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The control of material flow between external warehouses and assembly plants in the material supply to automotive industry

Master's thesis in the Master's Program Production Engineering

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Abstract

In this competitive world, most of the automotive manufacturers focus on updating the production system constantly to satisfy their customer demands. Most of the manufacturing companies found Lean production as a more efficient way of production. Lean production focuses on producing the products with short lead time and throughput time thus delivering the products to the customer in short interval of time.

The thesis is a part of an ongoing research project in Division of Supply and Operations Management, Chalmers University. This study is performed on four different automotive manufacturers in Sweden to analyze how different manufacturers control the flow of material between their warehouses and the assembly plant. Out of four different automotive manufacturers considered, three manufacturers using external warehouse and one manufacturer using warehouse within the assembly plant. To focus the flow of material, in each of the cases pallet flow and box flow has been considered for this study. The Material Flow Map (MFM) for different automotive manufacturers that were created as a part of the previous study is used for this thesis work.

The main purpose of this thesis is to identify how controlling the flow of material from an external warehouse to the assembly line affects the different activities performed which therefore influences the lead time and throughput time. It involves in analyzing the different activities such as handling, administration, transportation, storage and time involved in those activities which affect the lead time and throughput time. The thesis also contrasts the lead time and throughput time between having the warehouse externally and internally.

Our thesis started by identifying the literature for the common factors that affected the lead time and throughput time within the automotive manufacturers. In addition, a plant visit is done to collect the empirical date based on those factors obtained from the literature study requires for this thesis work. Data obtained by means of previous study, literature and plant visit showed us different activities such as handling, administration, transportation and storage are the four main factors that affect the lead time and throughput time. Based on the data obtained, a cross-case analysis has been made to analyze what affects the throughput time and lead time for different manufacturers. The analysis showed the manufacturers with external warehouse store the material for a long time which increases the throughput time greatly when compared to the manufacturer with the internal warehouse. In addition, it increased the handling, administration and transportation activities and time.

As a suggestion to all the manufacturers, having their external warehouse within the company premises and following the principle of Just-In-Time (JIT) purchasing will reduce the overall throughput time and lead time. Use of same administration method by both the supplier and the manufacturer reduces the administration activities within the warehouse and the assembly plant.

Keywords: controlling the material flow, warehouse, lead time, throughput time

Preface

To begin with, we would like to thank Division of Supply and Operations Management for providing us the opportunity to carry out our graduate thesis work in the part of the ongoing research project and providing us an opportunity to enlighten our knowledge in an interesting field to us as a Production Engineers.

We deem it’s our duty to place our sincere admiration and heartfelt gratitude to our Thesis supervisor and examiner Robin Hanson at Chalmers University of Technology, who supported us throughout our thesis work by providing relevant information about the previous study that was carried out earlier and guiding us throughout despite of his busy schedule. Thank you for all the support you have provided.

Moreover, we are grateful to thank the Managers of four different automotive manufacturers for providing us their time and helping us to collect the empirical data required for our thesis work. Their willingness and patience to answer all the question regarding with our thesis work helped us greatly to complete our thesis work. The details provided by them enhanced the knowledge of logistics between the warehouse and assembly plant.

Gothenburg, May 2017
Rajkumar Koppiampatti Rajaguru & Brightson Chamavalappil Mathew

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List of Abbreviations

ERP – Enterprise Resource Planning

FIFO – First In First Out

JIT – Just-In-Time

MFM – Material Flow-mapping Methodology

RFID – Radio Frequency Identification

TPS – Toyota Production System

WIP – Work in Progress

WMS – Warehouse Management System

1. Introduction

This chapter starts with the description of the problems faced by the different automotive manufacturer. The problem background is followed by purpose of this thesis work, scope and delimitations and credibility of this thesis work.

1.1. Problem Background

The choice of inventory levels, supply methods and warehouse location has a great impact on the efficient working of an assembly line (Battini, 2010). The current scenario of manufacturing technology in automotive industry focuses on the principles of mass-customization enabling the customer to decide the specifications of the product (Coletti & Aichner, 2011). To satisfy the customer demands, most of the manufacturers in automotive industry produces multiple automotive products on the same assembly line. According to Bellgran & Säfsten (2010), manufacturing operational activities has been influenced by the customer, as the customers are given the freedom of customizing their product which results in increasing the complexity of the production.

Among the different complexity faced in the production, one complexity is ensuring the efficient and reliable supply of materials to the assembly line. The trend of mass-customization increased the number of parts to be delivered in short planning and delivery cycles from the suppliers (Boysen, 2010). One of the challenges faced by the material supply system is to find the sufficient place to store the different part numbers for custom manufacturing parts that are used for the automotive assembly. Hence the use of external warehouse has come into practice which ensures the space required to store the materials required for the assembly plant as well as increasing the chance of supplying of a wide variety of components to the assembly plant (Hanson et al. 2016). At the same time, the use of external warehouses could also increase the lead time when a need is signalled in the assembly line and there is a delay in a truck delivering the required materials to the assembly plant from the external warehouse (Boysen, 2010).

Lead time is greatly dependent on the positioning buffers and how it is signalled for replenishment. The increase in lead time results in holding a lot of stocks which consumes too much of spaces within the assembly plant. In addition, external warehouses affect the throughput time, stock turnover rates and amount of man hours needed for material handling. In order to have minimum lead time, it is necessary to identify the correct size and position for Work-In-Progress (WIP) inventory buffers required for the assembly line (Lutz et al. 1998). To maintain buffers in the assembly plant, it is necessary to have minimum storage space and allocating those minimum storage space among the buffers to increase the overall output in the assembly line. It is also necessary to replenish the buffer level with proper signalling method to ensure the continuous flow of material in assembly line while considering the delivery frequencies of material to assembly plant from an external warehouse and quantity of material delivered.

Inspired by the method of Toyota Production System (TPS), Just-In-Time (JIT) was the main principle focused by most of the automotive manufactures (Boysen, 2010). Just-In-Time principle might increase the transportation activity which increases the economic cost for the company and pollution in the environment. To ensure the economic and environmental sustainability, the automotive manufacturers focused on transporting different materials required for the assembly plant together in the required quantity ensuring the reduced transportation cost and environmentally sustainable.

According to Farhani et al (2011), Lead time is defined as “the elapsed time from an internal or external customer place an order until it is delivered to its designated place”. The time required to manufacture and deliver goods to the customer should be as low as possible. Hence it is necessary to have Work-In-Progress (WIP) inventory buffers to attain short lead time. According to Johnson (2003), throughput time is defined as “the length of time between the release of an order to the factory floor and its receipt to finished goods inventory or its shipment to the customer”. According to Jonsson and Mattsson (2009), throughput time in material management is defined as “the length of the time from when the material enters a production facility until it exits”. Hence it is necessary to identify suitable buffer location to achieve short lead time and short throughput time.

As the world is changing fast and the customer expectations are high and different, it important to have a short lead time for the company to succeed in the market. And companies require already proven methods to establish a short lead time and lean concept would help in having a short lead time for the process (Locher, 2008).

To achieve short lead time and throughput time, controlling the material flow plays a vital role. The automotive manufacturers control the material flow by replenishing the material to point of use in assembly plant either by delivering the material directly from the external warehouse or having an additional storage point in the assembly plant and delivering from it.

1.2. Purpose

The main purpose of this thesis is to identify how control of material flow from an external warehouse to the assembly line affects the different activities performed which therefore influences the lead time and throughput time. It involves in analysing the different activities such as handling, administration, transportation, storage and time involved in those activities which affect the lead time and throughput time. The thesis also contrasts the lead time and throughput time between having the warehouse externally and internally.

1.3. Scope and Delimitations

The thesis is focused only on controlling the material flow within and between external warehouse and assembly plant. Inbound deliveries from the external suppliers are not in focus. The thesis focusses only for production industries dealing with automotive manufacturers. Production industries with external warehouses are focused to a greater extent and for a reference warehouse within the assembly plant is considered.

1.4. Thesis Outline

The thesis is divided in to different chapters which are briefly described below.

Chapter 1 Introduction describes about the problem faced by the automotive manufactures in storing the materials required for the assembly. It is followed by explaining the purpose of the thesis work.

Chapter 2 Theoretical Framework describes the theoretical approach required for this thesis work. It focusses more on how lean helps in reducing the throughput time and lead time in the material flow.

Chapter 3 Methodology gives clear description about the method used to collect the data in pre-study. In addition, the detailed explanation about how the authors of this thesis work has collected the data required for this thesis work. The chapter also explains how the calculations are made to calculate lead time and throughput time.

