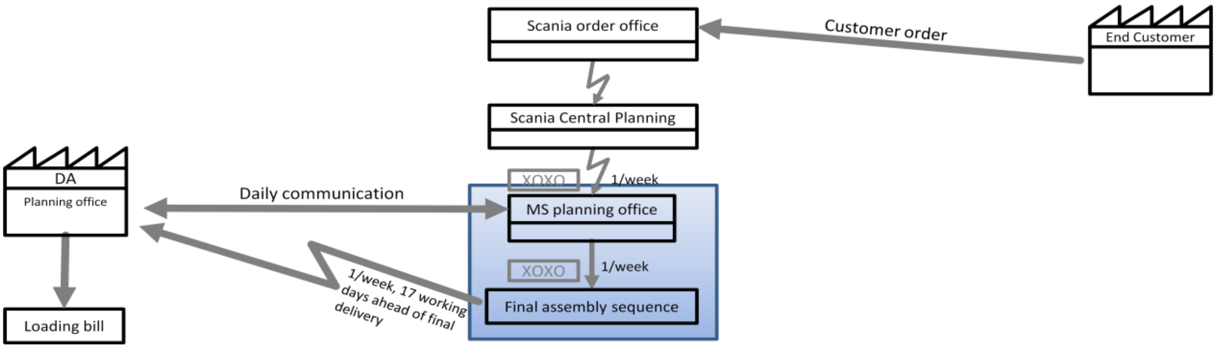

Figure 14: Information flow, Creation of final assembly sequence

As this sequence is set, each truck to be assembled are assigned a unique chassis id and an end assembly time, which will govern the time components are delivered and received at MS. If the sequence has to break the less serious mixing rules, the final assembly area or areas from which the rule originates are consulted for a discussion whether they can handle the extra heavy mix or not, dependent on staffing issues etc.

This production sequence is then locked and relayed to all component manufacturers and suppliers about 17 working days before the start of the period. This is to give enough time for upstream suppliers to get materials, produce parts and ship them to MS. Scania has a policy of letting each PRU deal with their own disturbances, and thus the scheduled sequence to suppliers and component manufacturers will not change even if disturbances such as a delayed engine from one supplier causes a change in the final assembly sequence in Södertälje. All parts from other suppliers will be collected as planned either way, and the delayed truck will be put back into the sequence as soon as the late part can be delivered.

As the axle manufacturer, DA, receives the status 2 sequence, this list is further broken down into individual chassis and axles. This is then combined into planned individual shipments from DA to the corresponding PRU, which serves as the basis for the local production sequence. This sequence is created according to local mixing rules, incorporating orders from the other PRU:s DA supplies with axles. Efforts are however made to keep the sequence as similar as possible to the shipment schedule in order to reduce the need for sorting the axles before loading them into the trailers heading for the customer.

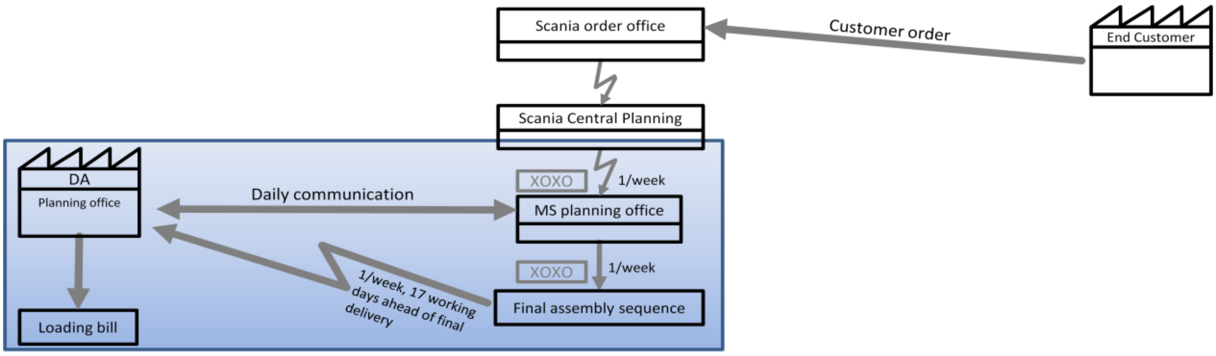

Figure 15: Information flow, supplier communication

The production planning at MS have daily contact with the part suppliers regarding the status of the shipments that are due to arrive within the next two days, exchanging information and status of any parts that are going to be, or might be late, and any other delivery issues that might require MS to initiate a sequence change of the final assembly. If any potential problems are visible, DA and MS keep a closer contact throughout the day, relaying any news and status updates so that sequence changes if possible can be avoided unless absolutely necessary. Such sequence changes at MS are made as late as possible, allowing the suppliers a chance to deliver the part before it is needed. In order to allow for this flexibility, each PRU have buffers of approximately one day worth of incoming parts to handle any disturbances. Since the suppliers most of the time manages to deliver even late goods before they are needed on the assembly line, sequence changes are usually not done until roughly three hours before the truck enters the main assembly line if the part deficit is known beforehand. On rare occasions, if serious unforeseen problems that cannot be handled arise during assembly, such as major part quality defects or other issues, the truck can be lifted out of the assembly line and shifted out of sequence at a certain point after the start of the assembly.

6.3.2 Shop floor information flow and handling of sequence changes

At the start of each day, each part of the material handling organization at MS involved in the axle flow prints the latest sequence list which will govern their work during the day. This list, which is printed from the Scania material ordering system MONA, has a detailed sequence of which parts are needed for each chassis. In this case the list holds information of which axles are needed for each truck and when the axles are to dock with the main chassis.

The pre-assembly forklift (PAF) thus loads the axles into the pre-assembly front- and rear-axle conveyor systems according to this list when the corresponding conveyor gives the light signal for replenishment of axles. In the case of odd axles, which are treated separately, the PAF operator requests these axles via radio and gets them delivered outside the regular flow. This is performed by the transporting forklift (TF) that transports the axles according to the same sequence list. The same goes for the unloading forklift (UF), although this forklift unloads and sorts according to the sequence of chassis that are going to be assembled the next day, which means that sequence changes have often not taken place when this sorting occur.

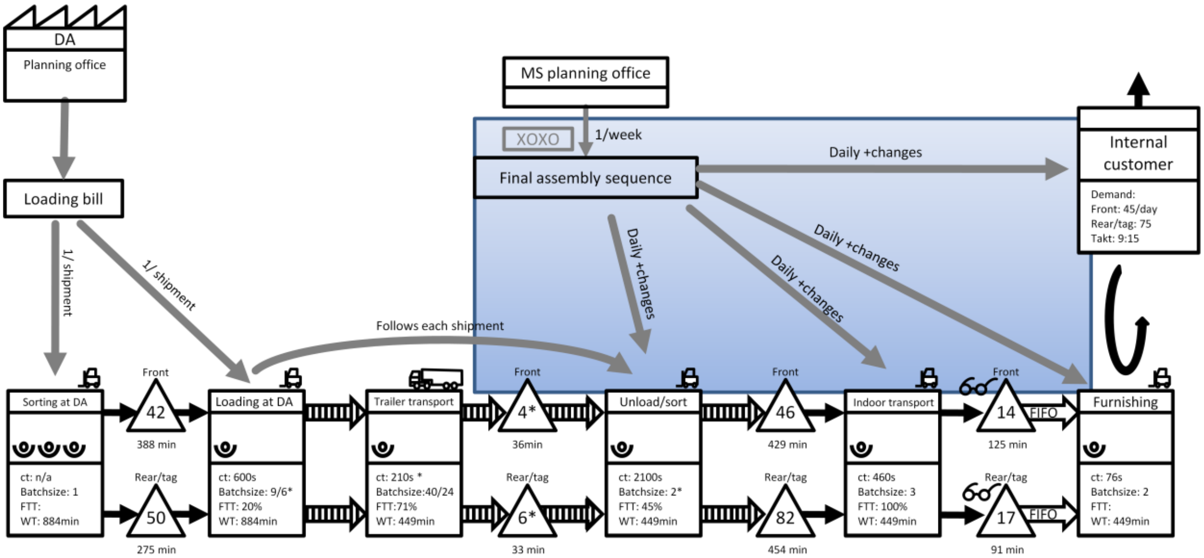

Figure 16: Information flow, sequence information

When a sequence change is set and rolled out, operators and production supervisors are informed of the change via mobile text message and email. Dependent on how late the change is done, this affects the axle flow in different ways. If the change is done three hours before the chassis enters the final assembly line, this means roughly seven hours before the axles are to enter the pre-assembly conveyor.

From the start of the frame assembly until the axle docking there are 26 assembly stations, which with a buffer of five extra chassis after the first part of the assembly line gives a time of 4 hours 40 minutes with a takt time of 9 minutes 15 seconds. As approximately one hour worth of production of work in progress is held in the pre-assembly and in the pre-assembly conveyor, this gives 3 hours 40 minutes from the chassis enter the final assembly line until the axles are required in the pre-assembly. Given the three hours of planning time for sequence changes as mentioned above, this gives just under seven hours.

The axles that are affected are thus often located somewhere in the outside buffer, and the transporting forklift (TF) needs to do some resorting to lift axles out of the sequence when they appear in the front of the buffer. If the sequence change is done earlier, the UF sometimes have not yet unloaded and sorted the re-sequenced axle, and can thus put these axles into the buffer according to the new sequence and avoid the resorting when the axles are to be transported to the inside buffer. In the case of very late sequence changes, when the axles already have been moved to the indoor buffer, the PAF put these axles to the side, to be collected by the TF and brought back to the outside buffer as new axles are brought inside.

The forklift unloading the trailers (UF) and sorting them into the outside buffer gets a sequence list with each trailer, detailing how the axles are stacked on the trailer, thus providing the operator the information on what is on the trailer, what is missing, and what needs to be resorted.

This sequence list is the same list that governs the sorting and loading at DA, and is the manifestation of the breakdown of the status 2 sequence into separate trailers as described earlier. If any problems occur in the production at DA and an axle destined for a certain trailer is too late to make the trailer, this is communicated to the material handling personnel via radio and that particular axle is left out of the trailer. The axle is then either shipped in the next trailer heading for the same PRU, or sent as a speed transport separately at higher cost dependent on the wishes of the customer. In the case of MS, very late axles are occasionally driven by forklift the few hundred meters between DA and MS.

7 Waste analysis of current state

In this chapter, the different parts of the flow will be analyzed in depth in order to identify the different wastes and inefficiencies that exist in the system. Each waste that is identified will be analyzed and potential fixes to the individual problems will be presented. These solutions will in later chapters be analyzed and combined into more complete solutions with a more thorough consequence analysis.

7.1 Buffer handling at axle Pre-assembly

In order to target the inefficiencies embedded in the flow, some of the specific issues that have been noted during the empirical research and investigations will be described.

When loading the front axles delivered in small racks into the pre assembly conveyor, the PAF needs to do one extra handling of each axle. The PAF lifts a stack of two axles from the buffer, set them down next to the conveyor, drive around to the other side of the stack of axles, pick them up again one by one and load them into the conveyor. The reason for this extra rotation of the axles before loading them is due to the risk of dropping the axles when picking them from the buffer as explained below.

As the racks are placed in the buffer, they are put after one another, packed tightly in order to minimize the space usage. This enables the TF to push the stacks of axles forward to allow for replenishment at the end of the queue as axles are picked from the front. This makes the lifting of axles a bit harder, since the PAF will risk lifting and tipping the next stack if reaching too far into the stacks. In order to minimize the risk of dropping the axle while handling it by the PAF, the small racks are oriented so as to let the middle cross member support the end of the forks in case the forklift does not reach far enough to get full support of the end cross member as shown in Figure 17. This problem does not exist for the large racks, as the cross members are parallel to the side members, as can be seen in Figure 12. The front of the rack in these images is defined as the end that is to enter the conveyor first.

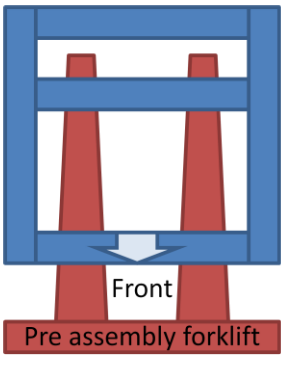

Figure 17: Handling of small racks

As explained in chapter 6.2, a large space just outside the pre-assembly is taken up by a buffer of incoming axles. On average, 10 trucks worth of axles are stored in the buffer, translating into 1 hour 40 minutes worth of stock. The buffer is very rarely close to being empty. This is an example of the waste of excess inventory, and as such should be a candidate for elimination. It can be argued though, that it is a necessary waste because of the fact that during cold weather conditions the axles need to be kept inside about one hour before entering the pre-assembly in order for the axles to achieve a reasonable temperature for handling by the pre-assembly operators.

In this buffer, the axles are stacked two in height in each of the two rows (front- and rear/tag axles). This is the maximum height allowed and for the most part, the axles are stacked accordingly. Since not all front axles come in the same sized racks and thus cannot be stacked, some axles are placed “solo”, thus decreasing the fill rate of the space. In order to alleviate this problem somewhat, front axles are allowed to be stacked one axle out of sequence, if this allows for the axles to be stacked two in height.

As explained in chapter 6.2; when the TF replenishes the buffer at the pre assembly, it does so from behind, in a FIFO manner. This means that the line of axles grows backwards as it is replenished. In order to fit more axles in the line, the forklift therefore has to push the line forward every now and then. Because the axles are placed directly onto the concrete floor, there is a lot of friction built up between the heavy axle racks and the floor. If the forks don’t fit the racks exactly right, there is a risk that the racks or the hydraulic extension forks are damaged, incurring large costs for repair or scrapping. This has been known to be a problem ever since this solution was implemented, yet nothing has been done so far to fix it. Plans are being investigated though, to install some kind of tracks or sliding surface to minimize the friction and effort needed to push the axles forward, thus allowing for the TF to move the queue more easily.

Additionally, it is a very loud operation as well as dangerous because it’s hard to see to the end of the row of axles when pushing, which poses a risk of hurting people or equipment. In order to be able to push the line of axles with the forklift, there can’t be too many axles in line; otherwise the forklift isn’t strong enough. When there are too many axles in buffer to be pushed, the driver of the TF occasionally chooses to drive around to the other side of the axle queue and move a couple of stacks, thus making it easier to push the rest of the axles from the back. This action is not something that is officially required of the TF driver, but is rather something that he/she does by his/her own initiative in order to keep ahead of schedule. Sometimes this job is carried out by the PAF in between its regular duties. Either way, this unnecessary movement and handling takes time from other more value adding work. The fact that the TF has time to do this is an indicator that the TF is under balanced and thus have capacity to increase its output.

Considering this background, conclusions can be drawn that the main improvement areas to work with is the **unnecessary handling of front axle racks**, **the buffer levels**, **the inefficient and unsafe pushing of the buffer**, **and the space utilization at the buffer**.

To target the rotating of the small racks, two possible solutions have been identified. The first alternative is to change the design of the small racks by adding another cross member, as shown in Figure 18 in order to avoid the need to rotate the axle before it enters the pre assembly. This would also increase safety in

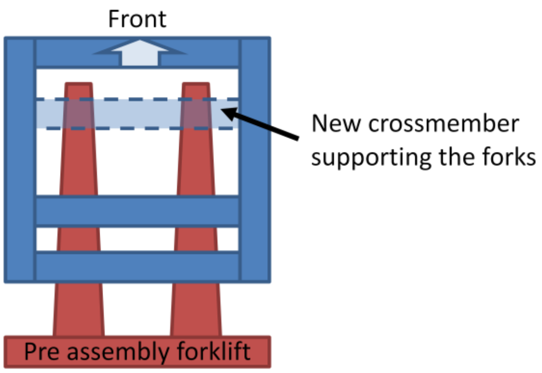

Figure 18: Redesigned small rack

other transports of the rack, as the risk of dropping an axle decreases.

The cost of such a solution is approximately SEK 2 000 000 for changing all the 10 000 available small racks in circulation. However, this would overall save about 40 hours of work yearly for the PAF and the UF while creating a much safer handling with less risk of dropping axles during handling. An additional saving would then be the reduced cost of scrapping due to dropped axles, which 2010 induced costs of almost SEK 700 000 at MS alone.

The second alternative to this issue is to exchange the small racks for large ones, currently used for rear/tag axles. This will remove the need for rotating the axle, but will increase the space usage throughout the flow. On the other hand, switching to larger racks also address the issue of space utilization in a positive way, as the use of same size racks allows for stacking the axles two in height consistently. However, as the racks are larger, the space used will be approximately 30 percent more, accounting for the mix of large and small racks in current operations. Switching to only large racks also poses some problems in the pre-assembly conveyor as the racks and yokes are a bit too high and some minor modifications would need to be done to the conveyor. Unless large racks are used for all axles for all PRU:s, the special handling for MS axles would cause severe problems at DA, since these axles need to be added as separate entities in all DA systems, thus complicating the flow and planning considerably. Since the lowering of fill rate for the trailer transports by only transporting large racks would induce very large costs for Zwolle and Anger transports such a solution would have large problems becoming profitable.

In order to adress the issue of the buffer levels, a solution to the axle heating during the cold parts of the year need to be adressed. This can be done either by having them stored inside for some time before assembly, as is done today, or by a heater that during cold weather can heat the axles in a short time. Unfortunately, no simple feasible heating solution have been found, and the only remaining alternative is thus keeping the axles indoor for about an hour in order to thaw them for handling. It is thus both possible and recommended to decrease these levels somewhat, as the current levels can be seen to be a bit excessive, especially during the warm parts of the year.

To eliminate the dangerous pushing of the axles, either a fundamental redesign of the buffer need to be done, such as using wagons carrying the axles; or some sort of track or sliding surface needs to be installed. Installing such a sliding surface is as described earlier already being investigated by MS and will hence not be investigated furter in this thesis. Solutions including wagons will be discussed and evaluated further in chapter 9.1.

7.2 In-plant transportation

The sole task of the TF is to constantly provide the pre-assembly with axles from the outside buffer. A common way for the TF to pick axles is to first lift out the first stack of two from the buffer, move it to the side, and then lift out the stack previously under it, drive up to the first stack and lift them both. This extra handling occurs because the TF usually wants to move more than two axles at a time. The axles in the outside buffer is sequenced in such a way that the axles that are to be used at the pre assembly first is stacked further out, on top of the stacks, and the ones that come after are stacked further in, at the bottom of the stacks. In order for the first stack to arrive at the pre-assembly first, it needs to be placed in the outer part of the forks, forcing this extra handling, which of course isn't value adding.

During the actual transportation of the axles, it is common for the TF to stop and wait because of the dense traffic inside the plant and the congestion it incurs. As stated in chapter 6.2, the TF uses a heavily congested route, leading more or less straight to the axle pre-assembly. Along this route, shelves of material are placed along a large part of the route, meaning that the TF has to compete for the space on the route with forklifts supplying the pallet racks along the way. Though these are generally the most time consuming stops, the TF also has to do regular stops for other forklifts, box trains, wagons, people etc. On average, the TF has to stand still for 26 seconds on each of its 41 transports to the inside buffer each day, totaling at almost 20 minutes of non value-adding waiting time per day. Of the observed stops, roughly forty percent were caused by the forklifts furnishing the pallet racks along the route.