Chapter 4 Empirical Findings presents the data collected from four different automotive manufacturers. In each of the case two – three cases of material flow have been explained. Throughput time and lead time for each of the case have been calculated and described.

Chapter 5 Cross-Case Analysis explains the different comparisons made between the four different automotive manufacturers with the data obtained in empirical findings. The chapter provides the clear description of analysis.

Chapter 6 Results gives the clear description of results obtained from the analysis.

Chapter 7 Discussion and Future Studies explains the different suggestions provided to the considered automotive manufacturers to attain short lead time and throughput time. The chapter also describes some proposal how the research work could be taken up further.

2. Theoretical Framework

This chapter describes the theoretical approach of this thesis work. Initially, how controlling the production and logistics will improve the lead time and throughput time has been explained. Later how lean concepts will help in achieving the short lead time and throughput time for the automotive manufacturers has been explained in depth.

2.1. Control of production and logistics

In today's changing world, the idea of large safety stock to balance the high demand uncertainty and varieties is not practical. In Fact, it can lead to high inventory cost and an unstable material flow in the supply chain network. This, in turn, leads to long lead time and makes it hard to make the customer delivery on time. So according to Meissner (2010), the need to have a highly flexible logistics and production system is vital for the industry to survive.

To obtain a predictable or short lead time the automotive manufacturers have been executed the built-to-order strategy which could meet the demands of product variety following the mass customization method. The success factor for this approach is the logistical ability to deliver the necessary components of different variant just-in-time and also to manage the turbulent market development and the never-ending fluctuating demand. This is carried out by fulfilling the following strategies such as flexible and highly responsive workflows. It is also important that these strategies should never impede the delivery reliability and the efficiency of the value adding process (Meissner, 2010).

There are some factors which could hinder the above-mentioned approach and it would lead to an unstable material flow in the supply chain as well as can incur an expensive production and logistics system. The first factor is the lack of availability and validity of the information of the demand between the suppliers or partners in the supply chain. The main reason for a high safety stock in the automotive industry is due to the lack of proper information exchange and the sudden demand changes (Meissner, 2010).

Secondly, the differences in the quality of production could lead to unstable lead times. The fluctuation in quality of production could be when the product does not satisfy the required standards or has any defects on it etc. This could lead to delay in production which hinders the practice of on-time delivery to the customer (Meissner, 2010).

There lot of issues which increases the lead time and throughput time in the assembly plant of an automotive industry. So these issues inside the assembly plant could be classified into 4 types. Starting with the position of buffer storage at in-house logistics (Emde, 2017) . In most of the cases in automotive industries the emphasize is given on how much area is allocated for the storage, the safety stock to be maintained at each level. The things which are less considered are the distance between the buffer storage and the point of use or the next point of delivery. The distance between buffer and the delivery point could add on to the lead time and throughput time considerably. When it comes to distance the vertical height, position of material stored in the buffer also could add on to the time. Also, according to the classic lot sizing model's different items can be mixed and stacked together if the company has a facility of large warehouse. But if the company doesn't have a warehouse and uses the principle of small picking areas as supermarkets, the method of stacking together is not practical. Different items cannot be stored in the same shelf, as it would increase the effort to pick the materials (Ohno 1988). So how to store the materials in the storage also become an issue which needs great attention which is less bothered in some automotive industries (Emde, 2017).

And finally, the amount of material to be carried on the vehicle during each tour also has an impact on the throughput time. So, it is important to fix a minimum stock to be loaded on the vehicle for each transport to reduce the process time for transport (Emde, 2017).

2.2. Lean Production System

After world war II, the economic condition of Japan was not good as they have only minimum resources. This became the starting point for them to follow the principle of efficient production with minimum resources and thus arises the concept called Toyota Production System (TPS). TPS focused on the philosophy of "more value for less work" (Liker, 2006).

Toyota focused more on this philosophy right from the beginning to attain the efficient way of production. But in 1990, James Womack et al made a clear description of the TPS in his book "The Machine that changed the world" and coined a term "Lean Manufacturing" (Liker, 2006). It explained the concept that TPS required less of all to attain the desired customer value. The concept of TPS made the attraction globally especially in the field of academics and then the lot of research work has been carried out in this field. In a short period of time, Lean Manufacturing got transformed to Lean Production which is more or less the same as TPS.

Liker (2006), has made great efforts in understanding the philosophies of TPS and written the book "The Toyota Way Field book", explaining the philosophies in depth. Most of the automotive industries were developing their own method of efficient way of production to smooth line their process. Research made by Liker shows that company willing to implement lean focuses on eliminating the wastes as a starting point.

Muda is the notation used to describe eight different wastes such as

1. Overproduction,
2. Waiting time,
3. Transportation,
4. Over processing,
5. Excess inventory,
6. Unnecessary movements,
7. Defects and
8. Unused employee creativity.

These activities are considered to be non-value added activities.

Out of 14 principles mentioned by Liker (2006), Some principles that correspond to the flow of the material are listed below.

"Create a continuous process flow to bring problems to the surface"

Traditional manufacturing method focused on having large inventories due to their process inefficiency while TPS focuses more on attaining one-piece flow by eliminating non-value adding activities for their manufactured products. According to Liker (2006), reducing the inventory level will reveal the problem outside but creating and controlling the flow of material will help in attaining minimum inventory level and also identifying the process inefficiency leading to achieve a suitable solution.

In the process of ideal flow, the operator in the assembly line will trigger the supplier in the warehouse when there is a need of material on the assembly line. This will take some time to transfer material from warehouse to the assembly line. According to TPS philosophy, the company should have material flowing through the assembly line in small batches rather than having excess inventory near the workstations that is waiting for the operations to be performed.

Lean Production focuses on attaining one-piece flow by making suitable arrangements for the production and its equipment's. Here work cells are grouped together by means of product produced. But in the traditional manufacturing method, machines with the same process are grouped together. According to Liker (2006), traditional manufacturing focuses on utilizing the machine 100% by maintaining substantial inventories to attain small capital income for the product produced but TPS focuses on having short throughput time throughout the factory. As a result of TPS, it is possible to create the smooth flow of material in the assembly line while having the minimum batch size and eliminating overproduction and at the same time satisfying the customer's requirement in a short period of time.

The principle mentioned above focuses only on value adding activities in a continuous process. The main concept is to improve the material flow process continuously and making it visible throughout the organization.

"Use Pull system to avoid overproduction"

The term pull system refers to the movement of material only when the order is received. The concept behind the pull system is that the customer pulls the material through the consecutive stages of the supply chain.

The main focus of the lean is to minimize the wastes mentioned above and increases the flexibility. One of the most important lean principles is to achieve pull system environment within the company.

According to Liker (2006), pull system in a shop floor refers "that step 1 in a process should not make (replenish) its parts until the next process after it (step 2) uses the original supply of parts from step 1 (that is down to a small amount of safety stock)". In simple words, the workstation should only produce products required to the following station only in required quantity at the required time.

According to Hines et al (1997), pull system should be followed out throughout the enterprises (Figure 1). From the figure, it is understood that the customer should initiate the process of pull from the company. When the customer order is placed, the production should take place for what was ordered in a right quantity at the right time and as a result it up streams the demand. This method of pull system helps to attain the concept of Just-In-Time (JIT).

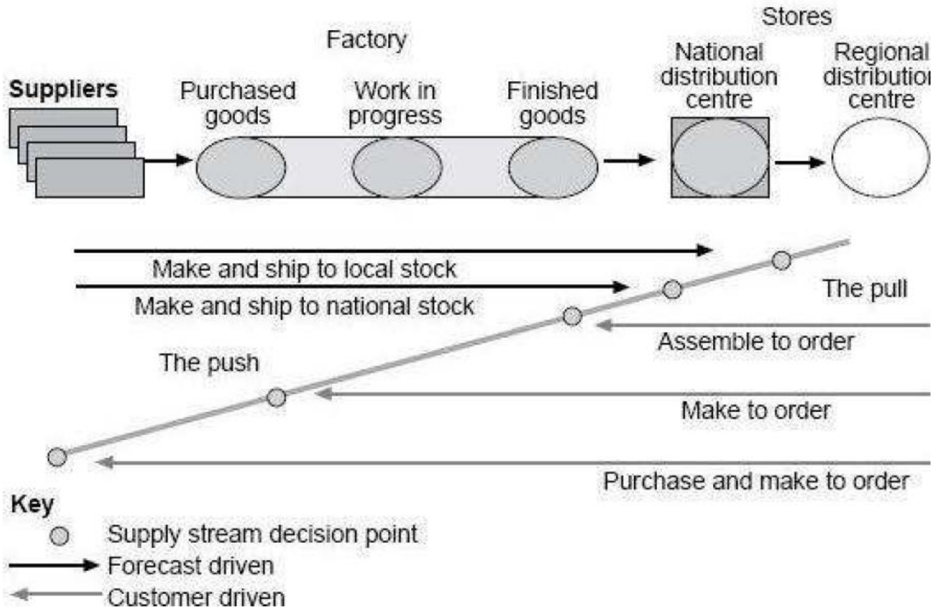


Figure 1 Pull System (Hines et al. 1997)

"Build a culture of stopping to fix problems, to get quality right the first time"

According to Liker (2006), solving the issues as soon as they arise is more effective and cost efficient in traditional mass production rather than identifying and solving the problem or quality errors towards the final stage of the production. By this method, products on work in progress could be prevented from the same quality issues.

In a lean environment having low inventory level, it is necessary to make errorless products in the first time itself since there is no or fewer inventory buffers. By the concept of "eliminating waste", the company should focus on solving the problems in the initial stage itself resulting in saving time and money (Liker, 2006).

2.2.1. Just-In-Time (JIT)

According to Liker (2006), JIT is considered to be the pillar of TPS. "Removing as much as possible, the inventory used to buffer operations" (Liker, 2006), JIT ensure that the company produces and deliver products only to the actual requirement in a short lead time to satisfy the customer.

JIT focuses on satisfying the customer demand on a daily basis (Liker, 2006). For this reason, it is necessary that the suppliers also attain the same leveled production or else the suppliers will be forced to maintain high inventory levels while their customer have minimum inventory level (Mattsson. 2004).

2.2.2. JIT Purchasing

According to Liker, it is necessary for the company to have close cooperation with their suppliers regarding with procurement of materials. The main problem relating to the purchasing in the production unit is to understand the relationship between the materials supplied and the impact of materials in the production unit of the company (Gadde and Hakansson, 2011).

The main principle of JIT purchasing is that of proving the right quantity of material at right time. This eliminated the concept of storing the material in large batch size and thus reducing the throughput time greatly. It ensures the continuous supply of raw materials to the production process and delivering the finished goods to the customer as soon as possible. In such cases, the suppliers or the warehouse is kept near the production company to provide the materials in frequent deliveries at short batch sizes. In addition, it helps in eliminating the inbound quality inspection when there is a collaboration between the buyer and the supplier (Skjott - Larsen et al, 2007).

2.3. Lean Logistics

Lean logistics is defined as “the logistics part of lean manufacturing and consist of three groups as the in-bound logistics (from supplier to factory), in-plant logistic (logistics in the factory), and the outbound logistics (from factory to the customer) (Kilic et al, 2012). Lean logistics obtain its base from Toyota Production System. It is based on the supply chain between obtaining raw material till delivering the products to the customer focus on achieving less lead time. This approach helps to identify the problems in different stages of the supply chain and focus on eliminating those problems.

Lean logistics focuses on two main objectives (Baudin, 2004).

1. The first objective is to deliver required quantity of material at the right time to the production unit dealing with in-plant logistics and as well as to the customer dealing with the outbound logistics.
2. Eliminating the waste in the logistic process without affecting the delivery.

Logistics within the company are classified into two types, in-plant logistics and outbound logistics (Baudin, 2004). The effectiveness and efficiency of in-plant activities are greatly dependent on in-plant logistics, which are directly related to the production lead time. In-plant logistics plays a major role in maintaining the flow of material in the assembly unit. Hence in-plant logistics is considered to be the key factor for Lean logistics. Outbound logistics helps in transferring the finished goods to the customer.

2.3.1. Material Handling within the warehouses and plant

Material Handling is the part of the flow of material in the warehouse and the assembly plant. The Material Handler is responsible for solving all the issues related to the availability of the material while the assembly operator concentrates only on their operations (Bicheno, 2004). In a specific interval of time, the material handler goes through the specific route in the assembly plant and look for the shortage of material that might occur. The material handler performs the necessary actions to prevent the problem to occur. The operator in the assembly line can also signal the material handler about the unavailability of the material or in case if the wrong part number has been delivered to the assembly line.

The main purpose of the in-plant logistics is to supply the required materials to the assembly line from the stock in the right quantity at right time. It is hard to deliver only the required quantity at right time. At the same time, it is not efficient to have too big buffers near the assembly station. Reducing the distance between the assembly line and stocking area or integrating the assembly line will improve the efficiency of material handling in the assembly plant (Baudin, 2004).

The vehicle used in in-plant logistic within the assembly plant plays a major role (Baudin, 2002 ; Baudin, 2004). The vehicle should be capable of satisfying a various need within the assembly plant, Forklift is one of the commonly used vehicles in concerned with in-plant logistics of the assembly plant used in lifting pallets of bigger size. However, it requires high initial investment and trained forklift operators. Similarly, pallet jacks can be used for transferring material for a short distance. Tugger trains can be used to transport material if in the case of material has to be transferred to the different assembly line. Conveyors or roller beds can also be used to transfer goods automatically but in turn, it increases the investment and maintenance cost. In certain cases, the external warehouse is located outside the premises of the company where trucks are involved in transferring the material from to the assembly plant (Sampka & Godarzi, 2010). This, in turn, increases the transportation time and overall throughput time.

While transferring materials within the assembly plant from stock, it is necessary to transfer material of different part numbers together required for the assembly line. In that cases, an ordinary forklift or tugger train can be used which reduces the investment on vehicles. In addition, it makes easy for the operator to sort out the mixed parts which are considered to be the useless work and it also occupies the minimum space which results in clear visibility in the assembly line (Sampka & Godarzi, 2010).

In-plant logistics should be customized to satisfy the plant needs. The basic principle is to use the appropriate vehicle, efficient route for transportation, proper batch sizes and a suitable machine that satisfy the plant needs greatly (Baudin, 2004).

2.4. Material storage within the plant

When the in-plant delivery equipment like forklift or tugger trains transfer the material to the assembly line of the automotive industry, “It is common that some material goes straight from receiving dock to production and are never stored by the material organization” (Baudin, 2004). In certain cases, the automobile manufacturer order parts to the supplier when the final assembly is just started. In those cases, the supplier transfers those ordered materials immediately in the truck to the assembly plant which is directly delivered to the assembly line by means of in-plant delivery equipment without being stored in the company storage.

In today's scenario, most of the automobile manufacturers store the required materials in their warehouses which are located close to the assembly plant. So, it is easy for them to transfer required quantity of materials to the assembly plant from warehouse whenever it is needed.

2.4.1. Supermarket

The main purpose of the supermarket is to act as a storage point between the warehouse and the assembly line of the automotive industry. When materials are unloaded from the trucks in the warehouse, the material handlers move the materials on the palette to the store and sort them out. In certain cases, the materials on the palettes need to undergo a repacking process such as labelling which is required for transporting the material to the assembly plant, Supermarkets are usually placed in the assembly unit near the assembly line. The material handlers within the assembly unit act as a "Water spiders", where their main purpose is to deliver the required parts to the assembly line from the supermarket. Here the material handler who acts as water spider in the assembly plant plays a crucial role in delivering the right part numbers in required quantity at right time (Baudin, 2004). This again helps to achieve the minimum lead time in replenishing the material in the assembly line.

Baudin (2004) in his book described that "Before or instead of going to supermarkets, items with the following characteristics have to be stored in an incoming materials warehouse:

1. They arrive in minimum quantities that far exceed daily consumption, be it in the form of full truckloads consumed by the pallet or full pallets consumed by the bin.
2. They are used in multiple products whose demand volume and mix may change. Storing the items in a central warehouse postpones their pegging to a product—or family—and makes it easier to respond to changes.
3. The supplier's deliveries are irregular, and a safety stock is needed to avoid shortages.
4. Due to quality issues, all the supplier's products are required to go through incoming inspection or testing".

2.5. Material replenishment

Supplying required materials to the assembly line plays a major role in the performance of the assembly (Baudin, 2002). Shortage of the materials or delayed in transferring the material to the assembly line are the reasons for waiting time in the assembly line. At the same time, it is also not appropriate to maintain excess inventory in the assembly line which will push to the circumstance of producing more goods which will lead to maintaining an excess inventory of finished goods. In addition, picking and handling the material several times before it goes to the assembly line is considered to be the transportation waste. The most common method used for signalling the need for material is explained below.