The most axles the TF is able to carry are four racks of axles in two stacks of two. Because of safety issues and the maximum payload of the slide-out ends of the forks, the maximum allowed load is three axles and on average, 2.9 axels are carried on each transport. This doesn't mean that three axles are carried most of the time though; rather batches of two or four axles are very common. 2.9 axles are also somewhat more than needed per cycle and as such it can be considered a waste of overproduction. Some of this overproduction can be justified by arguing that it is needed for taking up fluctuations due to for example heavy production mixes.

The reasons why no more than three axles are allowed to be carried are twofold. Firstly, it is a safety issue. Carrying four axles, the vision ahead is significantly reduced and the risk of hitting objects or people increases because of it. Putting heavy loads on the hydraulic extension forks also cause them to bend slightly forward, which in combination with the increased turning momentum of carrying the axles further out increases the risk of dropping the axles in case of hard breaking or turning. One such incident occurred in late December 2010, where the forklift had to brake a bit harder than usual which caused the axles to slide of the forks dropping to the ground, damaging racks and axles. The second reason for the official standard on not carrying more than three axles at a time is the risk of over bending the forks, due to the stress put on them by the axles being put far out on the tip of the fork extensions. Calculations done within the scope of this thesis have determined the maximum load capacity for the hydraulic extension forks when carrying four axles to around 2500-2225 kg (Kooi reachforks, 2006). When handling rear axles, this is often surpassed, as the weight of four rear axles exceed this capacity. This poses serious risks in terms of accidents and equipment tear and should be treated as a serious hazard.

As stated though, these restrictions are regularly dismissed for the sake of efficient delivery, a practice seemingly accepted by everyone, because of a consensus that it is the only way possible to deliver the amounts of axles required. During the writing of this thesis, as this issue was discovered and communicated to the production supervisor and technician, stricter rules have been put in place enforcing the rule of maximum three axles per trip. A heavier forklift with more heavy duty extension forks have also been ordered in order to manage the handling of four axles at a time in the future.

For the processes of the TF, the areas identifiable for improvement are **the excessive handling of axles at the outside buffer**, **the frequent mid-way stops due to traffic** as well as **the safety- and equipment durability aspects of carrying up to four axles at a time**.

A possible solution for avoiding the extra handling in getting the right stack first at the outside buffer is to stack the axles in the buffer two out of sequence, thus allowing a pickup of the bottom two racks immediately after picking up the top two in the stack of four without having to put the first ones on the ground first.

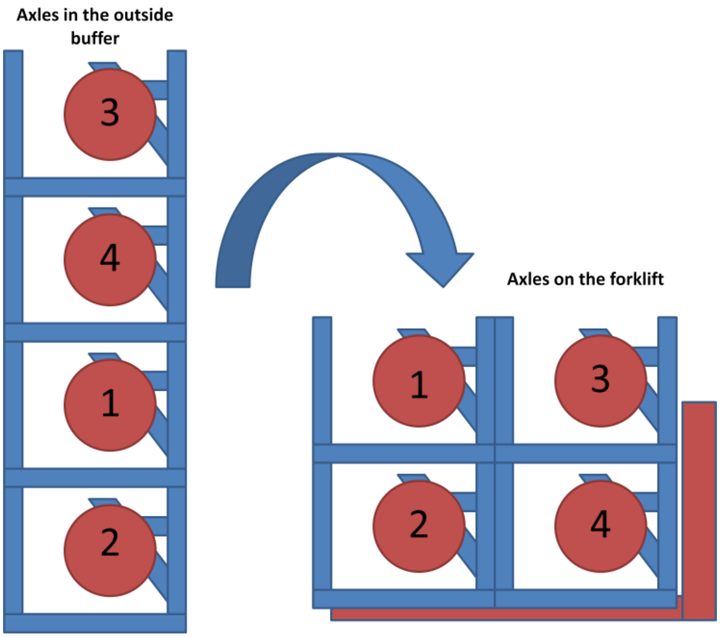

Figure 19: Axles sorted to avoid extra handling

However, this solution requires a fixed amount of axles to be carried each time by the TF and allows for less flexibility in how many axles to transport. A fixed number of axles for each transport is in accordance with the lean principle of standardized work, facilitating continuous improvement as the process is identical in each iteration (Liker, 2004). The loading into the buffer will however become more complicated, as the sorting has to be adapted to place the axles "two off" from the sequence, thus increasing the risk of errors in the handling.

In Figure 19, the axles are stacked four in height at the buffer, as is the current practice. As previously described, lifting four axles exceeds the maximum capacity of the forks, thus no system should be implemented which encourages carrying four axles. With a fixed number of three axles to carry each time, the same principle can be used to avoid the extra handling while not exceeding the capacity of the forks. In Figure 20 this handling of the buffer is illustrated. The forklift picks up axle two and three, and without having to put them on the ground picks up axle number one, thus holding them in sequence for the placement in the inside buffer. This handling introduces some issues however, as the space needed in order to keep the same buffer levels outside will increase as axles are stacked only three in height instead of four. At the inside buffer, every second stack is only one in height, as the TF leaves the axles in the same way as they are carried. This will increase the space usage indoors, thus allowing for fewer axles to be stored here. Given the current volumes however the buffer will still be able to contain a bit more than the one hour required to thaw the axles. A solution to keep the space utilization at the indoor buffer is to restack the axles into stacks of two each time the TF arrives at the pre assembly buffer. The issue of the more complicated sorting for the outside buffer is also apparent, as the axles need to be placed according to the figure by the UF for the extra handling to be avoided.

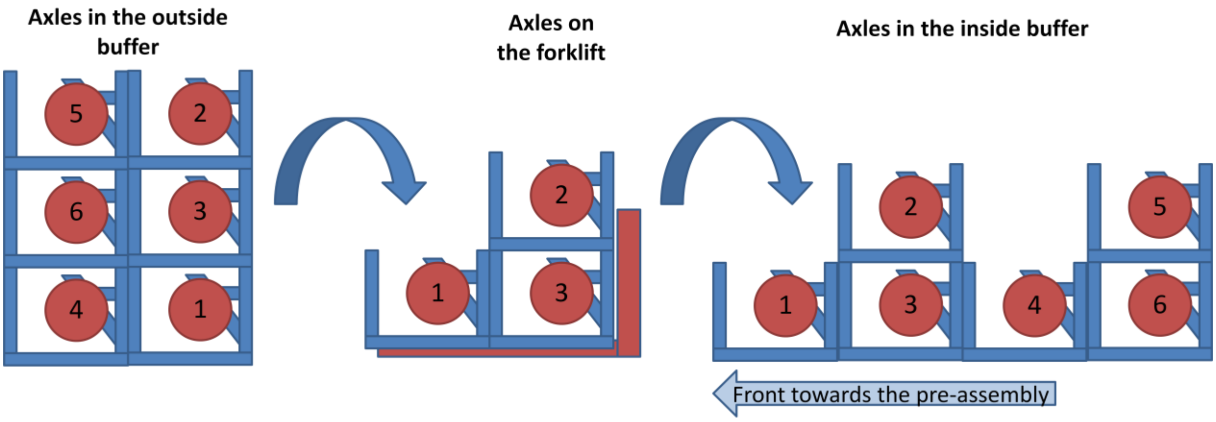

Figure 20: TF carrying three axles at a time, alternative one

A solution to this issue however is to sort and stack the axles as illustrated in Figure 21. This system will eliminate the need to make the initial sorting more complicated, thus simplifying the process, reducing the risk of errors, while still enabling swift and easy pickup for transport inside. The axles are here stacked according to sequence, picked up 2+1 and then unloaded with the double stack placed on top of the single axle.

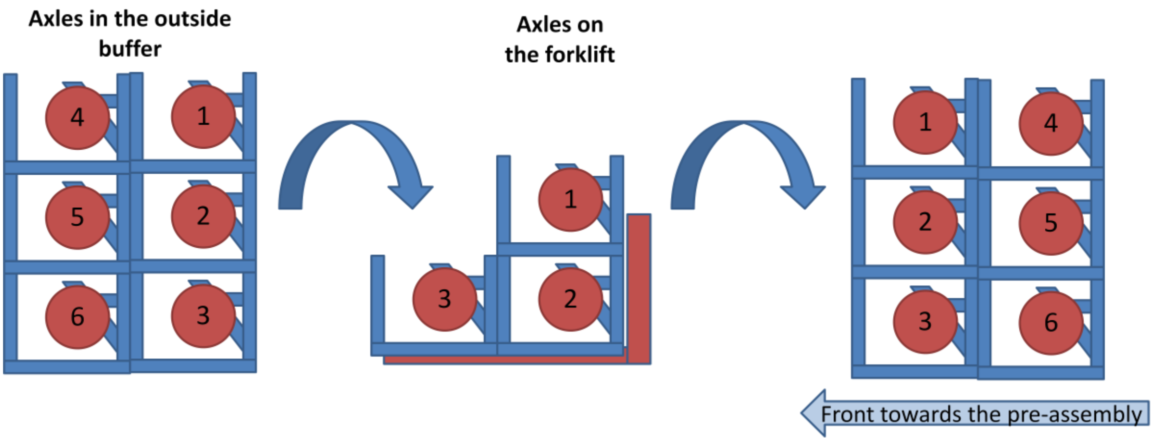

Figure 21: TF carrying three axles at a time, alternative two

A downside of this is however the height of the inside buffer, as this requires axles to be stacked three in height, which contradicts the lean principle of using visual control in order to prevent hiding of problems (Liker, 2004). Axles stacked this high inside the factory will limit the visibility and hamper the ability to get a quick overview of the situation by a glance. Higher stacks will also pose an increased security risk since higher lifting is more dangerous than handling of lower stacks. The stacking of three axles indoors will however increase the space utilization, thus freeing up this space for use by other parts of the organization. But as the stacks of axles need to be pushed forward intermittently, such a solution require some sort of sliding surface to avoid having to push the higher stacks which is a large safety hazard.

When dealing with the heavy congestion and the subsequent stops inside the plant, the bus line furnishing around areas 1 and 2 in Figure 22 cause the majority of the stops in terms of total time standing still. To address this issue, and to get rid of the forklifts blocking traffic, these areas have to be redesigned quite heavily. In other parts of the plant, projects are underway switching the line side pallet racks for racks of small-boxes and kits, thus reducing inventory close to the assembly line and enabling more efficient assembly operations, as described in chapter 1.1.1. Instead of forklifts supplying the façade, this is then handled by special small-box transports, which are more efficient and does not block as much of the traffic-lanes as the normal forklifts. The supply operations are also faster, as boxes are handled manually without any lifting devices and fewer parts are supplied each time. As fewer parts are resupplied with each trip, the transports are more frequent, but this fact should however be alleviated by the shorter time spent at each station.

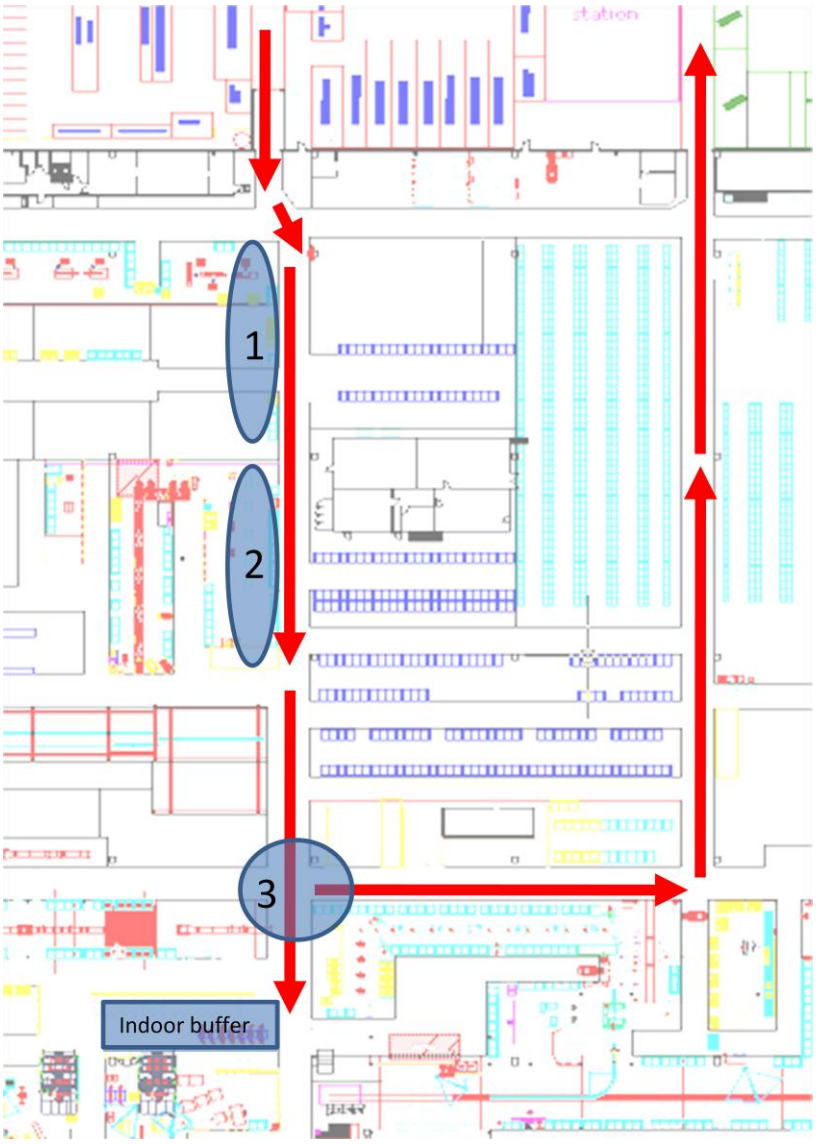

Figure 22: TF-route with the most frequent congestion areas

As the process of increasing small-box traffic and exchanging pallet racks for small boxes and kits progress, it may be of interest to prioritize these areas in order to alleviate the issues for the axle transports and to improve the traffic situation in these heavily congested areas.

The congestion at the intersection at area 3 is also a cause of many of the stops, but these are mainly quite short and do not affect the axle transport to the same extent. Stops at this area are both more rare and harder to avoid, as this is one of the main transport lanes thru the plant.

Another way of addressing the time standing still with axles in the isles is to have less frequent transports. In order to achieve this, more axles need to be transported with each trip. As this can't be done with a forklift, other solutions such as transports by trains pulling several wagons with axles need to be investigated. This is done in chapter 9.1.

7.3 Unloading at MS

Unloading at MS is performed by a single unloading forklift (UF) and contains a few identifiable inefficiencies, one of course being the previously referenced re-sorting. One of the main issues in this resorting is to rearrange all axles in stacks of two instead of stacks of three. These stacks of two are then combined to stacks of four at the outside buffer as described in chapter 6.2. In addition to this rearranging of stacks, the axles are resorted and tag axles are merged into the sequence in the correct stacks together with the rear axles. For this resorting there are also a series of rules for the order of which the axles should be stacked. These mainly refer to the order in which the axles are to be placed on the chassis, and thus in which order they are required in the pre assembly. For certain axle types and axle combinations, there are some exceptions, where the axle in question is removed from the sequence and delivered to the pre assembly based on a call off ahead of time as explained in chapter 6.2.

Front axles are still handled separately, and apart from the breakdown into stacks of two, there are also some rules of how to handle the combination of big and small racks, as these can't be stacked on top of one another and front axles come in both kinds of racks.

As the unloading and sorting is performed by a single forklift, it takes quite some time to unload the trailer and load the axles into the buffer in the right sequence. Apart from the need for resorting, the forklift used here is significantly smaller than the one used at DA, and can thus not handle the same weight in each lift. When unloading, the axles are lifted of the trailer and placed in a row on the ground in the correct order, from which the axles are then once again picked up and lifted into the buffer storage. This is necessary partly because of the incorrect sequence in which they come from DA and partly because the racks are placed in different directions, as described in Figure 23, on the trailer. The racks are loaded this way due to balance issues on the trailer. Since the axles aren't placed in the center of the racks, placing the racks in the same way on the trailer would shift the center of gravity of the combined stack to one side, resulting in an unevenly distributed weight on the trailer. The added complexities of these different factors

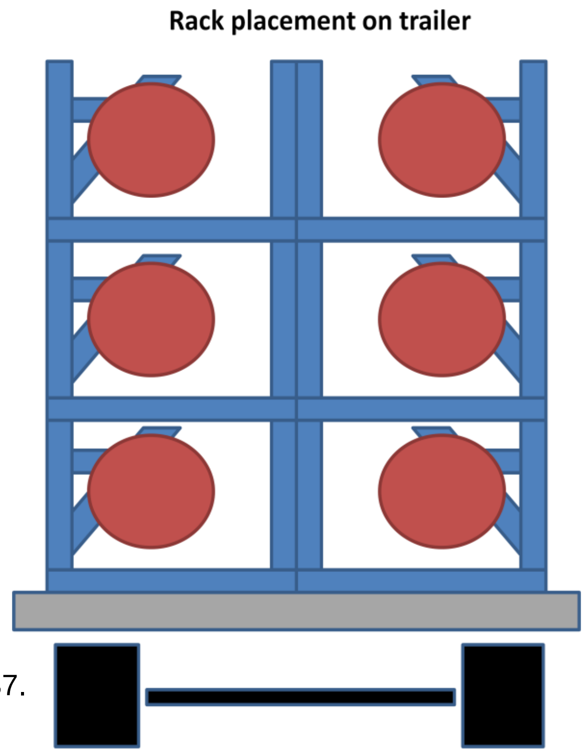

Figure 23: Racks loaded on trailer

incur multiple lifts and movements of each axle as well as long distances for the UF to move, resulting in an extensive total unloading and sorting time of 35 minutes.

All of these resorting operations at MS constitute wastes in several ways. The overly complex method of sorting the axles twice according to different sets of rules, having to redo a lot of the work already performed on the axles can be seen both as wastes in the form of unnecessary processing, unnecessary movements and wastes in the form of defects (Hines & Rich, 1997; Liker, 2004), as sorting axles from a faulty sequence into a correct one should only have to be done once.

The unloading and resorting operations lift each axle approximately three times from the time the axles arrive until the axle sits in the outside buffer. See Appendix 1: Handlings/axle in current system, for details.

For these operations, the main areas targeted for improvement are thus **the re-sorting, the breakdown from stacks of three to stacks of two** and **the overall handling and extra movements that the forklift have to perform.**

All these problems can be significantly reduced by simply receiving the axles in better sequence on the trailer. This can be implemented to different degrees, differing in complexity of implementation. They all have to originate at the axle manufacturing units shipping department though, where routines will have to be changed in order to accommodate the new standards of MS receiving. The highest degree of sequencing would be to start mixing rear- and tag axles in the same stacks on the trailer, thus eliminating the need for mixing them together on site at the MS reception. As this implies the stacking of rear axles on top of tag axles, the previously referenced balance problem of top heavy stacks will come into play with such a solution.

A further degree of sequencing would be represented by the mixing of front axles with the rear- and tag axles. Because of the fact that front axles come in small racks though, it would not be possible to stack the axles in exact sequence with the current rack design. If the small front axle racks were changed into big ones similar to the ones for rear- and tag axles though, an exact sequence could be achieved without sacrificing the fill rate, which would otherwise be necessary. This way, axles could be sorted either in a straight sequence maximizing fill rate, or according to the truck that they're going to be fitted to. For example, for trucks with three axles, the axles would be stacked in threes, whereas a truck with two axles would get at stack of two and trucks with four or more axles would get two separate stacks of two or more axles in each. It's worth noting though, that this solution could decrease the fill rate due to the front axles being held by larger racks. Up to 30% more space would be taken up by front axles, possibly prompting the need for more deliveries.