2.5.1. Two Bin System

In Two, Bin system inventory is carried out by means two bins. When the material in the first bin is used by the operator on the assembly line, a signal is made by the operator indicating the need for material replenishment. The second bin contains the enough quantity of the material required for the operator to carry out the assembly until the replenishment takes place. In Two bin system, the material is replenished based on the demand. Thus, it acts as a pull system and helps in attaining JIT system (Jonsson & Mattsson, 2011).

The two Bin system used Re-order point method to replenish the material. Re-order point is calculated using the formula

Re-order Point = Safety Stock + Demand x Lead Time

Re-order point is defined as “the inventory method that replaces an order for a lot whenever the quantity on hand is reduced to a predetermined level known as the order point” (Jonsson & Mattsson, 2011)

Safety Stock is defined as “the quantity of stock planned to be in inventory to protect against fluctuations in demand or supply” (Jonsson & Mattsson, 2011)

Demand is defined as “the need for a particular product or component” (Jonsson & Mattsson, 2011).

Lead Time is defined as “the span of time required to perform a process or series of operation. In Logistics context, the time between materials are ordered from the supermarket and the receipt of the materials” (Jonsson & Mattsson, 2011)

2.5.2. Kanban System

Kanban system is used to ensure the continuous supply of material to the assembly line from the warehouse. In this method, the materials from the warehouses are loaded in specific quantity to the container (bin) and are placed in the lineside buffer located near the assembly line (Faccio, 2014). The replenishment for material in the line side buffer can be triggered by means of empty bins or cards. The triggering method is usually done by means of an electronic signal or paper flow (Jonsson & Mattsson, 2011).

The main advantage of kanban system is to ensure the continuous supply of material to the lineside buffer frequently in small quantity from the warehouse required for the assembly line. It helps in maintaining minimum inventory level in lineside buffers (Faccio, 2014). In addition, the system is highly visible and does not require high investment to implement (Kouri et al, 2008). According to Jonsson & Mattsson, 2011, for successful implement of kanban it is necessary for the manufacturing industry to have stable demand. According to Caputo & Pelagagge (2011), kanban based supplying of materials is not suitable for the industries with a high variation of products and low demand. The kanban system also reduces the work-in-progress within the industry.

2.6. Material Management – Administration activity

Most of the automotive manufacturers depend on organized event in their material flow for their operations to take place effectively. Software such as Enterprise Resource Planning (ERP) which provides crucial data to the entire supply chain and manufacturing operation by means of collecting the real-time data. ERP is enhanced by means of adding bar coding or Radio Frequency Identification (RFID) applications throughout the process of supply chain and manufacturing operation (McFarlane. & Sheffi, 2003).

2.6.1. ERP and WMS systems

In the current scenario, most of the automotive manufacturers have implemented or initiated the ERP system and Warehouse Management System (WMS). These systems help in tracking the material through different process throughout the supply chain. ERP system helps in optimizing the time and improving the efficiency of the supply chain by providing the details "what is required by when and what is available from where".

For the efficient use of ERP and WMS system, most of the automotive manufacturers uses barcoding method to identify the pallet of parts, storage location, work-in-process and finished goods inventory (Kärkkäinen and Hokmström, 2002).

The general step by step procedure involved in ERP system and how barcoding is used in the supply chain is explained below (Kärkkäinen and Hokmström, 2002) .

2.6.1.1. Registration of received goods

The material that is received by the company from the supplier is usually provided with the labels in their packing to satisfy the company's requirement of material management. In certain companies, the receiving department logs in the information about the received materials from the supplier and provide new labels or bar code to the identify the material before it is transferred to the storage location.

2.6.1.2. Inventory management

The warehouse operator transfers the material to the desired location by means of scanning the bar code. The method of bar code scanning provides the accuracy since the warehouse operator scans both the material as well as the new storage location to complete the transfer operation and the information is recorded in the ERP system.

2.6.1.3. Transferring the material from storage to assembly line

When the need for material is signalled from the assembly plant, the picking operation takes place. The picking operation involves in retrieving the required material from the inventory. The operators involved in transferring the material from storage to assembly plants are directed to the exaction location of the material and providing the information about quantity required to pick by means of the system. The operator again scans the barcode to update the information about the removal of inventory in the storage which is updated in the ERP system.

2.6.1.4. Work-In-Process

Th picked materials from the storage are scanned again to ensure that the right materials are picked in the right quantity. The materials are transferred to the assembly line and scanned again to confirm the materials have been delivered to the desired location. This helps in updating ERP system that the material is consumed in the assembly line.

3. Methodology

This chapter describe the methodology used to obtain the empirical data from the four-different automotive manufacturer required for this thesis work. It also gives clear explanation about the calculation procedure followed to obtain lead time and throughput time

3.1. Data Collection from previous study

As an approach to this thesis work, the data's that has been obtained by previous studies performed at the Division of Supply and Operations Management has been utilized. The previous study was performed by three researchers Hanson et al., (2016). Four case studies made by these researchers from four different automobile assembly plants are used, since the flow of material were similar between the cases. In case 1-3, material flow is managed by means of an external warehouse whereas in case 4 the material flows into the assembly plant from the supplier directly without any external warehouse. The researchers drew the maps of material flow using Material Flow Mapping (MFM) methodology. The map provided the details regarding material flow, signalling method and details regarding four different activities such as handling, administration, transportation and storage. The reason for having a case with an internal warehouse is to make a comparison between the lead time of the product having an external warehouse and internal warehouse. In all the case studies two – three kinds material flows have been considered. As a starting point of this thesis, we will focus on four case studies made in the automotive industries that was made by the previous study. For the same four cases, the authors of this thesis work will collect additional data such as process time for each activity while considering the batch sizes.

3.2. Empirical Data

The thesis is based on an ongoing research at the Division of Supply and Operation Management. The materials which have been obtained from the previous study such as case description, internal data of the companies, Material Flow Mapping (MFM) which is used as a pre-study for this thesis.

The thesis consists of collecting qualitative data by interviewing the company representatives for each case to collect the process time for all the activities based on MFM map. A field visit to the companies has been done to observe all the activities and the process happening right from the warehouse to the assembly station. The video clips of all the process happening in each case made by the previous study has been analysed for material flow to analyse the current state material flow. The interviews together with a field trip and video clips have given a deep insight into the material handling, various administrative activities, throughput times from external warehouse to the assembly line, stock turnover rates, and a number of hours required in the material handling.

In addition to the interviews, a thorough literature study related to logistics and material handling relation to a decentralized and centralized warehouse in the automotive industry has been done. There are quite a lot of journals and articles in the Chalmers database with the keywords such as an external warehouse, material flow, material supply, buffer, inventory, lead time, throughput time, value stream mapping etc., which has been used for a basic foundation for the study.

3.3. Material Flow Mapping

According to Finnsgard et al (2011), "Material Flow-mapping Methodology (MFM) is presented in the paper, including measurements specified at the material supply activities as handling, administrative, transportation and storage processes". The Material flow map (MFM) approach would help in identifying the process interaction and interconnection between sequential steps in a flow. In addition, the map would help in describing the flow of material and enable us to visualize the required non-value-added activities which in turn helps to improve the operations performed (Finnsgard et al, 2011). It has been evolved from Value stream mapping, which is a lean management tool to identify the different wastes in the material flow which could cause an increase in the lead time and throughput time. MFM made by the previous study will be added with more information like process time and batch quantity which would help in obtaining throughput time and lead time for all the cases. It also gives a clarification of how the information signal between the activities has an impact on the material flow and operation performance. It also gives an understanding of how the improper signalling process can delay the material flow as well as reduce the process performance which in turn affects the lead time (King & King, 2015). MFM is an important to visualize the process time at each workstation, inventory level and the information flow throughout the supply chain (Che Ani et al., 2014).

By this method, we create the current state map of material flow from external warehouse to assembly line with the help of MFM map and videos made by the previous study. The current state maps were developed with the process time and batch quantity for each activity in the material flow which was obtained by means of a field visit to the company. Throughput time and lead time are calculated as explained in chapter 3.4 for all the cases. Then the cross-Case analysis has been made to compare the performance between the cases which would help to identify the problems affecting the lead time and throughput time for each case separately.

3.4. Measurement of throughput time and lead time

In each of the flow, the throughput time and lead time has been calculated for a specific part chosen. In each flow, the specific part has been chosen based on the high consumption material and ensuring the material flows according to the Material Flow Map created in the previous study. Before choosing the material, we have gone through the list of high consuming material that flows according to the Material Flow Map by means of company database for all the cases. From the list of high consuming material, a specific part is selected based on analysing which material is available on that specific day during our plant visit for us to measure the flow of material physically.

To calculate lead time and throughput time in all the cases, the process time for each activity as per Material Flow Map is obtained by means of manually measuring the process time by stopwatch for every process, interviewing managers & operators and obtaining information from the company's database. Activities such as handling and transportation were been able to measure by means of stop watch. Time regarding the administration activity were obtained by means of interviewing managers of the respective companies. Time regarding the storage activity cannot be measured by means of stop watch as it might consume so much time. So, for this activity we have considered the time by obtaining only form the company's database. Since the process time varies for all the activities in each trial, we collected the minimum and maximum time required for each activity by means of measuring it by stop watch, interviewing managers and from company's database as explained earlier. The average process time was calculated for all the activities based on the information obtained which would help us to compare the performance of the four different cases. Certain process takes place only in regular interval of time such as truck leaving external warehouse to the assembly plant. In such cases the material has to wait in the truck before leaving the external warehouse. In such cases, obtaining the more exact time was difficult by means of measuring it by stop watch (as it varies every time) or obtaining data from company's database (which is not available). So, from the data obtained by the interviewing managers, the waiting time for the minimum, average and maximum values are considered to be the same. Similarly, in certain process like waiting time before the material is unloaded seems to be different in each trial. This is because the operator who drives the material from one place to another place has to unload the material himself, sometimes the forklift operator is either ready to unload the material immediately or the forklift operator has to drive a bit before unloading the material. In such cases, to simplify the calculation, we used the time that was obtained while interviewing managers where, the minimum, average and maximum process time considered to be the same

In our calculation, Throughput time is measured as the sum of all the process time from the initial registration of goods till it reaches the lineside buffer. Lead time is measured as the sum of the process times of all activities between the cycle of ordering new materials (replenishment) and till the material reaches the lineside buffer. The time taken for certain administration activities that are carried out in parallel to other process has not been considered since they do not add up the throughput time or lead time

The process time for the first pallet of the considered part to flow through the specific activity as in pallet flow map is considered as the minimum process time and the time that is taken for the final pallet of the respective batch to flow through the specific activity is considered as the maximum process time. Similarly, in box flow, the process time for the first box to flow through the specific activity as in box flow map is considered as the minimum process time and the time that is taken for the final box of the respective batch to flow through the specific activity is considered as the maximum process time. Since focusing on minimum or maximum process time provides minimum or maximum lead time and throughput time respectively for the material. In order to do a cross case analysis, an appropriate throughput time and lead time is required. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is considered.

3.5. Validating the result

The thesis is a part of an ongoing research project in Division of Supply and Operations Management, Chalmers University. Since the thesis is based on ongoing research, the pre-study material would be appropriate for our purpose of the study. The empirical data collected from the previous study (Hanson et al., 2016 & Appendix A) made by the Division of Supply and Operation Management and the data collected by the authors of this thesis work from the four different automotive manufacturers makes the thesis work credible. The collected data will be organized and documented based on the requirements for this thesis. A documented report has been sent to the respective companies to verify the data as well as to get a feedback. This makes the study more credible and trustworthy. As three manufacturers have an external warehouse and one manufacturer has an internal warehouse, a cross-case analysis has been made to analyse the effects of having an external warehouse comparing to that of internal warehouse.

3.6. Ethical Issues

The literature study used for the thesis has been given the required reference at the end of the report. The consent of company representatives for collecting the data through interviews and other visual observation for the study has been done prior to the step. The permission to document the data and to publish them online was also made. And certain specific data which the company thinks confidential such as company name for all the four-automotive manufacturer was not mentioned in the report. The terms and conditions of Chalmers has been followed for carrying out the thesis and no such kind of plagiarism or manipulation of data has been made to obtain the result in our study.

4. Empirical Findings

In this chapter, empirical findings from the four different automotive manufacturers have been explained in detail. In each case, two to three types of material flow have been considered. Based on the methodology described in Chapter 3, lead time and throughput time for the material flow has been calculated.

4.1. Case Description from the previous study

Four case studies made by the three researchers Hanson et al., (2016) from four different automobile assembly plants are used since the flow of material were similar between the cases. In case 1-3, material flow is managed by means of an external warehouse whereas in case 4 the material flows into the assembly plant from the supplier directly without any external warehouse. The researchers drew the maps of material flow using Material Flow Mapping (MFM) methodology (Appendix A). The MFM methodology also includes administrative activities such as scanning of barcodes, kanban cards, loading the material information in computer and labelling. The earlier study on material flow did not focus only on single part number rather focused on the category of flow including a lot of part numbers. In addition, the study did not consider throughput time of the different part numbers, as each part number has a different level of inventory and consumption rate. An overview of the four cases is mentioned in Table 1

	Type of assembly	**Category of material flow studied**
Case 1	Truck chassis assembly	Materials in pallets
		Materials arriving in pallets from suppliers, repacked to boxes in external warehouse
Case 2	Truck engine assembly	Materials in pallets
		Materials in boxes
Case 3	Car assembly	Materials in pallets
		Materials in boxes
		Materials arriving in pallets from suppliers, repacked to boxes in plant
Case 4	Truck engine assembly (no external warehouse)	Materials in pallets
		Materials in boxes

Table 1 Overview of four different cases

4.1.1. Case 1 – Truck Chassis Assembly

In this case, the warehouse is located externally from the assembly plant but both the assembly plant and the external warehouse lies within the same gated area. Hence there is no interaction of regular traffic for transportation of goods to assembly plant from the external warehouse. Two type of flow has been considered for this case. In each of the flows, the throughput time and the lead time has been calculated.

4.1.1.1. Pallet flow

The pallet of materials arriving from the suppliers is unloaded by means of a forklift in an external warehouse. The unloaded materials are placed in the goods receiving area after which they are provided with new labels. Then the forklift picks the pallets with labels and transfers it to the storage tents (external warehouse in this case) where they are loaded into the storage racks. When the signal is received from the assembly plant indicating the need of material, the forklift retrieves the pallets from the storage rack and load it on to a MAFI train. A MAFI train is a transport system used to deliver the materials to the respective location in an industry. So MAFI train is used to deliver the pallets from storage tent (external warehouse) to the assembly plant. In the assembly plant, the forklift unloads the material from MAFI train and loads into the tugger train. A tugger train delivers the pallets to the assembly line at the required location. Here two bin is maintained in the lineside buffer. When the first bin is empty, the assembly operator scans the empty pallet in the lineside buffer which indicates the ordering of new pallet of material. The material replenishment is done to the lineside buffer before second bin gets empty.

The Material Flow Map (MFM) for the pallet flow is illustrated in Figure 2 below.