To sort the axles into a more feasible way, the axles could be sorted to have all axles for a certain chassis on the same trailer. By reserving certain rows on the trailer for stacks of front axles, there is no need to change rack types for front axles, thus eliminating this problem. Such a solution would still retain the majority of the benefits from the completely mixed stacks, creating a more leveled flow corresponding better to the customer demand and increasing the cover time of each trailer while maintaining a lower level of inventory. Such a solution will bemore extensively discussed and analyzed in chapter 9.1.

The restacking of racks from three in height to two in height is an operation that is hard to circumvent. Because the UF isn't allowed to carry three axles in height, under current conditions the stacks have to be rearranged in order to be sorted into the outside buffer. With the kind of forklift doing the unloading today, the only way to avoid the problem would be to let the axles arrive in a maximum height of two per stack. This would shorten handling times for the UF, although it would also lower the fill rate of the trailer and require extra trailer transports and extra time slots for loading at DA. This solution would also increase the space requirements at DA to accommodate for the additional transports and the sorting of the axles.

Regarding the placement on the trailer, the opposite positioning of the racks, and the problems that arise from it, there are a couple of basic ways to get the racks to face the same way after unloading. Not considering the alternative to place the racks the same way in the trailer, because the weight ratio can't be disregarded, there is the alternative to place them on the ground and drive around them before sorting them into sequence, which of course is the way it's done today. A second possibility is to open the trailer along both sides and pick the first line of axles from one side and the second line from the other side. However, this requires work in the form of opening both sides of the trailer as well as further traveling distances for the fork lift. This amount of extra work in the form of increased driving distances and the extra time needed to open the other side of the trailers is not profitable compared to the extra handling of turning the axles. If the back wall of the trailer would be open constantly, it would be more feasible. But if the trailer is open on both sides constantly, the axles need to be more rigorously secured during the transports, thus increasing the time needed for both securing the axles at DA and to remove the lashing as they are to be unloaded.

Concerning the size of the forklift at DA versus MS, a larger forklift at MS would speed up the unloading by allowing for more axles to be carried at once. It would also address the safety issue, as no extension forks would be needed, thus reducing the risk of dropping the axles, as explained in chapter 7.2. The use of such a large forklift however would limit its usability for other tasks, as it would be unable to handle other tasks requiring transports inside the plant. A larger forklift would also cause significantly higher rental costs and combined with its more limited usability it is not recommended.

7.4 Trailer transport

The trailer transport, covering a total distance of 1,5 km for a round trip to DA, makes this trip seven times a day, three for truck rear/tag axles, two for truck front axles, and one each for front and rear bus axles. The transport lead time from leaving MS with empty racks until returning with a full load is a little more than 30 minutes. In these transport operations, no obvious wastes can be detected, as the truck uses the shortest route with regard of the traffic regulations, road stretches and the other traffic in the area. This could possibly be improved a little bit, but as potential savings would be minimal, this will not be considered further.

However, as the roundtrip takes only a bit over 30 minutes, this means that for transporting seven trailers in one day, as is this trucks only task, only about four hours of the available working time is used. This constitutes the classical waste of waiting (Liker, 2004) as the truck is often waiting for the next trailer to finish unloading at MS before the next roundtrip can be made. The unloading is however not the only reason for this waiting. As DA supplies the Scania PRU:s at Zwolle and Anger, the 24 available slot times at the DA shipping area are divided among the sites. Particularly the trailers heading for Anger need to be sent of early during the day in order for them to be on time for the ferries along the way to France. Trailers for Zwolle are sent throughout the day from eerie morning to late at night. This means that the MS-trailers have to adapt to the shipping schedule and the allotted slot times for replenishment of axles from DA.

There is only really one waste of importance that will be taken into account here, and that is of course **the waste of waiting**.

To solve this problem of waiting, it is necessary to improve the utilization rate of the transport mode. One way to minimize waiting times and maximize utilization rates of the truck could be to assign it additional tasks, such as transporting other components in between its axle transporting duties. Another possibility is to assign the truck more frequent deliveries from DA. This is inhibited though, by the possible slot times at DA and the resources needed in order to load the trailer more frequently. It also implies a waste of overcapacity in the trailers, as more frequent deliveries implies a lower fill rate.

A more drastic solution is to simply eliminate the truck and trailers and implement another solution which incorporates smaller load bearers that arrive more frequently. This allows for low waiting times as well as high resource utilization rates. It does also put extra demands on the axle handling process at DA though. Such solutions is analyzed in chapter 9.1

7.5 Loading at DA and load planning

The loading of the trailers are performed by a larger forklift able to lift a maximum of two stacks of three large racks or three stacks of three small racks, as shown in the figure below. However, because of the mix of rear/tag -axles and big/small -racks, many trailers have a less than maximum fill rate, as axles can't always be stacked three in height. There is also a number of other rules that govern the sorting of axles and their subsequent loading such as maximum allowed weight and the mix of axles dependent on the chassis assembly sequence.

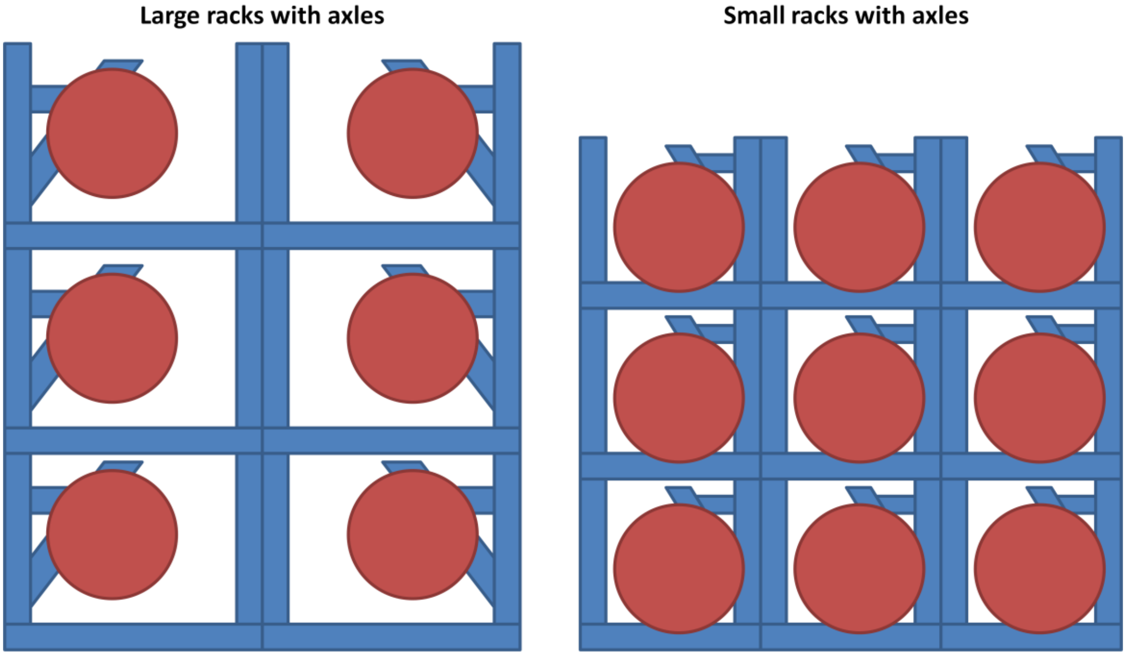

Figure 24: Stacking of axles in large/small racks

Tag axles heading for MS are always placed in separate stacks on the trailer with rear axles. Reasons for this rule vary depending on who is questioned about the trailer sequence. At DA, one reason put forth is that this is how the customer (in this case MS) wants the axles sorted. MS however does not share this view, since the tag axles need to be sorted into sequence when unloaded from the trailer. A couple of years ago however, before the conveyors were installed at the axle pre assembly at MS, tag axles were handled in a separate flow and separate tag axle stacks in the trailers were preferred. This sorting rule is thus probably a remainder from that time, which has not been prioritized because of the move of DA from Falun to Södertälje and the subsequent chaotic situation of reorganizing a production unit at a new site.

Other sorting rules are linked to the weight of the axles. This rule concerns the heaviest axles, which are placed at the bottom of their stack in order to keep the stack as stable as possible when lifting and stacking the axles three in height. Since the weight difference between the heaviest and the lightest axles are quite substantial, this is also presented as a reason to keep the tag axles separate instead of in the same stacks as the rear axles. The customer (MS axle pre-assembly) wants the axles destined for the same chassis arranged with the rear axle stacked on top of the tag axle. This enables the rear axles, which require more pre assembly than the tag axles, to enter the pre assembly first. Due to the weight difference between a tag axle and a rear axle, DA is reluctant to stack them in this way, as they argue that the stability of each stack is compromised and thus increases the risk of dropping the axles during handling, posing a hazard both in terms of damage to the axles themselves, but also to personnel in the vicinity.

These factors are also the reason why the axles, despite the re-sorting, don't come in exact sequence to MS and why the trailer capacity is not fully utilized, resulting in a lower fill rate.

This issue of fill rate is however not considered as important by the shipment planning at DA for the trailers heading for MS as for the ones heading for Zwolle or Anger. Issues such as weight limits for shipments are not considered either, as the transports for MS are done within the Scania enclosure and thus do not use public roads. Since the MS trailers only travel a short distance at slow speeds, the axles and racks are not secured as rigorously as for the other PRU:s, thus saving time at the loading and unloading of both axles and empty racks.

It is important to point out though, that maximizing the fill rate of the trailer wouldn't necessarily improve the overall performance of the axle transportation. Rather, it's very possible that smaller loads shipped more frequently could be the medicine this flow so sorely needs. This is in accordance with the theories of continuous flow presented by Liker (2004) among others, which is described in chapter 5.2.1. Because of the extensive work needed at DA with the later solution, inefficiencies can be identified in both systems and the best solution needs to be found somewhere between a continuous one piece flow and the large batched deliveries.

The inefficiencies identifiable here are thus mainly connected to the restrictions regarding how to load the axles onto the trailer, specifically the **separation of different axle types and the subsequent unnecessary movements.**

The solutions to the problems here are to a large extent similar to the ones suggested for the unloading process at MS described in chapter 7.3, namely a rearranging of the axles within the trailer. If this rearranging were to take place here, that would eliminate a lot of work for the UF at MS. As stated, a mix of rear- and tag axles would eliminate a lot of extra handling, since separate rearrangements could be avoided. As stated, the reason for separating is claimed to be that MS wants it that way, a claim contradicted by MS themselves. Another factor is the previously mentioned instability issues regarding stacking heavy rear axles on top of lighter tag axles. This issue is definitely relevant for transports to Zwolle or Anger, but the short way between DA and MS with trailers moving within a closed compound at low speeds, this issue is not considered as significant as trailers heading for the continent on highways and ferries.

7.6 Buffer handling/sorting at DA

There are a few identifiable inefficiencies at the axle manufacturing unit. Most of these can be traced back to the fact that when axles arrive to the shipping area, they are not sequenced according to shipping schedule, as mentioned in chapter 6.2. A direct consequence of this is the necessary forklift driven re-sorting of axles before they are shipped. This takes place in a fairly limited space, incurring congestion as well as unnecessary storing times. The resorting of axles is naturally a step that would preferably be eliminated, but due to the production sequence limitations this is currently impossible. As mentioned earlier, three forklifts are used in this resorting, of which one would be abundant if the axles would be produced in the correct sequence. As it is used today, the buffer is pretty large and at any given time it holds about one day worth of production.

The wastes in this part of the supply chain are thus **excess inventory, and unnecessary handling**.

Both these problems could be traced back to the sequence in which the axles leave the factory. If this sequence was to be adapted to the sequence in which MS would like to receive the axles in the end, the rearranging process in the shipping area would become redundant, leading to less handling and a possibility to lower inventory levels. This is a common goal for DA and MS that is currently being pursued, although it's not yet possible to implement fully. It has been estimated though, that about 15 out of the total 34 sorting spaces could be eliminated by sequencing the axle production at DA to the order in which the axles are to be loaded. The current practice of using high inventory levels to handle the unevenness and lack of synchronization between the production lines is thus hiding the problems at the assembly lines by alleviating the pressure to solve these problems, as any production disturbances is transferred to more work for the shipping department.

Also, as previously have been suggested, if axles could be mixed more freely, a lot of excess handling and inventory could be avoided. If front axles could be mixed in with rear- and tag axles, separate sorting spaces for the types would be unnecessary and space could be saved by mixing them on the same assigned space and the more leveled flow would increase the cover time with lower buffer volumes. The main issue with such a solution is the planning system used at DA, since this is adapted to separate front and rear/tag axles. Such a problem is however only information related, and an adaptation of this computerized system should thus not be allowed to constitute a significant hurdle in order to create a better more leveled flow.

8 Future state requirements

In this section, workloads and potential bottlenecks of a future state will be defined and conclusions as to which parts of the flow that needs to be expanded or improved will be drawn. Starting at the MS pre-assembly and moving backwards to DA, the flow is analyzed through an assumed production rate of 70 trucks per day.

The planned capacity increase at MS will have quite some impact for the flow of axles. In order to manage the flow needed to produce 70 trucks per day in MS some of the operations will reach their maximum capacity and thus need to be changed. While the production increases, no significant changes in the product mix are to be expected, and the current situations of approximately 2,7 axles per vehicle is believed to persist even in the future. This means that approximately 190 axles need to be handled in the flow each day with a takt time per vehicle of just under 6 minutes. In order to calculate the capacity of the future system, a balance of 85% will be used for logistics activities as a maximum utilization. For the final assembly line operators, a balance of 95% is used. The lower level of balancing for logistics depends on the more dynamic nature of the activities.

Starting at the pre assembly, the PAF will manage the increased workload handling the axles, but the other furnishing tasks at the pre assembly might require additional capacity as these flows of parts will increase in the same manner as the axles. As the PAF position will have to dedicate a larger part of the day to the axle handling, the position with its current tasks need to be rebalanced and some tasks relocated to other positions.

The indoor buffer currently holding a little under 2 hours of buffer, consisting of on average 13 front axles and 16 rear/tag axles or in total: approximately 12 chassis. With a production of 70 trucks/day, this would require a buffer corresponding to 20 chassis if the same cover time should be kept in the buffer. As the space available at the indoor buffer is currently used to a high degree, this will cause a problem and a need for reducing the cover time in order for the axles to fit in the space allotted. In the current situation, 20 chassis worth of axles can be stored in the buffer only if it is always kept right at its maximum capacity, filled to the brim with axles. Naturally, this is not possible to achieve more than temporarily, and is not possible to uphold in the long run. Since the axles are picked from the inside of the buffer, and the stacks thus need to be “pushed” forward in regular intervals as described in chapter 6.2 and 7.1, this would be impossible with a completely full buffer. The buffer cover time thus will have to be lowered.

Given the current average number of axles stored in the buffer, which can be seen as a reasonable level, possible to uphold even with a higher production level. The cover time held in the buffer at a takt of around 6 minutes represent a little over one hour worth of axles. The axles thus have considerably less time to achieve a comfortable temperature in case of cold weather, but at an average cover time of one hour this is still reasonable.

The forklift performing the transport from the outside to the inside buffer have in its current operations an average cycle time of 460 seconds, or 7 minutes 40 seconds, for a transport of on average 2,9 axles. This time is including the stops measured during the transports as described in chapter 7.2. Over an entire day, this result in 314 minutes of activity per day to transport the on average 120 axles currently needed for the production leaving the TF balanced at a little under 70%.

If balanced at the target for logistics operations at 85%, the TF would be able to conduct 49 cycles in one day, delivering almost 150 axles (representing a takt of 55). At a production rate of 70 vehicles, the 190 axles needed per day would thus require an additional 30% from another position supporting in the delivery of axles between the buffers. As the production quantity increases, it is however very probable that the congestion will become an even greater issue, thus increasing the cycle time of the TF and increase the need to around 1,5 positions.

The forklift handling the unloading of the trailers and the loading into the outside buffer currently uses 60% of the day to the axle handling for trucks and buses. The truck axles alone use around 200 minutes/day, and could thus handle all the unloading of truck axles within a single position; given that bus axle unloading is handled by a different position. A problem arises however as the trailers currently are used for both bus and truck axles. If the same sharing should continue, the UF would be close to maximum capacity unloading axles for both these flows and would no longer be able to handle unloading of engines or prop-shafts as is done today. The tasks of the UF thus need to be divided between several positions. A suitable solution would be to combine the increased workload of the UF and the TF between three positions at the higher production level. If the amount of sorting done at MS could be reduced however, by a better sequencing at DA, the need for additional positions and forklifts might be reduced or even eliminated. With an unloading without the need for re-sorting the axles the time for unloading the axle trailers is estimated to be halved by forklift operators working with the unloading.

As for the trailers between DA and MS, the five trips used for trucks and the two for buses with the two trailers available would need to increase significantly in order to transport the 190 truck axles needed each day. Instead of five trailer loads of truck axles, 8 loads would be needed each day in order to accommodate the needs. Even though MS trailers need considerably less time for loading at DA since the load does not need to be secured as rigorously as for Zwolle or Anger trailers, as described in chapter 7.4, the slot times for loading at DA is still 30 minutes per trailer. In order not to jeopardize security at the loading, DA is reluctant to reduce the length of the slot times. In the current slot schedule, there is room for some extra shipments in the first part of the day, which in theory could handle the increase in MS traffic. However, this would require unchanged quantities for the other PRU:s, and is thus not a likely scenario.

Currently, the majority of the trailers heading out from DA does this during the first part of the day, leaving the evening shift with only a half full shipping schedule and several free slot times. In order to handle the increased volumes, these slots have to be utilized to a higher degree. The loading at DA will thus have to balance the higher number of shipments over the entire day in order to cope with all the axles heading for MS, Zwolle or Anger. The evening shift is currently only run at reduced capacity, with shipments heading for Zwolle until late at night. Increases in volumes for the Scania final assembly sites will thus require full utilization of the evening shift. A solution to utilize the afternoon slots to a higher degree will be described further in chapter 9.1.

The sorting operations at DA present another problem when volumes increase. As each trailer load currently requires at least one sorting space, given the current cover time required at DA, the increased number of axles held at each point in time due to the increased number of shipments will cause a lack of available buffer storage space at the DA shipping area. Unless either the buffer volume or the amount of sorting can be reduced, this will cause a major bottleneck for the DA handling, requiring a costly expansion of the shipping area.

9 Solution ideas

In this chapter, solutions will be presented that has larger implications for the entire flow. The target of these solutions are to correspond to the Scania production system and to enable a future flow more in line with the priorities of SPS and the goals of this thesis.