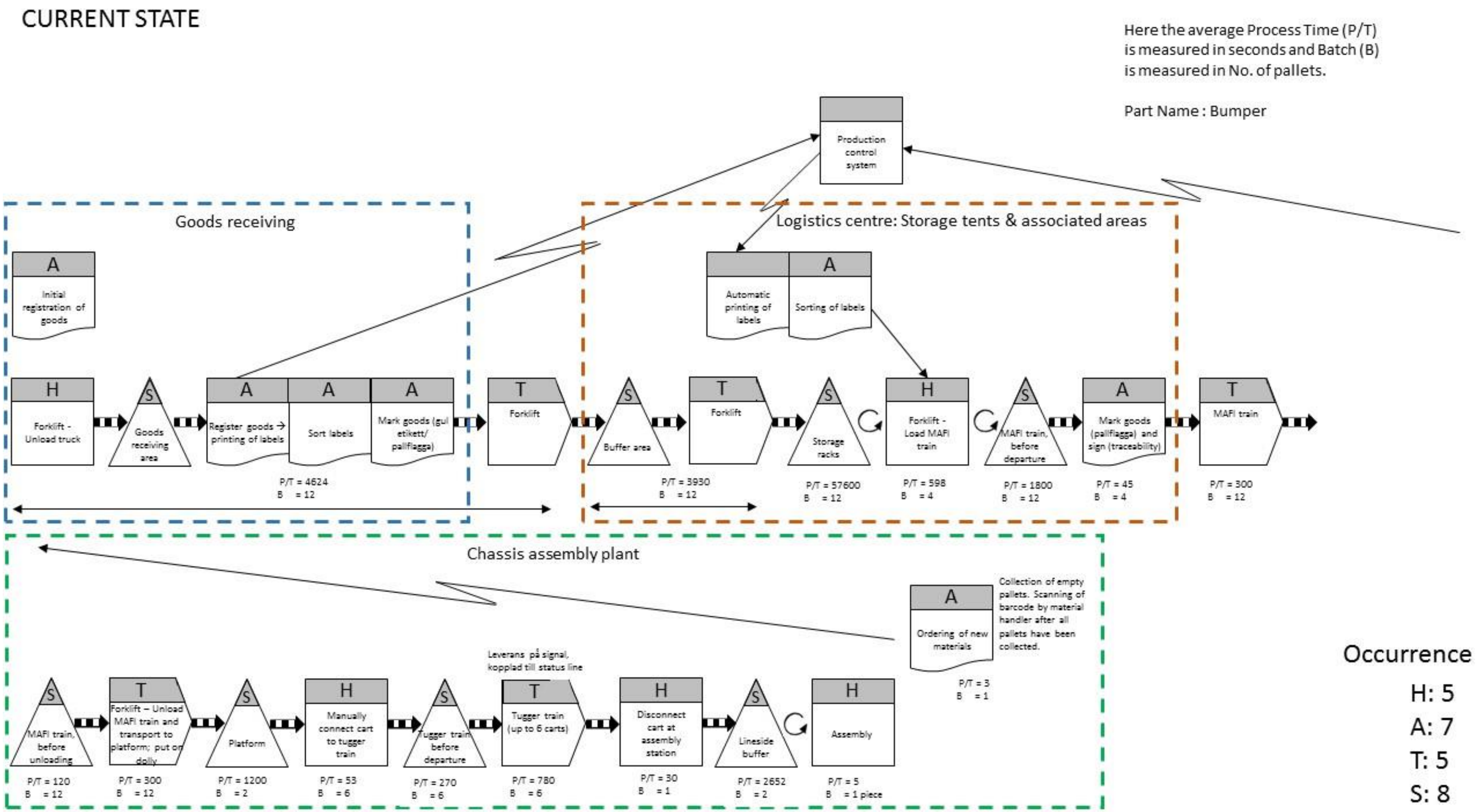


Figure 2 Material Flow Map - Pallet Flow

Measurement of throughput time and lead time

In pallet flow, we have considered a specific part which is Bumper. The reason for selecting this specific part is that it passes through all the processes in the material flow map and is also a highly-consumed component in this case. A pallet consists of 12 pieces of the bumper. The company receives 12 pallets of bumper every alternative day from the supplier. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is considered. 12 Pallets that are received from the supplier are considered as batch till the pallet reaches the storage racks in storage tents. From the storage racks, the pallets are transferred to the assembly plant one by one. In the assembly plant, 1 bumper is used for every 408 seconds. So, on an average 6 to 7 pallets of the bumper are required to the assembly unit in a day. From the storage rack, along with the bumper varied materials are transferred to the assembly plant by MAFI train and Tugger train. Since dissimilar materials are transferred together the batch quantity is considered accordingly. In the table mentioned below and in the material flow map (pallet flow), the pallets have stored a maximum of two days. So, the first consuming pallet has minimum process time and the final consuming pallet takes the maximum process time to reach the assembly.

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Goods Receiving				
1.	Forklift unload trucks	2048	4624	7200
2.	Goods Receiving area			
3.	Register goods			
4.	Sort labels			
5.	Mark goods			
6.	Forklift			
	Throughput time (Goods receiving)	2048	4624	7200
External Warehouse (Logistic center according to flow map)				
7.	Buffer area	660	3930	7200
8.	Forklift			
9.	Storage racks	28800	57600	86400
10.	Forklift load MAFI train	281	598	914
11.	MAFI train before departure	1800	1800	1800
12.	Mark goods	30	45	60
13.	MAFI train	300	300	300
Throughput time (External Warehouse)		31871	64273	96674
Chassis Assembly Plant				
14.	MAFI Train before unloading	120	120	120
15.	Forklift - Unload MAFI train	240	300	360
16.	Platform	600	1200	1800
17.	Manually connect cart to tugger train	15	53	90
18.	Tugger train before departure	180	270	360

19.	Tugger train (Up to 6 carts)	360	780	1200
20.	Disconnect cart at assembly station	30	30	30
21.	Lineside buffer	408	2652	4896
Throughput Time Chassis Assembly plant		1953	5405	8856
Total Throughput Time		35872	74302	112730

Table 2 Throughput Time - Pallet Flow

Table 2 describes the throughput time of one pallet of Bumper. From the calculation, it is found that the minimum throughput time 35872 seconds (9.96 hours) and the maximum throughput time is 112730 seconds (31.3 hours). Therefore, the average throughput time of the specific part number is calculated to be 74302 seconds (20.64 hours).

Process No.	**Process**	**Process Time**		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
1	Ordering of new materials (Assembly plant)	3	3	3
External Warehouse (Logistic Centre)				
2.	Forklift load MAFI train	281	598	914
3.	MAFI train before departure	1800	1800	1800
4.	Mark goods	30	45	60
5.	MAFI train	300	300	300
Chassis Assembly Plant				
6.	MAFI Train before unloading	120	120	120
7.	Forklift - Unload MAFI train	240	300	360
8.	Platform	600	1200	1800
9.	Manually connect cart to tugger train	15	53	90
10.	Tugger train before departure	180	270	360
11.	Tugger train (Up to 6 carts)	360	780	1200
12.	Disconnect cart at assembly station	30	30	30
Lead Time		3959	5499	7037

Table 3 Lead Time - Pallet Flow

Table 3 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer (Disconnect cart at assembly station) from the external warehouse for one pallet of Bumper. From the calculation, it is found that the minimum lead time is 3959 seconds (1.09 hours) and the maximum lead time is 7037 seconds (1.95 hours). Therefore, the average lead time of the specific part number is calculated to be 5499seconds (1.52 hours).

4.1.1.2. Box flow

In this flow, the pallets which are arriving from the suppliers must be repacked to boxes in the external warehouse. The material flow here is same as that of pallet flow material but instead of transferring the pallet directly to the storage tents, the pallets are transferred to the permanent building by means of forklift after the label has been attached to the pallets. In the permanent building, the pallets are left in the buffer and sorting area before they are transported to the buffer of the repacking area. After repacking, the boxes are placed on the pallets and are provided with new labels. After labelling the pallets are loaded into the storage area. The forklift transfers the materials from storage area to MAFI train which delivers the pallets of boxes to the assembly plant where they are unloaded to a roller conveyor. From the roller bed, the boxes are lifted to a box truck and are transferred to the storage rack. The boxes are left in the storage rack of the external warehouse until the need is signaled from the assembly line. When the need is signaled, again the box truck transfers the box from storage rack in the external warehouse to the lineside buffer of the respective assembly station.

The Material Flow Map (MFM) for the box flow Figure 3 illustrated below.