9.1 Four trailers acting as buffers – Stock on wheels

In order to address the goal of minimizing the buffer size, a solution would be to utilize the trailers transporting axles between DA and MS as a buffer on wheels, eliminating the need to unload the axles from the trailers, placing them in a regular buffer on the ground. This kind of system would eliminate the need for a dedicated unloading-position since the TF could pick up the axles directly from the trailer and transport them inside. As stated in chapter 9.2.2, such a solution would work very well in conjunction with a double loop train solution. However, in order to employ a system with the buffer residing on trailers, the axles need to be delivered in correct sequence from DA without the need for extensive resorting before transporting the axles to the indoor buffer. For this type of solution to be the most efficient, and to provide the maximum level of flexibility for setting up slot times for loading the trailers at DA and to be able to accommodate for the transport of bus-axles, the trailers should ideally transport a mix of front and rear-axles. This would allow for a longer buffer cover time, as the mix of axles can be better adapted to the true demand of the pre assembly, in accordance with both the lean philosophy of heijunka as described in chapter 5.2.3 and the Scania production system concept of leveled flow, that in SPS is a cornerstone of the normal situation (chapter 5.3 and Figure 3). Axles can then be shipped in the sequence they are needed and the complications of separate trailers with rear/tag axles and front axles having different cover-times would be eliminated as each axle-trailer have roughly the same mix of axles and thus cover the same buffer-time. As this allows for the trailers to be emptied in a steady pace, the slot times for transports can better correspond to a takt that is adapted to both the production at MS and DA, thus allowing for a more balanced flow.

In practice, one idea to achieve this is by stacking all axles in large racks, mixing them according to which chassis they are destined for with the lighter front axle on top of the rear- and tag-axles, as discussed in chapter 7.3. As the pre assembly even at a higher production rate will want the front axles in a separate conveyor, mixing them in the same stacks as the rest of the axles for the same chassis would still require some extra handling at the pre-assembly separating front and rear/tag-axles again. Thus this kind of solution leads to unnecessary processing as it complicates the sorting process both at DA and at the pre assembly.

Another possibility is to have a certain area on each trailer reserved for front axles. Each trailer currently holds a maximum of five rows of axles, and by dedicating the first one and a half rows to front axles (small racks first row, large racks second row) the mix on each trailer will correspond rather well to the rate of front axles compared to rear/tag-axles and the rate between front axles in small and large racks. With the current mix, roughly 20% of front axles come in large racks, and as these can't be stacked together with the small racks, some resorting will be required. However, it will still be considerably less resorting than in the current flow.

As explained earlier, with transports that are separated between rear/tag axles and front axles, the cover time will differ between the trailers holding front axles and the trailers holding rear/tag axles. This will cause the trailers with front axles to empty considerably slower thus not becoming available for transports as soon as required in order to handle the flow with four trailers. The system will thus require more trailers and more or less permanently tie up two trailers for front axles. These two trailers could however be used in combination with the bus axle flow, thus combining this flow with the truck-axle trailers.

9.1.1 Current state

With a takt of 45 chassis per day, a solution with separated font- and rear/tag axle trailers, would require at least four trailers all tied up with handling truck axles with no excess capacity to handle the bus axles. As the axles are consumed at different rates, it is very hard to adapt the transports to a fixed slot-schedule and the coordination between MS and the DA trailer loading would have to be extensive in order to accommodate for the variations. It is thus neither a leveled flow nor a flow that a takt can be applied to, and since both of these are important parts of the Scania production system this kind of solution is not recommended.

With mixed trailers however, the flow is both leveled and can easily be adapted to a fixed slot schedule for axle-loading at DA. In this solution, three trailers would be enough to handle the truck flow, with an average buffer level of 111 minutes or 30 axles. Bus axles in this flow would have to be handled separately with a dedicated trailer only transporting bus-axles. By utilizing a fourth trailer, the flow can incorporate the bus axles and transport them between shipments of truck axles. This will allow for higher utilization of trailer capacity and at the same time increase the buffer levels for truck axles to an average level of 200 minutes or 54 axles, as is shown in Figure 25. As bus axles are consumed at a significantly slower pace than the truck axles however, these have to be unloaded from the trailers in the same manner as is currently done in order to free up the trailer again to use in the paced truck flow.

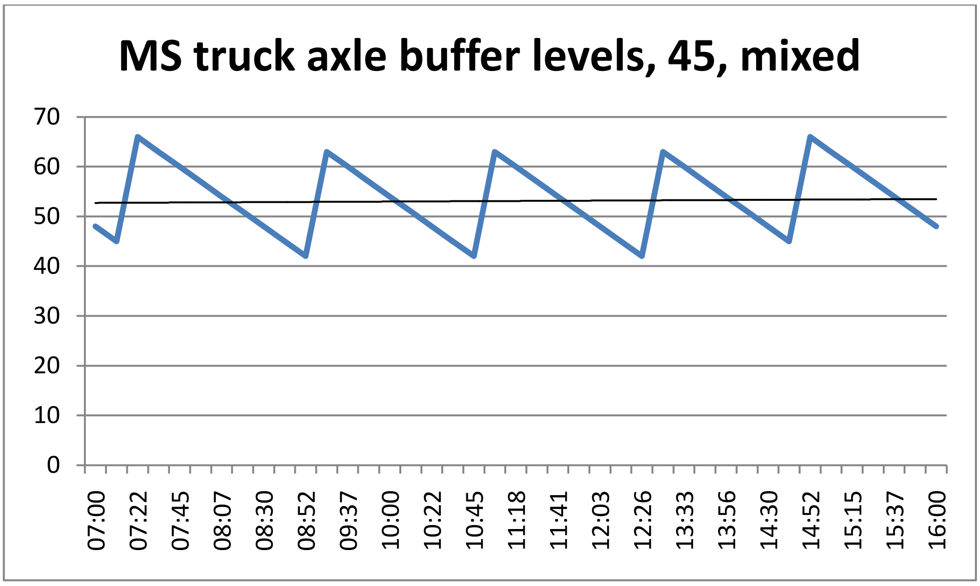

Figure 25: Buffer levels using four trailers solution, current state, mixed loading

This system can be fully adapted to the DA loading-slots with only small adjustments and little interference with trailers heading to Zwolle or Anger thus minimizing the need to reschedule the long hauls to the other Scania PRU:s.

9.1.2 Future state

With the future state of 70 chassis per day, four mixed trailers can support both truck and bus axle transports. As the rate of consumption is higher, trailers will become available for fetching of new axles sooner, thus facilitating a more balanced and even flow. The buffer level held with this system will gradually decrease during the course of each day as the axles are consumed. When MS stop production at the end of the day, the buffer will be at its lowest, and by utilizing the less congested afternoon shifts at DA, the buffer is refilled and prepared for the next day of production at the chassis assembly. This is represented in the below graphs by the large increase in bufferlevel that occur after 16:00, the size of the increase is because it represents two separate trailers that are transported sometime during the evening shift dependent on the DA loading schedule. As the specific time of such a replenishment is not of importance from the point of view of the MS buffer level, it is specified only as a time later than 16:00.

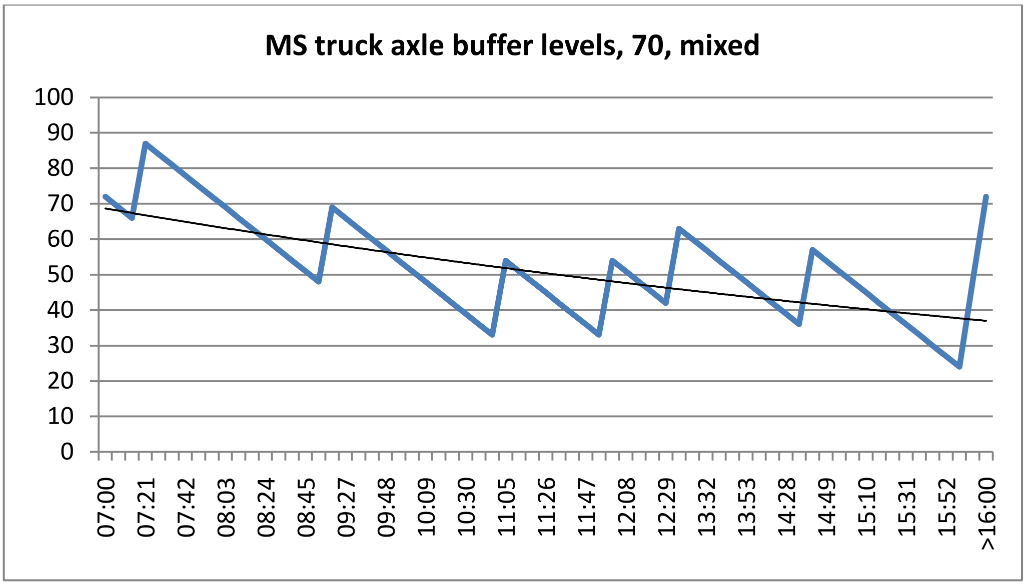

Figure 26: Buffer levels using four trailers solution, future state, mixed loading

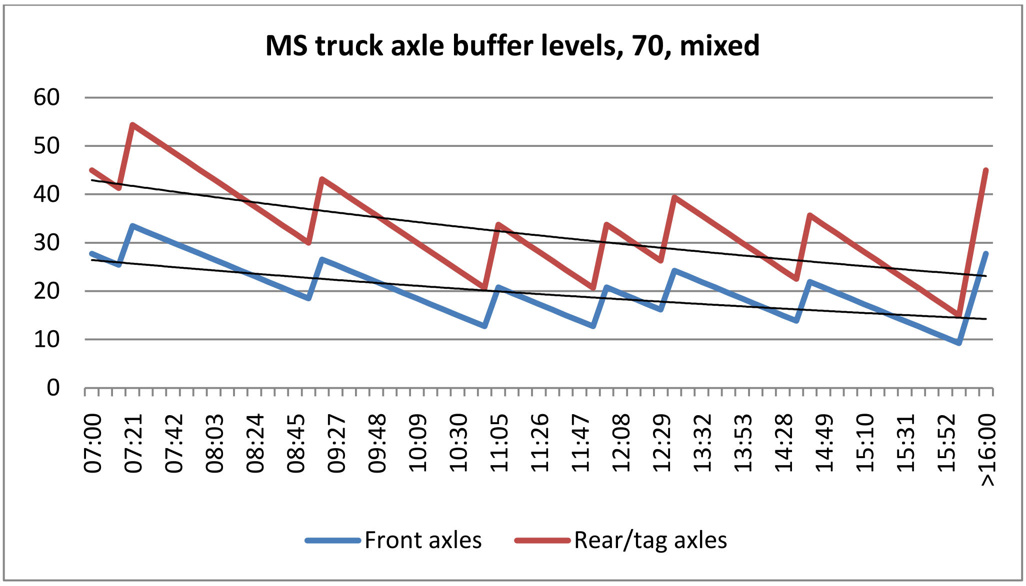

Figure 27: Buffer levels using four trailers solution, future state, mixed loading, illustrating levels of front- and rear/tag-axles

In the above graphs, the buffer level is shown for truck axles using the proposed loading. In this case, the shipments can be adapted to the current slot times at DA with only small adjustments during the most intense hours of the day. As mentioned earlier, two additional slots are required during the DA afternoon shift to refill the buffer for the next day. This system gives an average buffer size of 52 axles, providing a cover time of 124 minutes or a little over 2 hours worth of production. In Figure 27, the buffer has been divided into front and rear/tag-axles to illustrate the leveled volumes.

If axles are separated in front- and rear/tag-axles, just as described above for a takt of 45, the system would be able to support the truck axles using four trailers, but require bus axles to be handled entirely separate as the time margins between when a trailer is empty and when it is needed for the next trip is significantly less as the axles are used at different rates. As the volumes are higher, the faster overall consumption does increase flexibility compared to the situation with separated axles and a takt of 45.

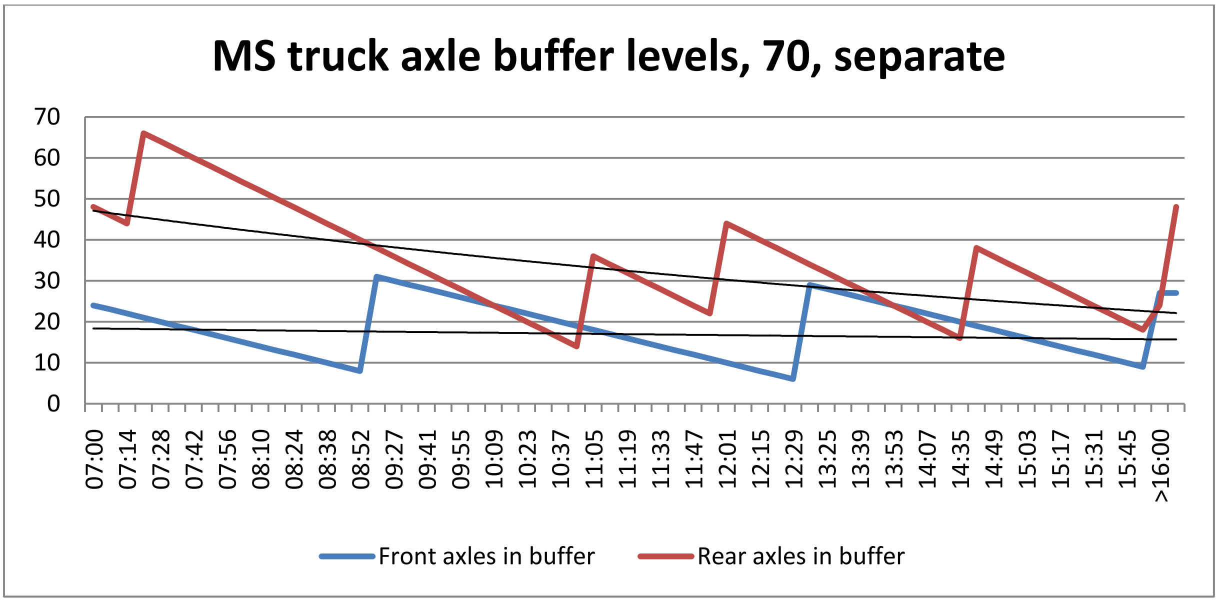

Figure 28: Buffer levels using four trailers solution, future state, separate loading

As can be seen in this graph, the buffer levels varies significantly during the day and are overall lower than in the above case with mixed trailers. And when comparing to buffer in Figure 27, the buffer when using separate trailers is not as leveled and contains greater variations and lower margins for error than the mixed solution. Due to the more complex consumption pattern, it is also significantly harder to adapt this solution to a fixed slot schedule with full trailers.

9.1.3 Benefits

By placing the buffer on wheels, approximately 600 m^2 of storage space is made available for other uses outside MS. As the buffer level is reduced, the flow becomes more visual, bringing problems to the surface and exposing them, facilitating process improvements. This is in accordance with the lean theories presented earlier in this thesis in chapter 5.2.1 and with the Scania production system principle of visualizing. As problems can't be hidden in the safety of buffers, they need to be dealt with in order for the system to sustain the flow of products. One such problem is the extensive resorting operations currently done by the unloading forklift at MS. With stock on wheels, resorting is still possible to some extent, as axles can be picked from the trailers one by one and thus combined into the correct sequence. However, as buffer levels are lower and axles are picked directly from the trailers, it is not possible to do as extensive resorting as today without disturbing the flow.

As the axles already are sorted once at DA keeping the current level of resorting at MS would be a complete waste. By some adjustments in the trailer planning and loading routines at DA, the axles can be delivered in such a way that they can be picked directly from the trailer and transported indoors, either by forklift or by trains and wagons.

With trailers mixed with both front and rear/tag-axles, the flow will be significantly better leveled, thus adhering to the Scania production system principle of leveled production. By keeping the buffer leveled, the content of the buffer and the trailers will better correspond to the demand of the internal customer: the axle pre-assembly. The production of transports will thus be governed by the consumption of axles by the customer and the production sequence, in perfect accordance with both one of the main SPS principles of consumption controlled production, and theories of continuous flow (chapter 5.2.1) and level scheduling (chapter 5.2.3).

As the stock on wheels solution can be adapted to the current loading with only minimal changes schedule at DA, this system is rather easy to implement without needing to reschedule and adapt the transports heading to Zwolle and Anger and will thus have minimal impact on the other Scania PRU:s

With the mixed loads, bus axles can be handled within the same system without requiring the need for extra trailers while at the same time maintaining an acceptable buffer level. This solution is thus in accordance with one of the side objective of this thesis to consider the flow of bus axles.

Since axles are picked directly from trailers, the current need for unloading is eliminated, and thus the position currently performing this task is no longer required. As 45% of this position is currently occupied by truck axles, this means a yearly saving of about SEK 275 000 at a daily takt of 45 chassis. When the volumes increase and more trailers are needed, the alternative cost of keeping the current way of unloading increases, as the UF will gradually have to dedicate a larger portion of its day to handle truck axles and less and less to handle engines, bus axles and prop shafts, thus requiring additional positions to handle these tasks.

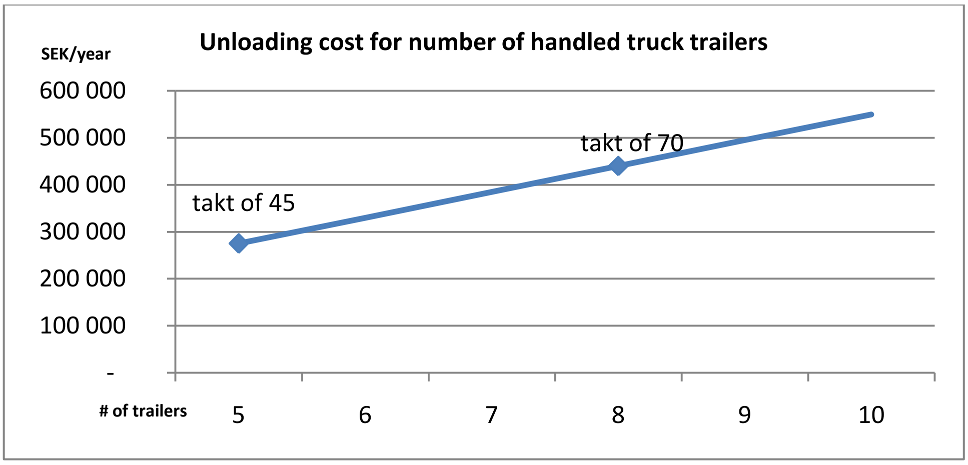

Figure 29: Unloading cost for truck-axle trailers

At a takt of 70, eight trailer loads of truck axles will need to be handled by the UF, representing about 70% of its available working time each day. Combined with the trailers with bus axles, this position will be balanced quite high and will have little possibility to undertake other tasks. The stock on wheels solution would at this volumes save about SEK 440 000 yearly by eliminating the need to handle truck axles as the UF will be available for other tasks.

The space savings constitute one of the major gains in this solution, by shifting to stock on wheels, approximately 600m^2 will become available for other purposes which depending on what the space is used for instead might induce other monetary savings. As space is scarce at MS, and a lot of operations contend over any available surfaces, reduction in space usage should be considered quite advantageous. In the below figure, the space used for the current solution is compared to the future state of using stock on wheels.

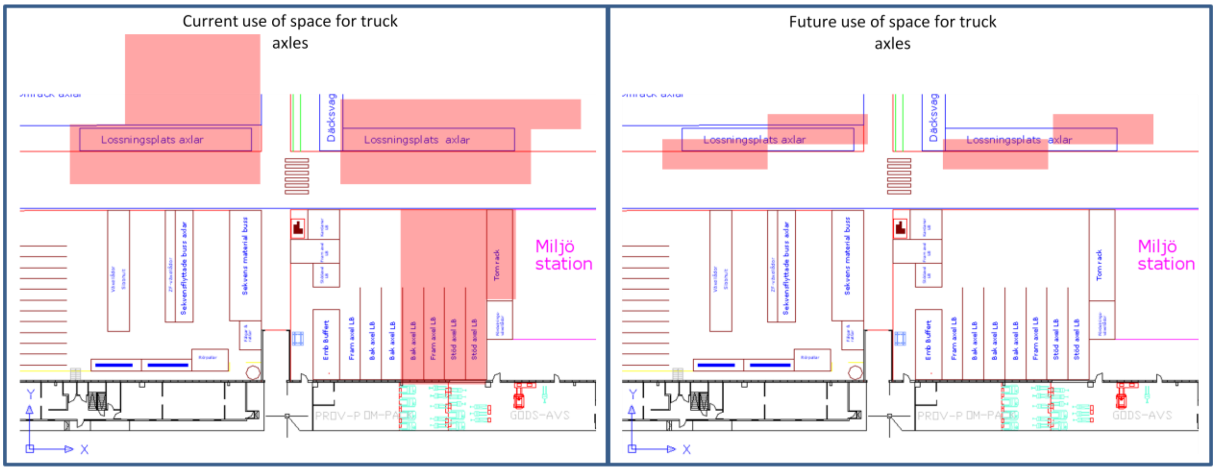

Figure 30: Current and future space usage outside MS

As can be seen, the reduction in space usage is significant, and the road is not obstructed to the same degree by axles being sorted before loaded into the buffer.

9.1.4 Problems

As the stock held at MS will be considerably lower than the current situation, this lowers the flexibility for MS to perform sequence changes as axles are not as easily accessible. In the current system, the planning department has a window of flexibility of half a day or about 4 hours for sequence changes, where a chassis can be removed from the sequence and the queue moved up in order to cover for part shortages or problems. As described in chapter 6.3.2 sequence changes are mostly performed about seven hours before the axles are required at the pre assembly. When using the stock on wheels solution, the axles that are removed from the sequence will not have arrived at MS, but will instead reside somewhere in the sorting area at DA. As these sequence changes does not need to be handled before the axle is to be used, no problem will occur unless the next axles in sequence have not arrived to MS. This means that as the sequence change is about to occur, the axles will most likely be ready and waiting at DA, and any disturbances regarding the axles should be identifiable and can thus be communicated during the continuous contact between the MS planning department and DA. And in the case of late axles, the correct actions can be taken. As the buffer is reduced from the current 430+ minutes to 200 minutes of axles in the outside buffer (current volume), this gives three hours and twenty minutes of average cover time, that combined with the indoor buffer will provide the half a day of flexibility that the planning department needs.

As the volumes increase to 70 vehicles/day, the average buffer cover time will decrease to 124 minutes if the four trailers are used, thus falling below the four hours of flexibility needed. To handle this, either an additional trailer can be used, increasing the average cover time to 180 minutes. The extra trailer will naturally incur more costs, which have to be weighed against accepting the lower cover time allowing for at maximum of 20 chassis being removed from the sequence before the MS buffer run out. With five trailers or 180 minutes of cover time, on average 29 chassis are available in the buffer to handle any sequence changes. Even with only 124 minutes of buffer, any problems that occur at DA should be clearly identifiable before the seven hour sequence change window, as the axles then will be in or just ready from the DA paint shop, and any disturbances related to the manufacturing should already have been communicated to MS.

If an additional trailer is employed, this will require more space outside MS, requiring space currently used by other operations in the area, and incur additional costs of about 15 000 SEK/month in trailer rental costs. However, as bus axles with their current volumes can be handled in a solution with four trailers, any significant increases would require additional transports, which could be handled if the solution is expanded to incorporate five trailers.

In relation to the issues of lowered buffers and sequence changes, a comparison can be made to the current flow of cabs from the Scania cab plant in Oskarshamn. In this flow, MS have a buffer of up to 11 cabs inside the plant and up to 24 additional cabs in trailers outside the plant or in transit from Oskarshamn. Sequence changes are in these cases handled at Oskarshamn and cabs are loaded in the trailers according to the next day's production sequence at MS. As Oskarshamn are about 4 hours drive from Södertälje, this puts some limitations on the changes that can be performed in order for the cab to be in time at the MS assembly line. DA however are located only a few minutes away, and emergency sequence changes can thus in extreme cases be fetched directly from the buffer at DA.

9.1.5 Implications for DA

In chapter 6.2 the current flow at DA is described, and in order to cope with a solution of mixed trailers, some changes need to be performed. Most of these changes are however pure planning issues and should thus not constitute any significant limitations. In regard to the physical implications, the front axles need to be combined with the corresponding rear/tag-axles. Since front axles are produced in better accordance to the final sequence and require less resorting, these can most of the time be placed directly in a sorted sequence, while the rear/tag axles require more extensive sorting. In order to alleviate a bottleneck in their production, DA is about to change the handling of axles in the conveyor system delivering the axles from the DA paint shop to the shipping area, from conveyors separated between front and rear/tag to a system where the first free conveyor is used regardless of axle type.

This causes the sorting to become somewhat more complex. However, this should not affect how well the output corresponds to the delivery sequence, thus it should not increase the level of resorting needed for front axles once the new working method have achieved a normal situation. One issue however is the lack of synchronization between the DA production lines of front and rear/tag-axles. As the rear/tag-axles have stricter mixing rules, there is on average two hours between the first and the last axles destined for a certain trailer arrive at the shipping area, thus requiring one of the sorting spaces until all axles have arrived. If front axles are to be mixed into the same trailer, they should consequently be stacked into the same space before being sorted. Due to the lack of synchronization between the production lines, the axles might need to stay in the sorting area longer, blocking the area for other uses. DA estimates this increased space usage to tie up each sorting space 50% longer on average. However, as the sorting of axles does not disturb the mixing in the production, they should arrive in the same degree of sequence, and the level of sorting/axle and the overall workload of the sorting forklifts at DA should largely remain unchanged.

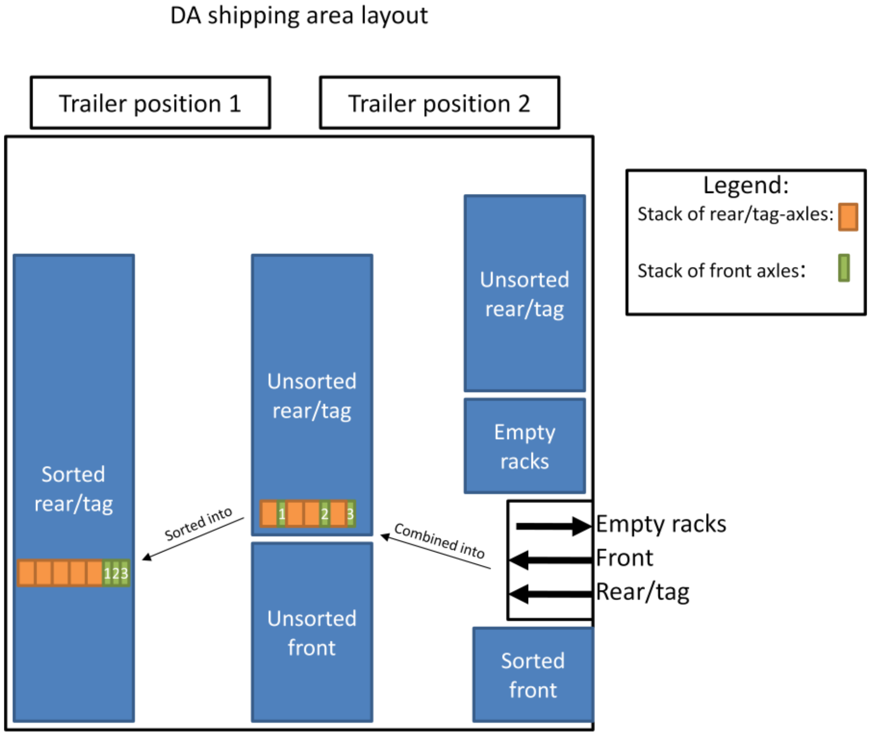

Figure 31: Proposed handling at DA

If the four trailer solution is adapted without the mixing front and rear/tag on the same trailer, little or no changes in handling is required by DA to handle the solution.

9.1.6 Profitability

As the number of trailers are expanded from 2 to 4, the trailer rental cost will increase by SEK 30 000 per month, totaling at SEK 360 000 per year. Cost savings are illustrated in Figure 29, and as explained earlier, at the current volume, savings of SEK 275 000 will be achieved. An additional saving will be that of reduced costs for repairs and service for the forklift, as this cost currently is about SEK 100 000 yearly. The handling of axles by far put the most strain on the forklift, and if 80% of this cost is divided between bus and truck axles, this gives a yearly saving of almost SEK 57 000 if the need to handle truck axles is eliminated.

Hence, in pure monetary terms, this system is not profitable at the current volumes, and an increased cost of around SEK 28 000 yearly is to be expected.

As the volume increases, and the number of transports with truck axles need to be increased, the solution becomes profitable at a takt around 50 produced vehicles per day, as the volumes of axles will be too high to handle in five shipments per day. The increased number of shipments will thus raise the cost of unloading and savings of avoiding this operation increases.

At a takt of 70, as is the target for the future state, cost savings in avoiding the unloading will be SEK 530 000 resulting in a yearly saving of SEK 170 000.

	Takt	45	70
Savings:			
	Forklift position	275 000	440 000
	Forklift repair	57 000	90 000
Cost:			
	Trailer rental	360 000	360 000
Payoff/ year:		**- 28 000**	**170 000**

In pure monetary savings, this solution is not profitable with the current volumes as increased trailer rental costs exceed the savings in reduced unloading activities. But as the volumes increase, so will the monetary profitability. However, as about 600m^2 will be made available outside MS that can be utilized for other operations and because the potential gains in using this space for other purposes is hard to quantify, the gains of the solution is in reality higher. As this solution also creates a much more leveled flow and balanced flow, presented in a more visual way and in better accordance with the true customer demand, the guiding principles of SPS is reflected in a much clearer way in the flow.

9.2 Trains

Considering the dilemmas presented, it seems like many of them could be solved by eliminating the forklifts and implementing a train based supply system utilizing one or several wagons connected to a pulling vehicle. One of the most important improvements that come from using trains is the reduction of the excessive handling along the transport. Additionally, the safety issues that arise from using forklifts, such as the limited visibility, risk of dropping axles and the pushing of the axle rows at pre-assembly can be significantly reduced using this type of transportation system. This is all in accordance with the SPS priorities as described in chapter 5.3.

There are two general ways of using trains for axle transportation. One is that a train is used all the way from DA, perhaps with a switch of wagons or puller outside DA for easier plant entry. The other is to keep the trailers used today and to simply use trains to replenish the pre-assembly from there on. One of the main ideas behind the usage of trains all the way from DA is that the sequence is to be set correctly at DA, thereby eliminating the need to re-sort the axles upon arrival at MS. For a single loop solution, as described in chapter 9.2.1, this allows for the train to be driven straight to the pre-assembly without stopping, enabling a leveled and visual flow as preached by the SPS (chapter 5.3). For the double loop solution (chapter 9.2.2), which still needs the unloading forklift, this will reduce the handling and allow for a direct reloading onto wagons.

In both cases of using only trains, the outside buffer at MS will be eliminated, forcing hidden problems to surface earlier and making the flow more visually manageable. Excessive inventory is a generic waste (chapter 5.1.1) and the elimination of buffers not only lowers the water level of the metaphorical lake described in chapter 5.2.1, but it also frees up space for other purposes. The elimination of the outside buffer makes about 650 m^2 outside MS available for other purposes.

An important factor that separates a train solution from the currently used forklift solution for transportation to the pre-assembly is that a wagon solution to a further extent represents consumption controlled production as specified by SPS in chapter 5.3. The reason for this is that the train sets at pre-assembly form a sort of kanban-system, where replenishment commences when a train set is consumed and the empty set acts as an indication that replenishment is needed.

At the pre-assembly, a train system will eliminate the need for the present activity of pushing the row of racks on the floor, which is unsafe, cause noise and risk damaging the forks of the forklift. For the PAF, a train system might enable a more efficient picking of small racks as they, depending on the design of the wagons, could present the racks the right way, eliminating the need to turn the racks 180^{o} before feeding the pre-assembly conveyors.

When considering a train solution, it's very important to keep in mind the way that the axles are loaded onto the train wagons. Because the axles need to be unloaded in an efficient way at the pre-assembly, it's beneficial to have them placed in such a way that the PAF can easily reach them from the side of the wagon. Unfortunately, this isn't the most efficient way to stack them considering the fill rate of the wagons. A decision therefore has to be made whether to prioritize either the ability to handle the axles easily, or a fill rate on the wagons. All solutions presented will include wagons that are loaded in such a way that the PAF can easily reach them from the side of the wagons. This isn't the most efficient way of loading with respect to fill-rate, but it will significantly facilitate the unloading at pre-assembly, a task that otherwise would not be manageable for the single PAF at a production rate of 70 trucks per day.

Unloading the wagons from the side is very space consuming and it's therefore important to consider how to place the wagons at the pre-assembly. Firstly they must be placed in such a way that the PAF can transport unloaded axles to the conveyors without being hindered by parked trains. Secondly, the trains must be able to be transported away from the pre-assembly area when empty. Because of the limited space surrounding the pre-assembly buffer area, the idea is that the wagons shall be able to be pulled in both directions, thus returning the same way they came in. The tractor pulling the trains will detach, use the route showed in Figure 32, and attach an empty set for return to its assigned loading space.

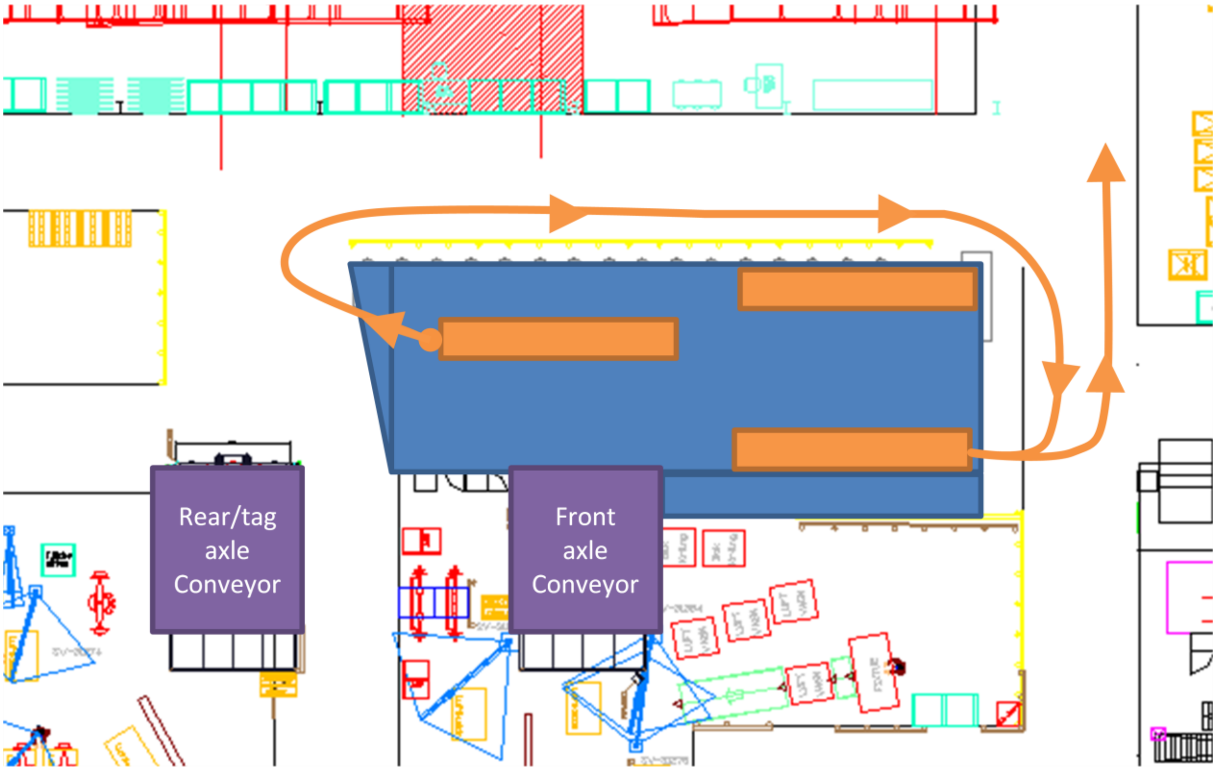

Figure 32: Tractor route, train drop off/pickup at pre-assembly

Although the lowering of buffer levels is in accordance with the lean principles, it's worth noticing that a certain level of inventory is necessary in order to handle material shortages and sequence changes. Implementing a solution utilizing trains will as stated lower that level, but it's important to make sure that it's possible to keep enough inventory at pre-assembly to maintain an adequate buffer level. Otherwise, the assembly line may run the risk of ending up with a material shortage. Also, the axles need to be held in indoor temperature for about an hour to make sure that they thaw to a manageable temperature if outside conditions are unusually cold. This is further complicated by the fact that the buffer at the pre-assembly will be held on wagons, thus taking up more space per axle than is currently the case.

Inside the plant, the train will relieve congestion due to the fact that the train won't have to enter the plant as often as a forklift, which isn't able to carry as many axles per cycle as the train. The safety, a SPS top priority as described in chapter 5.3, will be improved because rather than carrying stacks of axles in front of the carrier, the operators view is unrestricted when carrying axles on wagons behind the tractor. Additionally, the risk of dropping the axles is significantly reduced, due to the reduced number of handlings by forklift.

9.2.1 Single loop solution

In this section, a closer look is taken at the specific implications of using a single loop, i.e. using a train to transport the axles from DA to MS without stops or reloading in between the two end stations. Because space utilization and the ability to move within the pre-assembly buffer is of importance, suggestions for how to place the trains at the pre-assembly will accompany each specific train suggestion, in the form of a map of the buffer area and the suggested placement of the trains.

A single loop system relies on a single train performing the entire trip from DA to the MS pre assembly without stopping for re- or unloading on the way. There are visible implications of using such a system throughout the chain. Starting at DA, loading will be radically different from what it is at the moment, with smaller load bearers arriving more frequently. Estimates by the production supervisor at the DA shipping department, rate such a solution to be possible to handle alongside the regular flow without too much interference with the normal operations. In fact, it's even been said that it would be beneficial for the shipping department at DA to be able to load MS's axles in this manner, separate from other PRU's axles. At MS, no re- or unloading will be done until the wagons are stationary at the pre assembly. The train will be unloaded by the PAF and the sets of wagons that have been unloaded and filled with empty racks are then transported back to DA.

Current state

Using trains in this way will eliminate the positions of trailer transport, unloading/sorting at MS, as well as the transporting inside MS and replace them with the single position of a train transport. At the moment, the trailer transport of truck axles represent 0,7 positions and two trailers. The unloading/sorting consists of a forklift taking up 0,45 positions whereas the transporting forklift (TF) at the moment represent one whole position. In total, this is 2,1 positions that can potentially be eliminated by using this form of transportation. If replaced by one single position driving the train, 1,1 positions stands to be saved with this approach.

120 axles are currently transported each day. How many roundtrips per day that translates into for the train transport depend on the type of wagons used on the train and the frequency with which the axles will arrive at MS. This will be further looked into later.