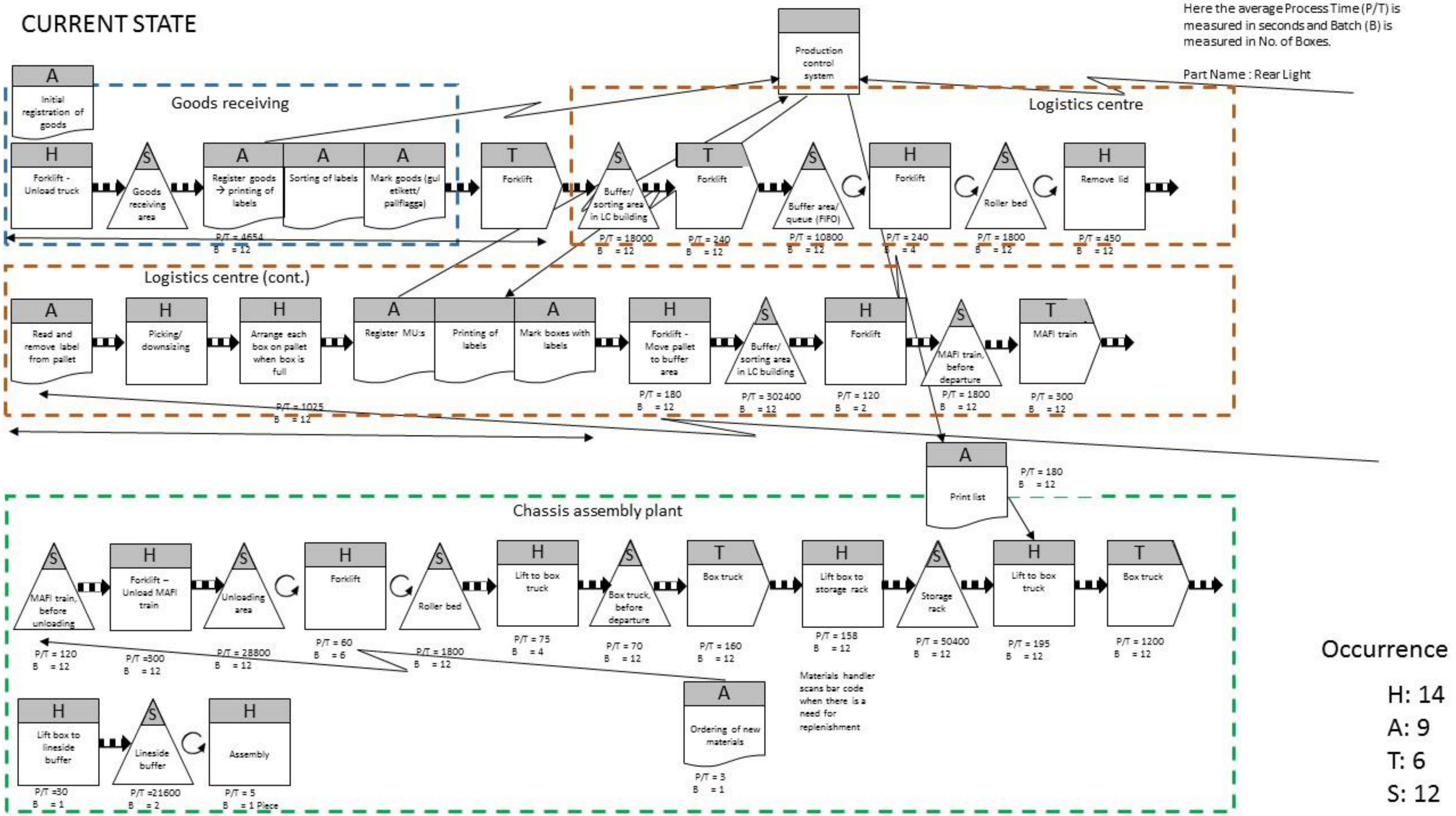


Figure 3 Material Flow Map - Box Flow

Measurement of throughput time and lead time

In this flow, we have considered a specific part model called Rear Light. The reason for selecting this specific part is because the part passes through all the process in the box flow map made in the previous study. The company receives 2 pallets of rear lights every week from the supplier. The pallets are repacked into boxes in which each pallet consists of 6 boxes and each box consist of two pieces of rear lights. The process time for the first box to flow through the specific activity as in box flow map is considered as the minimum process time and the time is taken for the final box to flow through the specific activity is considered as the maximum process time. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is considered. 2 Pallets (12 boxes) that are received from the supplier are considered as batch till the pallet reaches the storage racks in storage tents. From the storage racks, two boxes are transferred to the assembly plant at a time. In the assembly plant, 1 box of rear light is used for every 14400 seconds (4 hours). Hence only 2 boxes of rear lights are required to the assembly unit in a day. From the storage rack, along with the Rear lights varied materials are transferred to the assembly plant by MAFI train and Tugger train. Since dissimilar materials are transferred together the batch quantity is considered accordingly. In the table mentioned below and in the material flow map (box flow), the pallets have stored a minimum of a week and maximum of two weeks. So, the first consumed box has minimum process time and the final consuming box takes the maximum process time to reach the assembly.

Process No	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Goods Receiving				
1.	Forklift unload trucks	2108	4654	7200
2.	Goods Receiving area			
3.	Register goods			
4.	Sort labels			
5.	Mark goods			
6.	Forklift			
Throughput Time (Goods Receiving)		2108	4654	7200
External Warehouse (Logistics Centre)				
7.	Buffer area	14400	18000	21600
8.	Forklift	240	240	240
9.	Buffer area queue	10800	10800	10800
10.	Forklift	240	240	240
11.	Roller bed	1800	1800	1800
12.	Remove lid	300	450	600
13.	Read and remove label from pallet	900	1125	3600
14.	Picking/downsizing			
15.	Arrange each box on pallet			
16.	Register, printing and marking labels			
17.	Forklift move pallet to buffer area	120	180	240

18.	Buffer/sorting area	201600	302400	403200
19.	Forklift	120	120	120
20.	MAFI train before departure	1800	1800	1800
21.	MAFI train	300	300	300
Throughput Time (External Warehouse)		232620	337455	444540
Chassis Assembly Plant				
22.	MAFI Train before unloading	120	120	120
23.	Forklift - Unload MAFI train	240	300	360
24.	Unloading area	28800	28800	28800
25.	Forklift	60	60	60
26.	Roller bed	1800	1800	1800
27.	Lift to box truck	30	75	120
28.	Box truck before departure	70	70	70
29.	Box truck	160	160	160
30.	Lift box to storage rack	45	158	270
31.	Storage rack	14400	50400	86400
32.	Print list	180	180	180
33.	Lift to box truck	30	195	360
34.	Box truck	1200	1200	1200
35.	Lift box to lineside buffer	30	30	30
36.	Lineside buffer	14400	21600	28800
Throughput Time (Chassis Assembly Plant)		61565	105148	148730
Total Throughput time		296293	447257	600470

Table 4 Throughput Time - Box Flow

Table 4 describes the throughput time of one box of Rear Light. From the calculation, it is found that the minimum throughput time is 296293 seconds (82.30 hours) and the maximum throughput time is 600470 seconds (166.79 hours). Therefore, the average throughput time of the specific part number is calculated to be 447257 seconds (124.24 hours).

In this flow, when the material is ordered from the assembly plant the signal is sent to the storage area in the assembly plant as well the storage area in the external warehouse. The replenishment to a lineside buffer in the assembly plant takes place by transferring the material from the storage area in the assembly plant. Since this case has two storage points, two lead time calculations had been made. Table 5 shows the lead time of material replenishment from the storage area in the assembly plant and Table 6 shows the lead time of material replenishment from the storage area in external warehouse

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
1.	Ordering of new materials (Assembly Plant)	3	3	3
Chassis Assembly Plant				
2.	Print list	180	180	180
3.	Lift to box truck	30	195	360
4.	Box truck	1200	1200	1200
5.	Lift box to lineside buffer	30	30	30
Lead Time		1440	1605	1770

Table 5 Lead Time - Box Flow (Replenishment from local storage area)

Table 5 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the storage area in the assembly plant for one box of Rear Light. From the calculation, it is found that the minimum lead time is 1440 seconds (0.44 hours) and the maximum lead time is 1770 seconds (0.49 hours). Therefore, the average lead time for the specific part number is calculated to be 1605 seconds (0.46 hours).

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
1.	Ordering of new materials (Assembly Plant)	3	3	3
External Warehouse (Logistic Centre)				
2.	Forklift	120	120	120
3.	MAFI train before departure	1800	1800	1800
4.	MAFI train	300	300	300
Chassis Assembly Plant				
5.	MAFI Train before unloading	120	120	120
6.	Forklift - Unload MAFI train	240	300	360
7.	Unloading area	28800	28800	28800
8.	Forklift	60	60	60
9.	Roller bed	1800	1800	1800
10.	Lift to box truck	30	75	120
11.	Box truck before departure	70	70	70
12.	Box truck	160	160	160
13.	Lift box to storage rack	45	158	270
14.	Storage rack	14400	50400	86400
15.	Print list	180	180	180
16.	Lift to box truck	30	195	360
17.	Box truck	1200	1200	1200
18.	Lift box to lineside buffer	30	30	30
Lead Time		49388	85771	122153

Table 6 Lead Time - Box Flow (Replenishment from external warehouse)

Table 6 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the external warehouse for one box of Rear Light. From the calculation, it is found that the minimum lead time is 49388 seconds (13.71 hours) and the maximum throughput time is 122153 seconds (33.93 hours). Therefore, the average throughput time of the specific part number is calculated to be 85771 seconds (23.82 hours).

4.1.2. Case 2 – Truck Engine Assembly

In this case, the company has an external warehouse which is few hundred meters away from the assembly plant. Two types of flow (Pallet and Box) has been considered for this case. The transportation of pallets and boxes to the assembly plant from the external warehouse is done by Trucks at regular intervals. In each flow, throughput time and lead time has been calculated.