For the bus axles, a system of using wagons is very hard to implement due to the limited space available at the bus pre-assembly. It is therefore assumed that the bus axles will continue to be transported by trailer and forklift, as is currently the case. A reasonable assumption is that the trailer operator can be put to use somewhere else when not transporting bus axles. If the flows of bus axles are to be incorporated in a system using wagons for truck axles, a possible solution is to have the train carry an extra wagon for the bus flow. This wagon can then be detached and left outside MS for the axles to be picked up by forklift.

Future state

When approaching a production rate of 70 trucks or 190 axles handled each day, every position will have to handle 58% more axles. For the trailer transport, this means transporting eight trailers of truck axles to MS per day, given a linear increase in workload as the volumes increase, this would require a little over one whole position for truck axles only. The unloading and sorting, will need more time and under current system this will take up 0,7 positions, whereas the TF will demand 1,5 positions, thus not being able to handle the increased production rate without extra investments. In total, this comes to 3,2 positions, which means that 2,2 positions can be saved if this system were to be implemented with 70 trucks per day being assembled at MS.

Benefits

There are a number of benefits to this system compared to the system currently used. Firstly, like previously explained, a system utilizing only one transporting entity from DA to MS will replace somewhere between 1,1 and 2,2 positions, depending on production rate. In practical terms, it is hard to define the exact consequences without knowing the specifications of the train. These factors will be more precisely defined in the “train types” sections later.

At DA, using trains allows for the loading to take place beside the regular schedule of trailer loading for other European PRU’s. As the production rate increases towards 70 trucks per day, other PRUs served by DA will also increase their production, increasing pressure on the shipping department. Taking some of the pressure off the loading schedule would in such a case be beneficial.

With axles being transported in smaller batches more frequently from DA, a more even and balanced flow is achieved, which corresponds very well with the SPS principles of leveled flow and visual operations as described in chapter 5.3.

At MS, the train would be able to skip the unloading/sorting outside the plant. This will eliminate the buffer storage currently present by the entrance, as well as the spaces used for trailers and trailer unloading, thus freeing up about 650m^2 of buffer storage, including the extra buffers and sorting surfaces. The reduced buffers make for a more visual flow that doesn’t hide inefficiencies to the same extent as the present system of large buffers does; a basic principle of SPS (chapter 5.3)

Problems

A single loop type of solution requires a radically different way of loading axles at DA. The scope of this thesis and the solutions proposed has a limited timeframe of a couple of years before another, more advanced, solution will be put in place. Therefore, it might not be worth interfering too much with the way that DA performs their loading operations, just for them to change them again in a couple of years.

The lower buffer levels at MS means that sequence changes will need to be handled further back in the supply chain. Changes that could previously be handled within the buffer outside MS will with this solution have to be handled at DA, which will be the primary holder of axle inventory after the elimination of a MS buffer. This requires continuous contacts and close collaboration with the shipping department at DA, as more responsibility and work load are put on their operations.

Because of the long way back and forth all the way to DA, cycle times will be longer than if a double loop solution were to be used. This implies smaller margins of error and a bigger risk of shortage at pre-assembly. With the right train system though, the risk of shortage won’t necessarily become real, but during cold weather the axles need to be kept indoors for up to an hour to thaw before being handled. With a lower buffer level, the time spent indoors will be shorter, averaging at about 45 minutes at a takt of 70, as shown under *train alternative.*

Because the trains will be used outside, they will have to be adapted to different weather conditions. This means that a roof and three walls will have to be included in the wagon specifics. Additionally, a sturdier overall construction with more rugged wheels will be necessary, all in all resulting in a more expensive wagon.

A single loop system is hard to adapt to the bus operations. Because of the limited space at the bus line, it is not possible to adapt the same train system to the bus line. It could theoretically be possible to use a train of four wagons from DA, of which one wagon is dropped off before entry into MS and subsequently unloaded by forklift. This would leave the train with three wagons carrying truck axles, forcing a cycle time that would be hard to keep up with. Otherwise, the only feasible solution would be to keep the trailers coming like they do today, but only for the bus axles. In such a case, a secondary assignment would have to be given to the truck driver, who would otherwise be very under balanced.

Train alternative

Based on the limitations in buffer space, in-plant transportation restrictions and required train size for replenishment, a single train suggestion has been produced. In total, there will be four train sets traveling the route, with a single tractor to perform the pulling. There will always be one wagon set stationary for loading at DA, meaning that the tractor can simply leave a set of empty wagons and pick up a full set, thereby minimizing waste of waiting (chapter 5.1.1). Also, it leaves the loading forklift at DA free to load during a longer period of time instead of having to load exactly when the train arrives.

The trains intended for the purpose are made up of four wagons carrying four axles each. Since these trains are supposed to be used for the entire transport from DA to MS, they need to be weather proofed and equipped with rugged wheels. The cover time below includes the axles that are held in the conveyor, as does the average buffer.

	Per wagon	Per train
Width	1,4 m	1,4 m
Length	2,5	11,5
Capacity	2 axles	8 axles
Cost	SEK 100 000	SEK 400 000
	45trucks/day	**70trucks/day**
Cycle time:	<25 min	<16 min
Cover time:	67 minutes	45 minutes
Average buffer:	18 axles	-
# of trains:	4	-

Figure 33: Proposed layout at pre-assembly buffer, trains of 6 axles

With a cycle time of 16 minutes at 85% balancing, this type of train would stand fit with one single position handling the transportation of axles back and forth between DA and MS. On the other hand, as can be seen in Figure 33, the trains will barely fit in the allotted space at MS, making them hard to handle within the pre-assembly buffer. In effect, using trains of this size will require extra space to be possessed at the buffer. In addition, they will take up quite a bit of space in the factory during transportation.

+ Rarely enters MS (congestion)
+ Financially profitable

- Holds few axles in buffer
- Barely fits at pre-assembly
- Large for in-plant transportation

Profitability

The following is a profitability analysis for the alternative presented, i.e. a single loop of four trains of four wagons each.

The solution eliminates the unloading and transporting forklift positions as well as the trailers currently used. Included under forklift positions savings are forklift rental, employee cost and average repair costs. On the other hand, additional work for a loading forklift at DA has been subtracted from those savings. Savings are calculated for truck axles only, disregarding bus axles. Financial implications are calculated for a takt of 45 and 70 trucks respectively. Wagon costs are fixed costs derived from quotes from wagon manufacturer, while the rest are variable costs derived from equipment rental/repair- and employee costs.

Four trains of four wagons each.

	Takt	45	70
Savings:			
	Trailers:	1263000	1984000
	Transp. forklift:	550 000	875 000
	Unloading. Forklift:	225 000	400000
	Forklift repair	207 000	315 000
Cost:			
	Wagons:	1200000	1200000
	Tractor:	550 000	550 000
	DA position:	275 000	430 000
Payoff time:		**0,85 years**	**0,46 years**

9.2.2 Double loop solution

The above described train solutions assume that a single transport will be used the entire way from DA to the MS pre-assembly. An alternative approach to the train solution is to utilize two separate routs, one going from DA to the reloading zone of MS, from where a new separate route would be used. Considering the different characteristics of the two individual parts of the total route, it could be beneficial to use specialized modes of transport for the two sections of the transport.

There are two main ways of conducting a double loop. The first is to use trailers coming in from DA to be unloaded onto trains at MS. This option will be introduced and analyzed first. A second option is to use specially designed trains from DA to MS, where the axles are shifted to another type of trains, which are more adapted to moving about within the factory. The additional implications of this option will be discussed at the end of this chapter.

Using trailers from DA would put less stress on the shipping department at DA, since it’s possible to use similar ways of loading compared to what is currently used while still feeding the pre-assembly with alternate solutions. How the actual trailer transport can be designed is discussed further in chapter 9.1. In effect, what is done is that the transporting forklift is exchanged for a train going between the trailer unloading forklift and the pre-assembly.

If trailers were to be used for the first part of the transportation, little additional adaptations would be necessary for the bus line to be able to use the system. In fact, a similar system to the current one, with forklifts collecting axles from the trailers for further transportation to pre-assembly could be used. Depending on the type of trailer solution used, and the level of sequencing, the forklifts may either collect and transport axles directly from trailer, or collect and resort before plant entrance. An alternate solution to the trailer transport is discussed in chapter 9.1.

Current state

Using trains will induce fewer cycles per day, since more axles are carried each cycle. This will lead to less traffic within the factory, decreasing safety risks as well as congestion. Of course, the number of cycles performed every day depends on the size of the train and the number of axles that can be carried each time. For a train taking six axles, one cycle would take twice as long as the present required cycle time, i.e. 22 minutes, thus drastically reducing the number of transports needed within the factory.

Since the axles still arrive in trailers, the bus axles will be able to be handled in the same manner as is currently the case, thus avoiding the dilemma of fitting train wagons in the significantly smaller space at the bus pre-assembly.

Future state

At a production rate of 70 trucks per day, 190 axles would be handled. As one forklift manages a maximum of 150 axles, the current usage of a single forklift for in-plant transportation will not be able to satisfy the increased demand from pre assembly. If trains were not to be used, a second forklift would have to be introduced, meaning that a usage of trains at this stage of transportation saves one position. In the light of the “two forklift-alternative”, the train solution will decrease congestion within MS significantly, being able to carry more axles in one cycle compared to a forklift. How many more depends, of course, on the type of train selected.

Benefits

Compared to the single loop solution, a double loop with trailers coming from DA will not impact the way that DA handle their shipping as much. Trailers will still be used, and provided the axles are handled as described in chapter 9.1, the current slot times can be kept more or less as is. Considering the fact the solution proposed is of a temporary nature, as stated earlier, one could argue that there is a purpose in not intervening too much with current processes at DA.

In the double loop solution, the train will not have to transport the axles more than the 150 meters from the outside buffer to the pre assembly, incurring radically shorter cycle times. This is beneficial for several reasons. Firstly, the supply of axles to the pre-assembly will be more robust to disruptions than in the case with a longer transport and separate loading at DA. There will be larger margins for errors and disturbances, as larger safety margins can be used with the same sized trains due to the shorter route. As the wagons are smaller and carry fewer axles, they better correspond to the customer consumption and are closer to the ideal one-piece flow. Because the axles need to be kept inside for about an hour before being used at the pre-assembly, minimizing the buffer is not recommendable.

Another way that the shorter route is beneficial is that it is confined inside the MS plant, with only shorter stints outside for loading before returning inside. Because of this, the wagons won't have to be as weather proofed as they would have to be, had they taken the route from DA to MS, thus making for a cheaper and potentially smaller, roofless version of the wagons.

Problems

In comparison with the single loop solution, not as many positions can be saved because of the retained need for trailer transports and trailer unloading. Total savings will not be very large, if any at all, considering the potentially rising cost of the four trailer system discussed in chapter 9.1. Also, since forklifts will still be used outside the factory, the safety aspect comes into play more with a double loop solution. Safety of course being a top priority of SPS (chapter 5.3)

Because of the short route used, the train will not need to spend as much time traveling as in a single loop system, provided a similar train size. For the train to be fully balanced at a production rate of 70 trucks per day, it would have to take a minimum of two axles at a time. Because of the space needed for unloading and maneuvering at the pre-assembly and the time the axles need to spend there in order to thaw, this would not be a suitable train size. Rather, a train of at least six axles is desirable, meaning that the train operator will not be fully balanced throughout the day, thus being stuck with an overcapacity and forced waiting times unless other duties can be assigned alongside the axle flow.

9.2.3 Train to MS solution (Double loop)

A double loop system can be achieved without the use of large trailers. The idea is that a large train is to be used for transportation from DA to the door of MS, where the cargo is lifted off the train and taken to the pre-assembly by another more nimble and specialized vehicle. One option is to combine this type of solution with the above described train solution for indoor transportation. The result of such an approach would be that some of the benefits from the two separate systems can be combined into one solution. One should keep in mind though, that also some of the problems with the two ideas will be combined, such as the procurement of two extra sets of trains and the need to reload outside MS.

The large trains would be operated by a dedicated position that has no other responsibilities in addition to the operation of the large trains. Two sets of trains would be sufficient, due to the size of the trains and the required cycle times that arise from it. After wagon drop off, a forklift operator will unload the cargo and perhaps reload it onto smaller trains. This forklift will not be solely dedicated to this activity, but will also handle bus axles, which must be transported by forklift into the factory, as well as other tasks around the area. An estimated 0,4 positions would be dedicated for the unloading of truck axles at this stage.

The main benefit of this solution is the elimination of the costly trailers, as described for the single loop solution. On the other hand, two more trains sets will have to be procured. The train-train solution also enables a combination of some positive aspects of the two above described solutions, such as the possibility to provide a more leveled flow of axles from DA (chapter 5.3), while being nimble enough inside the factory. The specific economic benefits will be more closely examined later in this chapter.

Parallel to this thesis, a project is carried out that is investigating the possibilities for handling an increase in production through more far reaching structural changes. Discussions is being carried out concerning the possibility to use large wagons instead of trailers for outdoor transportation in that solution, which would extend the possible lifespan of the wagons suggested here for use as a means of transportation to MS.

The dilemma of bus axles is fairly easy to escape in a double loop system with large train wagons going between DA and MS. When the train is parked outside MS for reloading, a forklift can easily unload bus axles and thereafter transport them in to the bus pre-assembly in the same manner as is currently the case. With the large trains able to take 16 axles at a time, they will have no problem being able to carry the bus axles and the truck axles simultaneously.

Train types

Trains for internal loop at MS:

These trains are supposed to be used solely for the indoor transportation at MS. The most suitable train type for this kind of assignment is three trains of three wagons, carrying two axles each. This is drawn from a combination of the size of the pre-assembly buffer, the maneuverability of the train and the axles needed to be held at the pre-assembly. The cover time below includes the axles that are held in the conveyor, as does the average buffer.

	Per wagon	Per train
Width	1,4 m	1,4 m
Length	2,5	8,5
Capacity	2 axles	6 axles
Cost	SEK 50 000	SEK 150 000
	45trucks/day	**70trucks/day**
Cycle time:	<19 min	<12 min
Cover time:	56 min	36 min
Average buffer:	15 axles	-
# of trains:	3	-

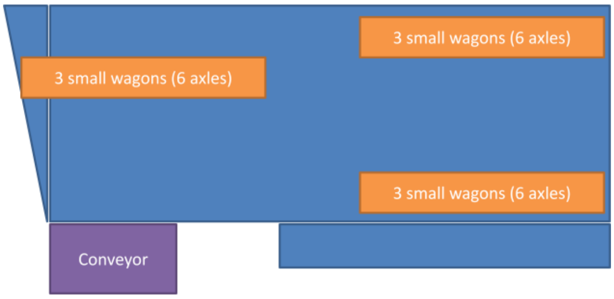

Figure 34: Proposed layout at pre-assembly buffer, trains of 6 axles

This is the same sized wagons as described under single loop, although the train is shorter. There are a couple of differences in wagons though. Firstly, since this train is meant to be used indoors with only shorter stints outside for reloading, the wagons don't have to be weather proofed. This means that they won't need a roof or walls and can make do with less rugged wheels, thus lowering the cost. As previously described, this train will fit nicely into the space at pre-assembly, and because of the shorter route used, it will be easier to replenish the buffer without running out of stock.

Trains for outer loop between DA and MS:

Since these trains are meant to be used solely for the purpose of transporting axles between DA and MS, without entering any of the two facilities, it is of a sturdier construction. Each wagon is also a lot larger, namely able to carry four times as many axles (eight). Each train takes two wagons, i.e. sixteen axles. One position will be used for moving the wagons between the facilities, using an empty wagon set at MS as an indicator for when to return to DA for reloading. Even though carrying both truck- and bus axles is an opportunity, calculations have been made solely for truck axles.

	Per wagon	**Per train**
Width	2,5 m	2,5 m
Length	5,5 m	12,5 m
Capacity	8 axles	16 axles
Cost	190 000	380 000
	45trucks/day	**70trucks/day**
Cycle time:	<50 min	<32 min
Cover time:	59 minutes	38 minutes
Average buffer:	-	12 axles
# of trains:	-	4

No more than two trains will be necessary, because of the large amount of time available per cycle. The reason for the size of the trains is that some buffer outside MS is desirable. One position might be able to supply MS with just one such wagon, the flow would be uncertain though, so using two wagons on each train is recommendable for the system to robust. Also, if the trains are to be used for bus axles as well, cycle- and cover times will be reduced, thus demanding a large load bearer.

Because the train is unloaded outside with lots of room, the forklift can unload the wagons from both sides, not having to worry about reaching out far to lift any of the axles. Unless combined with the trains described above, this solution will not handle the issues of forklift traffic within the factory of MS. It’s thus recommendable to implement both. Of course, this results in a different profitability and payoff period.

Profitability

This profitability analysis takes into consideration the double loop alternatives of using trailers to MS for further transportation by a train of three small wagons and, secondly, switching the trailers for large wagons as described in alternative 2 above.

Monetary savings aren’t as large for a double loop system as for a single loop, due to the fact that more positions will be needed for transporting and reloading. There are other benefits though, like the facilitated buffer replenishment and the smaller interventions into DA procedures. Like before, included under forklift positions savings are forklift rental, employee cost and average yearly repair costs. Savings are calculated for truck axles only, disregarding bus axles. Financial implications are calculated for a takt of 45 and 70 trucks respectively. Wagon costs are fixed costs derived from quotes offered by wagon manufacturers, while the rest are variable costs derived from equipment rental/repair- and employee costs.

Inner loop wagon solution, unchanged outer loop.

Current trailer system to MS, three trains of three wagons each to pre-assembly.

	Takt	45	70
Savings:			
	Transporting forklift:	550 000	825 000
	Forklift repair:	150 000	225 000
Cost:			
	Wagons:	450000	450000
	Tractor:	550 000	550 000
	Unloading forklift:	110 000	150000
Payoff time:		**11,3 years**	**1,3 years**

Outer loop wagon solution, unchanged inner loop:

Two large trains of two wagons each to MS. Forklifts inside MS.

	Takt	45	70
Savings:			
	Trailers	1260000	1 980 000
Cost:			
	Wagons:	760 000	760 000
	Tractor:	550 000	550 000
	DA position:	165 000	258 000
Payoff time:		**1,39 years**	**0,65 years**

Outer loop wagon solution, inner loop wagon solution:

Two large trains of two wagons each to MS. Three trains of three wagons each to pre-assembly.

	Takt	45	70
Savings:	trailer:	1263000	1984000
	Transp. forklift:	550000	875000
	Unloading forklift:	150000	275000
	forklift repair:	150000	225 000
Cost:			
	Wagons:	1 210 000	1 210 000
	Tractor:	1 100 000	1 100 000
	DA position:	165000	258000
Payoff time:		**1,43 years**	**0,60 years**

Outer loop four trailers, inner loop wagon solution:

Four trailers to MS, as described in chapter 9.1. Three trains of three wagons each to pre-assembly.

	Takt	45	70
Savings:			
	Transporting forklift:	550000	875000
	Unloading forklift:	275 000	440 000
	Forklift repair:	207 000	315 000
Cost:			
	Wagons	450000	450000
	Trailer rental	360 000	360 000
	Tractor:	550 000	550 000
	Unloading forklift:	110 000	150 000
Payoff time:		**37,5 years**	**0,8 years**

10 Conclusions

During this chapter, the presented solutions will be compared and related to the purpose of this thesis and the priorities of the Scania production system. The intent is not to present a recommendation of an ideal flow, but rather a support for evaluating the merits of each solution for Scania in order to decide the path for the future.

The reason for this thesis is that Scania needs a solution to the question of how to adapt the axle handling to an increase in production from the current 45 trucks per day to a future volume of 70 trucks per day. This question has been broken down into a number of sub-questions and criteria. The aim of the thesis has been to present solutions that address each of these sub-questions. As described in the introduction (chapter 2.1), the purpose was as follows:

> Analyze and improve the flow of truck axles from the axle manufacturing plant to the axle pre assembly under existing structural conditions.

Additionally, these objectives were added:

- Analyze lead times, buffer storage levels, information flows, transport solutions and handling in the axle flow.
- Deliver suggestions of alternate solutions of flows between the axle manufacturing shipping department and the chassis manufacturing axle pre-assembly.
- Minimize and preferably eliminate the buffer of axles in the chassis assembly plant.
- Minimize and preferably eliminate the fork lift handling of axles.
- The suggested solution should take into consideration the impact on the flow of bus axles.

As the operations at Scania is governed by the Scania production system (SPS) a secondary aim has been to find solutions that is coherent with the philosophies and guiding principles of SPS. Based on the lean principles, the SPS puts a lot of weight in the theories of levelled, balanced and visual flow as a subset of the normal situation. Four priorities, safety/environment, quality, delivery and economy are identified and ranked according to importance. The theories of SPS are collected and presented in the SPS-house (Figure 35), and have been discussed earlier in chapter 5.3

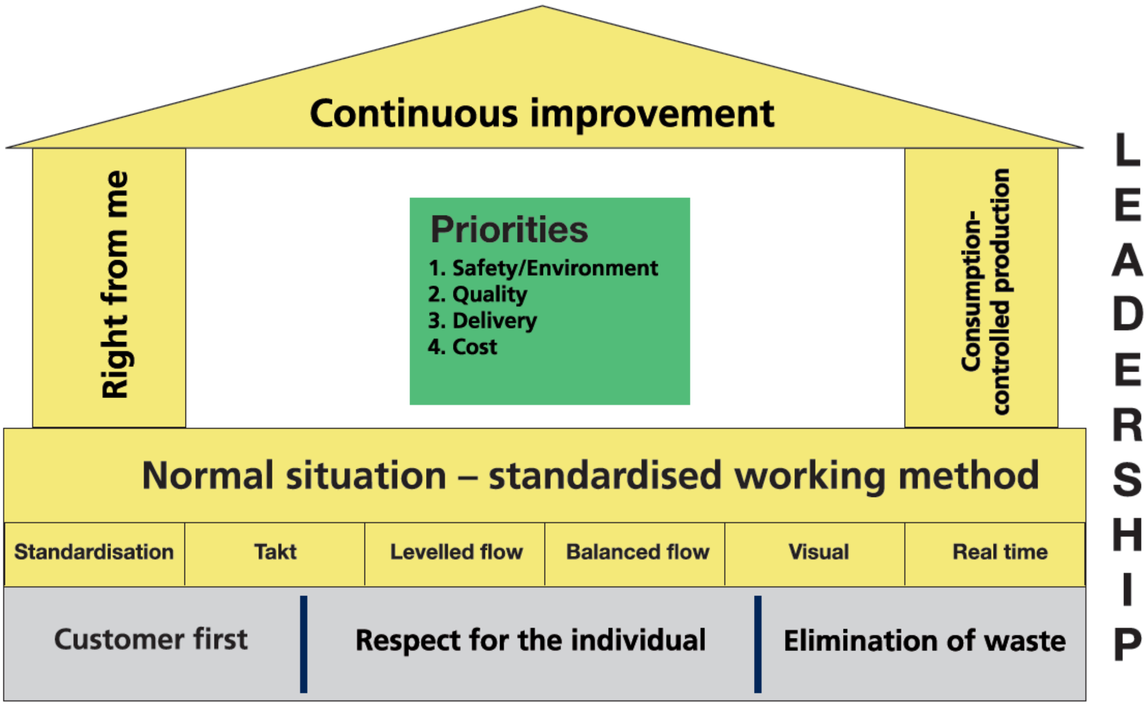

Figure 35: Scania Production System

Two main alternative solutions have been presented in chapter 9, which address large parts of, or even the whole supply chain of the axles from DA to MS. Along with these, a couple of separate solutions which take only single specific issues into account have been presented during the waste analysis in chapter 7. The following are summaries of the solutions, their implications and analysis regarding the relationship to the original objectives as well as to the basic production philosophy of Scania, SPS.

10.1 Single loop train implications

The first major solution presented is the "single loop" solution. This incorporates a single mode of transport all the way from the DA shipping area to the pre-assembly at MS, specifically a number of train sets performing the entire route. The following future state value stream map describes the solution.

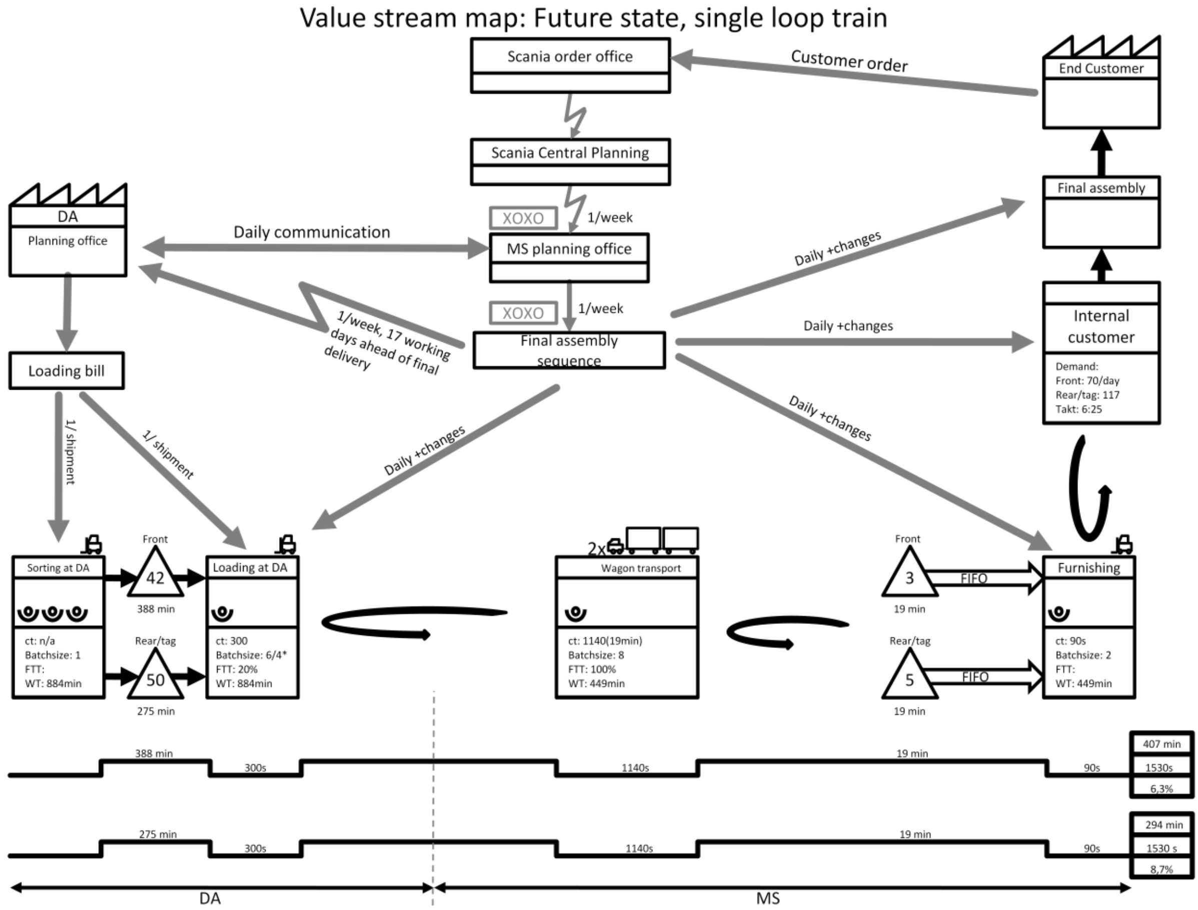

Figure 36: Future state VSM, Single loop

The main benefit of such a solution is the elimination of handling and buffers along the way that it enables. Eliminating the trailers and forklifts from the equation not only makes sense in monetary terms, but also in the more balanced and visual flow it enables. On the other hand, keeping large enough buffers at the pre-assembly present some challenges. Also, the solution is harder to adapt to the handling of bus axles.

As far as the “normal situation” goes, many of its sub-principles are improved in a single loop system. Perhaps the most significant improvement is the leveled flow it enables. Instead of the axles arriving at MS in trailers carrying 28 axles at a time, they will arrive in smaller batches of maximum eight axles per delivery. For the route inside MS though, the flow actually gets less leveled, as the forklifts used today travel more frequently and with fewer axles at a time. Here, the safety and congestion aspects of not entering the plant as often are of higher importance though.

10.1.1 Relation to SPS priorities

Safety/environment

- Because of the reduced handling and forklift use, using a single loop is significantly safer than the current system.

Quality

- Although arriving at the pre-assembly in larger batches, the transports to MS will be more leveled due to the elimination of large trailer transports.
- Front- and rear/tag axles in same delivery levels the flow and raises buffer cover time.
- Flow is more visual.
- Consumption controlled production through empty trains acting as kanban-signals.

Delivery

- Lower inside buffer and no outside buffer means sequence changes have to be handled at DA.
- Fewer handlings and shorter lead-time from DA.
- Hard to adapt to bus flow.
- Changed loading routines at DA required.

Economy

- Reduction of forklift/trailer positions gives payoff time of 0,9 years at a takt of 45 and 0,5 years at a takt of 70.
- Frees up 650 m^2 of buffer space outside MS.

10.1.2 Relation to Purpose

The purpose clearly states a couple of specific desirable outcomes of the solution. The most prominent of these are the eliminations of buffers and forklift handling at MS. This solution is by comparison the one that best suits these criteria.

The buffers outside MS are completely eliminated, leaving significant spaces for other operations to use. Additionally, the buffer at the pre-assembly will be significantly reduced. In actuality, what this means is that the buffer previously held at MS will now for the most part be held and handled by DA. This will require additional resources and space at the DA shipping department, a problem that needs to be handled if a single loop is to be implemented. Also, since the levels required for this solution will not leave enough axles in buffer for the axles to thaw in case of unusually cold weather.

Because the train will be able to go all the way from DA to the pre-assembly without intermissions, no forklifts will have to be used between the one loading at DA and the one offloading at the pre-assembly. In total, 1.45 forklift positions will be saved at a takt of 45 trucks/day and approximately 2,5 positions at a takt of 70 trucks/day.

Another important aspect is the impact on the flow of bus axles that this form of solution implies. The train would have a hard time serving the bus assembly line without failing it's duties to the truck pre-assembly. Therefore, an external solution would have to be employed for the transportation of bus axles. It would be possible to keep the bus axles coming the way they've done before, although that would result in a much underutilized trailer operator unless other duties could be assigned to that position.

10.2 Double loop implications

A second alternative is the double loop solution. In this thesis, two different ways of performing a double loop solution are discussed, either with two trains or with trailers and a train, both shifting from a larger to a smaller load bearer at MS.

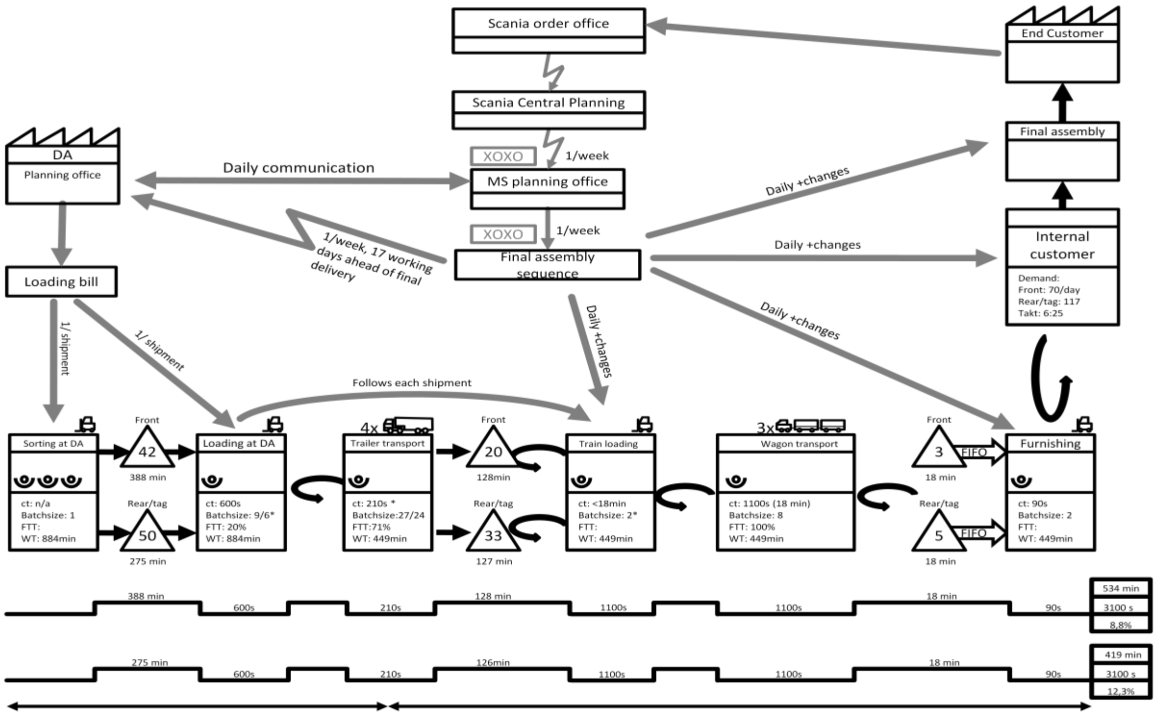

Figure 37: Future state VSM, Double loop

The benefit of using a double loop system is that it is possible to use a more adapted solution at each stage of the transport. With the two routes divided and the final transportation to pre-assembly much shorter, the delivery reliability will be higher. If a double loop solution with trailers is employed, fewer changes in loading routines have to be performed at DA, thus creating an easier transition to the new way of working.

With buffers decreasing, the flow will become more visual and wastes will be harder to hide within the system. Not as many positions can be saved though as in a single loop because there will be a need for two train/trailer operators, as well as a forklift shifting the goods from one load bearer to the next.

In order to provide a clear image, the different parts of a double loop solution will be examined one by one. Firstly the alternatives for the outer loop will be discussed, comparing the four trailer solution to the usage of wagons. This discussion will then be followed by an analysis of the inner loop with smaller wagons.

10.2.1 Inner loop trains

This solution discusses the possibilities of using trains for in-plant transportation at MS, while maintaining the current trailer solution for transportation between DA and MS.

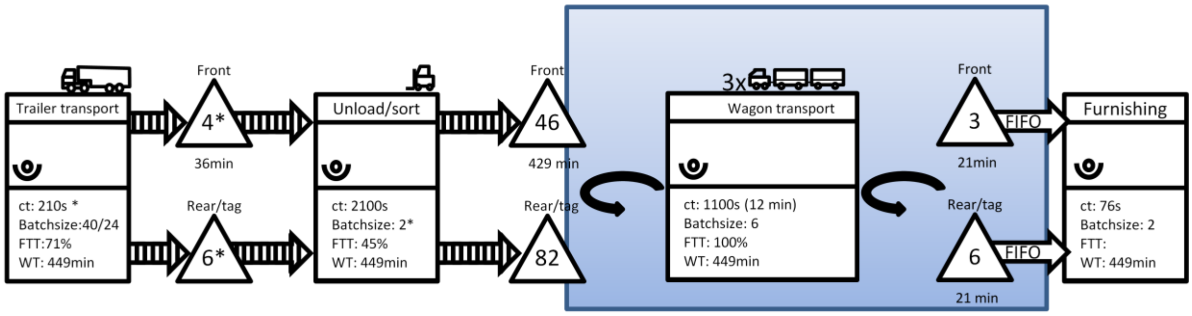

Figure 38: Inner loop wagons

A major benefit of using trains instead of forklifts inside MS is the improved safety, due to the reduced forklift handling. Another benefit is the less frequent entries into MS, which although it produces e less leveled flow, relieves congestion within the factory. At current takt, the wagons will replace a single forklift, but at a takt of 55 the forklift cannot perform the route alone, requiring a second forklift. At that point, the wagon solution becomes significantly more financially beneficial.

A solution like this can easily be implemented without affecting the transportation of bus axles. As the transportation between DA and MS is carried out in an unchanged way, the axles can be taken to the pre-assembly in a similar way as currently as well.

10.2.2 Relation to SPS priorities

Safety/environment

- Elimination of transporting forklift leads to less risk of dropping the axles, while at the same time enhancing forward vision and eliminating the need to push lines of axles at the pre-assembly.
- Less frequent deliveries mean less traffic indoors and safer operations.

Quality

- Front- and rear axles will arrive on the same train, making for more leveled flow and increased buffer time.
- A larger quantity per delivery is step away from one-piece flow.
- Consumption controlled production through empty trains acting as kanban-signals.

Delivery

- Outside buffer allowing for sequence changes in unchanged manner.
- Able to handle bus axles parallel to train loop.
- Inside buffer will be lower, presenting a lowest average buffer time of 35 minutes at a takt of 70.

Economy

- Eliminates need for transporting forklift.
- At a takt of 45, wagons will take 11 years to break even. At a takt of 70, it takes 1,3 years.

10.2.3 Outer loop trains

Outer loop trains incorporate two sets of two large wagons each, being transported between DA and MS, thus replacing the current trailer transport.

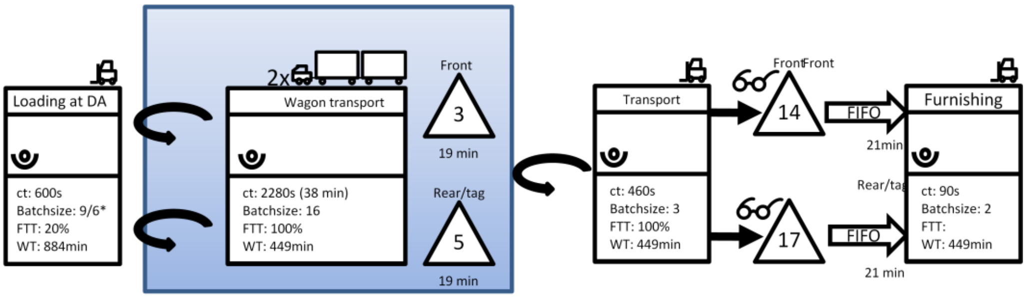

Figure 39: Outer loop wagons

By using wagons from DA to MS, the costly trailers won't have to be used, making for a fairly short payback period. Using wagons will also provide a more leveled flow from DA with significantly reduced buffers outside MS. Provided the trains are used as sole outside buffer at MS, about 650 m^2 will be saved for other purposes. A larger responsibility for sequence changes will have to be taken by the shipping area at DA, though.

No sorting forklift will be necessary, as the transporting forklift will pick the axles off of the wagons and move them directly to the inside buffer. This type of solution is fairly easy to adapt to the handling of bus axles. A forklift will simply pick the bus axles off of the wagons for further delivery, just as for the truck axles.

10.2.4 Relation to SPS priorities

Safety/environment

- Elimination of the sorting forklift incurs less handling and less risk of dropping the axles.

Quality

- The flow from DA will be more leveled, thus correlating better to the demands of MS.
- Consumption controlled production through empty trains acting as kanban-signals.

Delivery

- Smaller outside buffer of on average 28 minutes at MS means more responsibility for sequence changes will have to be shifted to DA.
- Requires adaption of loading routines at DA, since wagons will load twice as many times as trailers.
- No special adaption required for bus axle delivery.

Economy

- The wagons bought will result in a payback period of 1,4 years at a takt of 45 and 0,7 years at a takt of 70.
- Eliminates need for unloading forklift.
- Frees up 600 m^2 of buffer outside MS.

10.2.5 Four trailers – Stock on wheels

This solution suggests using stock on wheels as suggested in chapter 9.1 as the outer loop delivering the axles from DA to MS.

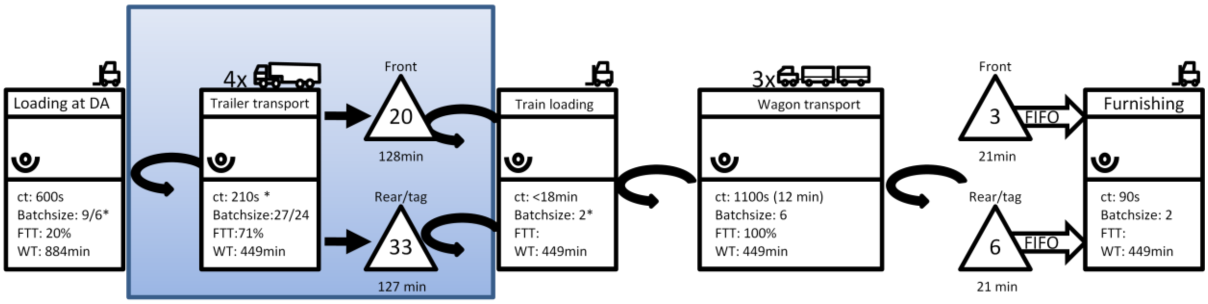

Figure 40: Four trailers - Stock on wheels

One of the major benefits of using such a solution is the reduced size of the outdoor buffer and the roughly 600 m^2 that is made available outside MS. There is also a significant reduction in the need for handling the axles as they reside on the trailers until they are to be transported indoor, hence the risk for mishaps and accidents are reduced.

The solution also leaves room to incorporate the flow of bus axles within normal operations without the need for special handling. As the trailer transports can easily be adapted to the loading schedule at DA, there is also little impact on the transports for Zwolle and Anger. The changed routines of sorting the axles at DA will require some additional space usage, but should not require any extra positions as the level of sorting does not increase compared to the current situation, it only changes in which order to sort the axles.

10.2.6 Relation to SPS priorities

Safety/environment

- Less handling of axles leads to decreased risk of mishaps/accidents. On average 3 less handlings/axle or 5 less handlings/stack due to reduced need for sorting and loading into outside buffer at MS.
- Reduced use of forklifts – less traffic and safer working conditions.

Quality

- More leveled flow better corresponding to customer demand.

Delivery

- Buffer allows for handling of sequence changes at MS, average buffer cover time of 200 minutes at takt of 45, 124 minutes at a takt of 70.

- Can handle bus axles alongside normal operations.
- Does not interfere with DA loading schedule for Zwolle and Anger trailers.

Economy

- Frees up 600 m^2 under MS canopy.
- Requires some additional space at DA due to unsynchronized front and rear/tag axle production.
- Break even at takt of around 50 trucks per day at MS. At a takt of 70, saves SEK 170 000 annually.

10.3 Double loop summary

By changing the outer loop to either a stock on wheels solution with trailers or wagons, the system gains significant improvements. With mixed loads, the axles delivered to MS better correspond to the demand, and the buffer level can thus be lowered while sacrificing less in terms of cover time. The flow is more leveled and the delivered mix of axles corresponds to the final assembly sequence without holding lots of extra inventory. If the outer loop is handled by wagons, the flow is even more leveled due to the smaller batch sizes in each delivery.

The inner loop will, if wagons are utilized, make the flow slightly less leveled as the deliveries occur less frequently with larger batches. But as the safety and environment aspect is the top priority of the SPS, and the reduction of forklift traffic is one of the main objectives of this thesis, this is still a positive tradeoff. By placing the inner buffer on wagons, the dangerous operation of pushing the stacks at pre-assembly can be completely eliminated, thus also increasing safety and decreasing the equipment ware of the forklift during this operation. From a delivery perspective, the wagons are less flexible than the current forklift handling due to the larger batches and longer cycle times. But compared to a single loop solution the double loop have significantly more time to transport, detach and switch train sets and return with a filled train to the pre assembly before the buffer have any chance of running out. Such a system is thus more robust to disturbances as the transported distance in each leg of the transport is shorter.

As with the single loop, the double loop will to a greater extent than the current system represent a consumption-controlled production, as the empty wagons will act as kanban signals for replenishment. This is true for the usage of inner loop wagons, but not for outer loop trailers, which are kept on a schedule. With the first leg on trains as well, the pick-ups can either be scheduled or not, depending on preferable routines at DA.

10.4 Relation to Purpose

As is true for the single loop, a double loop solution would result in a significantly lowered buffer level at MS. Unlike the single loop though, there will be some axles in buffer outside MS, either on trailers when using the four trailer solution described in chapter 9.1, or on wagons. In any case, there would be fewer axles in buffer at MS than it is during current procedures.

In a double loop system, there is a demand for re-/unloading forklifts outside MS. Such a position is estimated to constitute about 0,2 positions at current takt. If an inner train loop is implemented there will be no need for the transporting forklift, which demands a whole position at a takt of 45 and 1,5 positions at a takt of 70.

From a safety/environment perspective, the reduced forklift handlings that the changes imply significantly improve the situation by reducing the risk of accidents and mishaps. The yearly cost of scrapping and repair of dropped axles is close to SEK 700 000 at MS. Any reduction in handling will lower the risk of these costs coming into play.

Because the axles will be held in a buffer outside MS for a period of time before being transported inside to the pre-assembly, the solution is easily adaptable for bus axles. Similar procedures to current ones can be applied, where a separate forklift handles the transportation of bus axles to the bus pre-assembly.

10.5 Summary

As the production volumes of MS are expected to increase, the axle flow needs to be prepared to handle the increased workload. When the volumes increase and the takt gets higher, the current system will run into bottlenecks requiring additional positions and rebalancing of tasks.

As explained in chapter 8, at only a slightly higher takt, an additional transport of axles will be required each day, forcing changes in the DA loading schedule. When the takt reaches about 55 vehicles per day, many of the operations will become overloaded and will not be able to cope with the daily workload without serious risks of disturbances. One such bottleneck is the transporting forklift, which with this workload will have problems keeping up with the consumption rate at the indoor buffer. The unloading operations will also be very highly balanced and will have problems in managing the additional trailers with axles alongside the unloading of engines and prop-shafts. At DA the available slot times will be all filled up and shipments to Zwolle and Anger need to be moved to the afternoon to handle the MS volumes.

With this increased takt and subsequent decreased takt time at the pre-assembly constituting the pacemaker process, the risk of accidents during the repeated handlings of the axles increase as the time constraints get tighter.

The different solutions and their combinations all have different merits and implications, to clarify these, the alternatives have been summarized from a perspective of the priorities of SPS and pros and cons have been presented in the above chapter.

10.6 Suggestions regardless of solution chosen

The presented ideas are all holistic attempts to solve the problems through strategic changes in the way the axles are transported. There are a few specific minor improvements that have been identified as viable regardless of overall solution though, of which the most important ones are presented below.

Rebuilding of the small racks

Redesigning the small racks for front axles so that the forklifts in operation can lift them straight into the pre-assembly conveyors without turning them 180° as described in chapter 7.1. The cost for this is estimated to SEK 200 per rack, or SEK 2 000 000 for all the racks in circulation. In total, it will save

40 hours per year for the TF and PAF together and reduce the total yearly scrapping cost, which currently stands at SEK 700 000.

Switching the transporting forklift

The transporting forklift currently used is able to carry a maximum of three axles without exceeding its maximum capacity. Not being able to carry four limits the delivery capacity of the forklift significantly as well as the stacking efficiency. As long as a forklift is used for the transportation inside MS, it is recommendable to use a larger forklift able to carry four axles at a time. This would improve operations both from delivery efficiency- and a safety point of view, since the forklift currently often carries more than maximum capacity.

10.7 Final conclusions

Throughout this thesis, the flow of axles between DA and MS has been analyzed in detail. Each step in the flow has been investigated and a waste analysis has been conducted in order to identify potential improvement areas and inefficiencies. These inefficiencies have then served as the foundation for the formation of solutions attempting to address these issues in a future state with increased volumes.

The solutions revolve around two separate concepts, either a single loop system transporting the axles in one step from DA to MS using wagons, thus severely reducing handling and lead time; or a set of different double loop solutions using either wagons or trailers for the outer loop, and wagons to supply the pre-assembly with axles the final leg of the flow. The different parts of the double loop solution can naturally be combined in order to improve the flow more than can be achieved at each part of the system. But as each part have merits on its own, it may be beneficial to adapt them one by one and thus achieve a normal situation in one part ironing out initial disturbances and problems before implementing the next step.

From a financial perspective and from an SPS/lean standpoint, the most beneficial solution would be to apply the single loop strategy to the flow in question. It enables a large reduction in the need for personnel and equipment, while facilitating a responsive leveled flow directly controlled by the consumption. However, a double loop solution may be easier to implement as the loops can be implemented one by one as stated above, while being more robust as MS have more stock on hand at any moment.

The basic principle behind the choice of presenting these solutions have, in accordance with the initial purpose, been to reduce the use of forklifts and the number of times each axles is handled in the flow, reduce the buffers in the flow in order to expose problems and creating a more leveled just-in-time flow, while maintaining a system that is feasible in practice and not just in theory.

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12 Interviewed personnel

Anna-Karin Berglund	Manager - Production planning, MS
Bert Larsson	Truckdriver - Axle transports DA-MS
Björn Karlsson	Logistics Engineer, MS
Björn Säfström	Wagon supplier representative, ISAB Södertälje
Charanjit Sing	Logistics Engineer - Sequenced parts, MS
Emil Olsson	Process Engineer- Shipping department, DA
Fredrik Vinsa	Production Planner, MS
Håkan Hallin	Wagon supplier representative, Etebra Maskin och Vagn AB
Ingvar Neby	Delivery Planner, DA
Joacim Erixon	Delivery Planner, DA
Johan Lag	Production Supervisor - Shipping department, DA
Kristoffer Mannerheim	Process Engineer- Axle pre-assembly, MS
Maria Jonefjäll	Process Engineer, Axle Pre-assembly MS
Mats Gustavsson	Forklift operator - Axle unloading, MS

Appendix

Appendix 1: Handlings/axle in current system

Number of handlings, Current state (approximated for average circumstances)

DA

	handlings/axle
lift from finished axle-conveyor into resorting buffer	1
resorting operations (varies greatly)	2
load into trailer	0,25

MS (UF)

lift from trailer to the ground (2-3 axles)	0,50
sort tag into rear	0,5
restack in batches of two	1,5
rotate axles (turn the racks in the correct direction)	0,25
lift into buffer	0,5

MS (TF)

take two axles down from the stack (put on ground)	0,5
take two additional axles down	0,5
pick up the first two axles	0,5

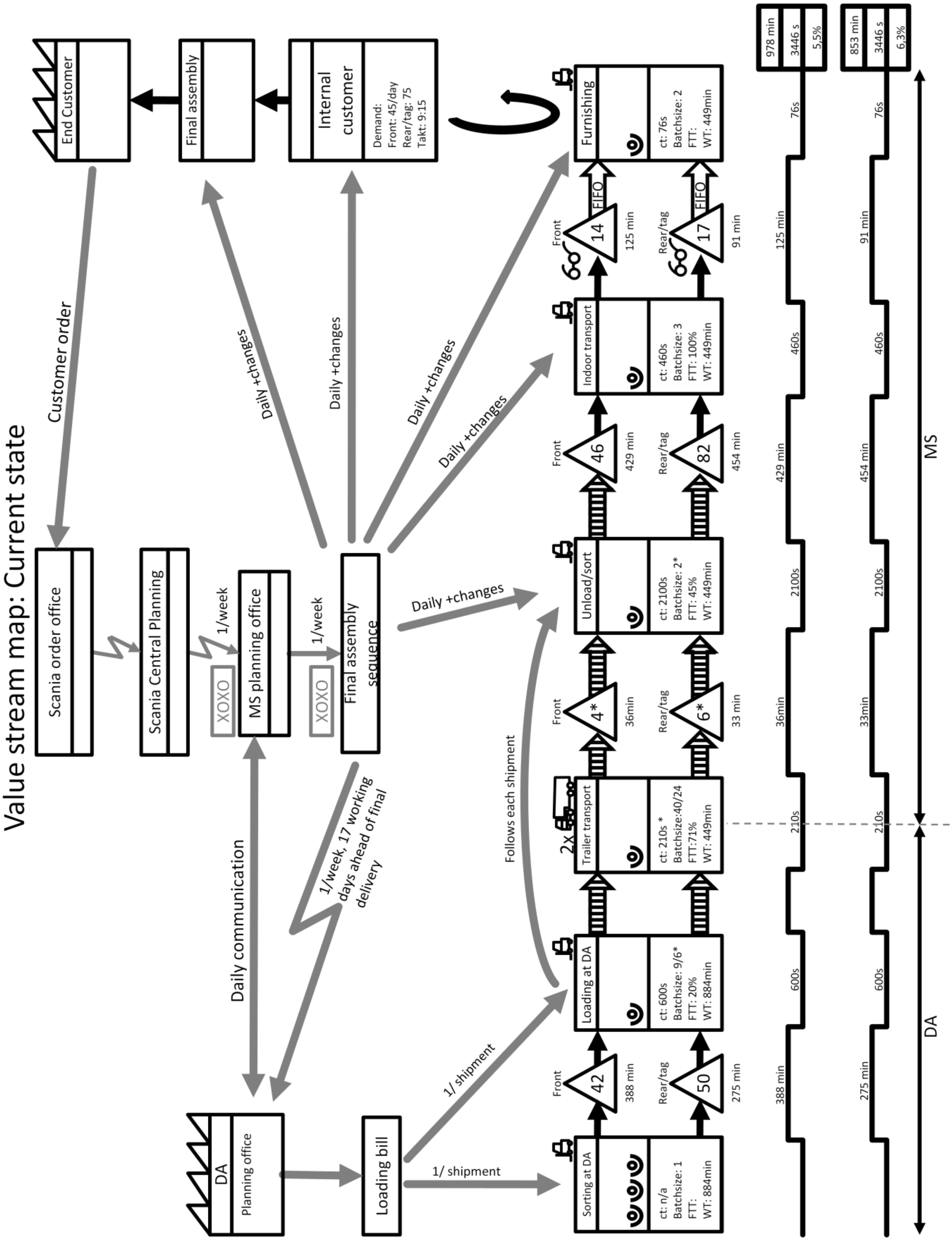
MS (PAF)

lift the stack, put down next to conveyor	0,5
lift the first axle into conveyor	1
lift the second axle into conveyor	1

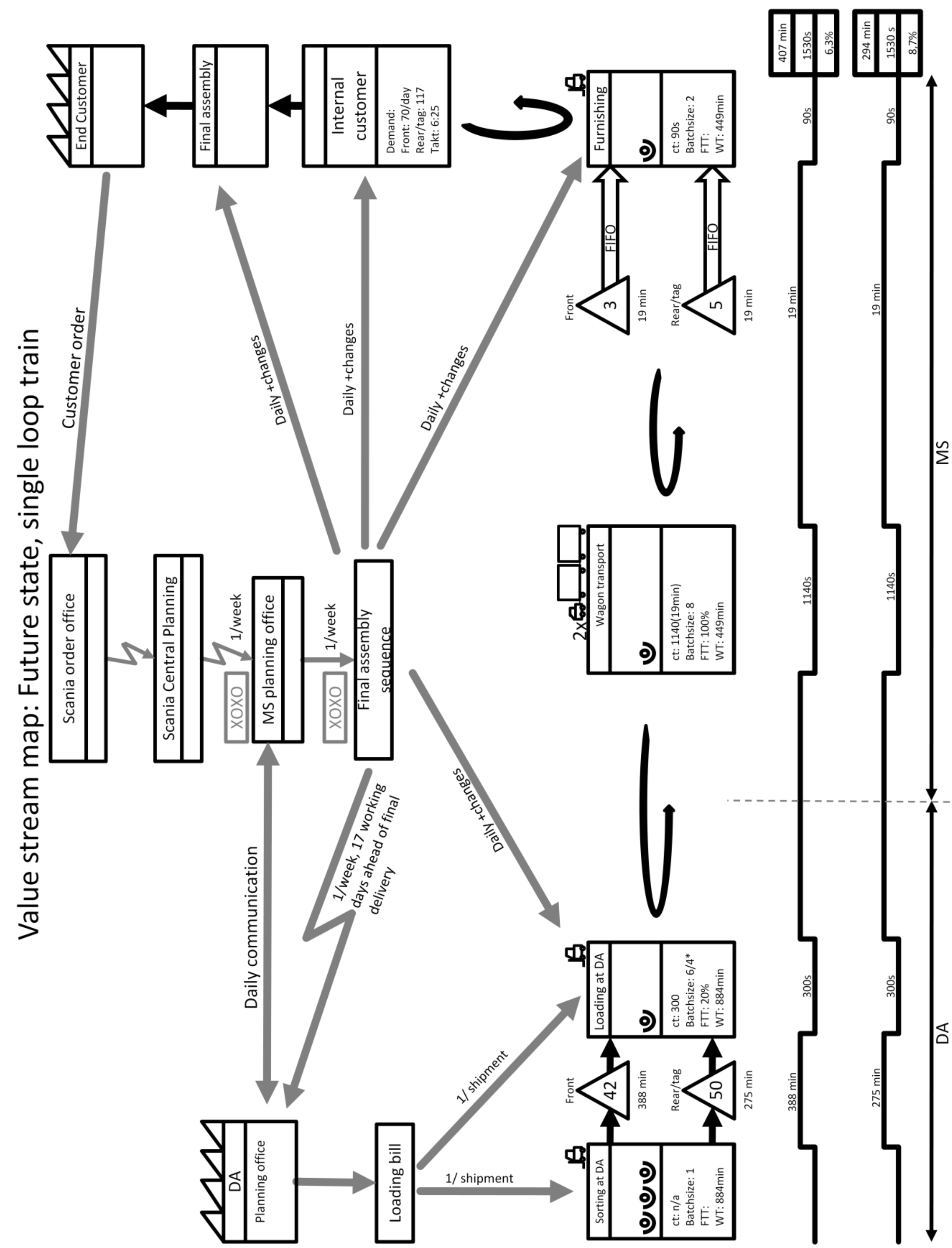
Summary

Total number of handlings/axle	10,5
Total number of lifts/stack	15

Appendix 2 current state VSM



Appendix 3: Future state VSM, Single loop



Appendix 4: Future state VSM, Double loop