4.1.2.1. Pallet Flow

The pallet of materials from the suppliers are unloaded from the trucks and placed onto a tugger train by means of a forklift. The tugger train then transports the pallets to the storage area in the external warehouse. The pallets are given a new label before it has been placed in the storage racks. The pallets are kept in the storage racks until a pull signal arrives from the assembly plant for replenishment. Upon a pull signal from the assembly plant, pallets of the required part number have been fetched from the storage rack by means of forklift and placed onto a tugger train. The pallets are given new labels again and the tugger train transports the pallets to a loading area which is out of the warehouse. A forklift is used to load the pallets onto a truck, which transports the pallets to the assembly plant. When the truck reaches the assembly plant, the pallet is unloaded by a forklift and placed onto a roller conveyor which carries the pallets into the assembly plant. A forklift is used to pick up the pallets from the roller conveyor and placed in a sorting area. From the sorting area, the pallets are picked up and transported to buffer location based on the matching part number by a forklift. And when there is a signal for replenishment, the pallets are transported to the point of use by a tugger train.

The Material Flow Map (MFM) for the pallet flow is illustrated in Figure 4 below.

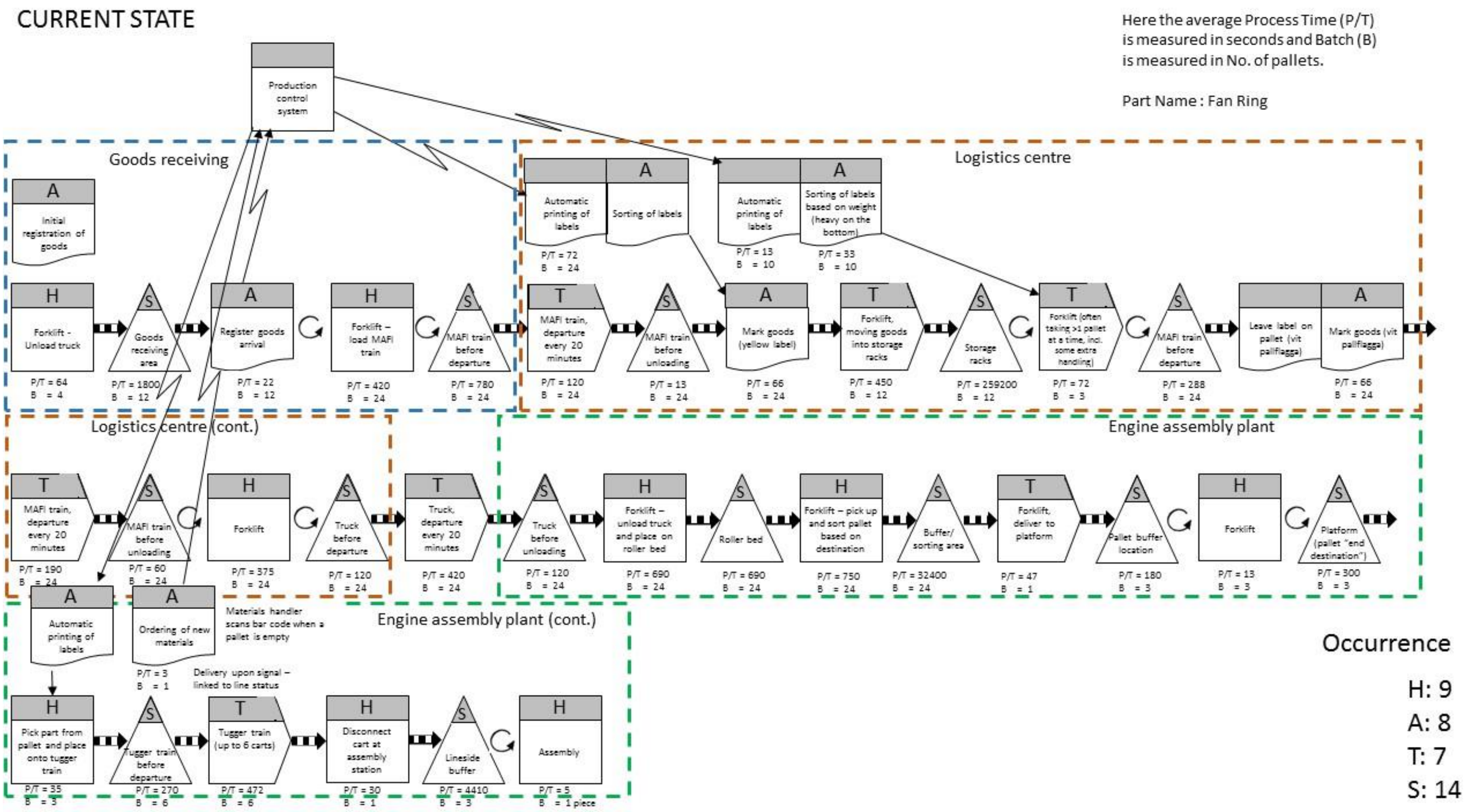


Figure 4 Material Flow Map - Pallet Flow

Measurement of throughput time and lead time

In the pallet flow, we have considered a specific part called fan ring which is one of the highly-consumed parts in this automotive industry and delivered every day from the supplier. The company receives 12 pallets every day and each pallet consists of 14 fan ring. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is considered. Table 7 describes the minimum, average and maximum process time for each activity. And based on these process times the throughput time (Table 7) and lead time (Table 8, Table 9) are calculated for the pallet flow.

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Goods Receiving				
1.	Forklift unload trucks	32	64	96
2.	Goods Receiving area	1800	1800	1800
3.	Register goods arrival	4	22	40
4.	Forklift load MAFI train	360	420	480
5.	MAFI train before departure	720	780	840
Throughput Time (Goods Receiving)		2916	3086	3256
External Warehouse (Logistics Centre)				
6.	MAFI train departure every 20 mins	120	120	120
7.	MAFI train before unloading	13	13	13
	Automatic printing of labels	13	72	130
8.	Mark goods (yellow Labels)	12	66	120
9.	Forklift moving goods into storage racks	180	450	720
10.	Storage racks	86400	259200	432000
	Automatic printing of labels	13	13	13
	Sorting of labels based on weight	6	33	60
11.	Forklift	72	72	72
12.	MAFI train before departure	288	288	288
13.	Mark goods	12	66	120
14.	MAFI train departure every 20 mins	190	190	190
15.	MAFI train before unloading	60	60	60
16.	Forklift	30	375	720
17.	Truck before departure	120	120	120
18.	Truck departure every 20 mins	420	420	420
Throughput Time (External Warehouse)		87949	261558	435166
Engine Assembly Plant				
19.	Truck before unloading	120	120	120
20.	Forklift unload Truck and place it on the roller bed	180	690	1200
21.	Roller bed	180	690	1200
22.	Forklift pick up pallets and sort based on destination	60	750	1440
23.	Buffer/sorting area	21600	32400	43200
24.	Forklift deliver to platform	47	47	47

25.	Pallet buffer location	180	180	180
26.	Forklift	13	13	13
27.	Platform	300	300	300
28.	Pick part from pallet and place it on the tugger train	10	35	60
29.	Tugger train before departure	180	270	360
30.	Tugger train	236	472	708
31.	Disconnect cart at assembly station	30	30	30
32.	Line side buffer	3780	4410	5040
Throughput Time (Assembly Plant)		26916	40407	53898
Total Throughput Time		117781	305051	492320

Table 7 Throughput Time - Pallet Flow

Table 7 describes the throughput time of one pallet of Fan Ring. From the calculation, it is found that the minimum throughput time is 117781 seconds (32.71 hours) and the maximum throughput time is 492320 seconds (136.75 hours). Therefore, the average throughput time of the specific part number is calculated to be 305051 seconds (84.73 hours)

In this flow, when the material is ordered from the assembly plant the signal is sent to the storage area in the assembly plant as well the storage area in the external warehouse. The replenishment to a lineside buffer in the assembly plant takes place by transferring the material from the buffer location in the assembly plant. Since this case has two storage points, two lead time calculations had been made. Table 8 shows the lead time of material replenishment from the buffer location in the assembly plant and Table 9 shows the lead time of material replenishment from the storage area in external warehouse

Process No.	**Process**	**Process Time**		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
1.	Ordering of materials (Assembly plant)	3	3	3
Engine Assembly Plant				
2.	Automatic printing of labels	60	60	60
3.	Pick part from pallet and place it on the tugger train	10	35	60
4.	Tugger train before departure	180	270	360
5.	Tugger train	236	472	708
6.	Disconnect cart at assembly station	30	30	30
Lead Time		519	870	1220

Table 8 Lead Time - Pallet Flow (Replenishment from local storage area)

Table 8 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer (Disconnect cart at assembly station) for one pallet of Fan Ring. From the calculation, it is found that the minimum lead time is 519 seconds (0.14 hours) and the maximum lead time is 1220 seconds (0.33 hours). Therefore, the average throughput time of the specific part number is calculated to be 870 seconds (0.24 hours)

Process No.	Process	Process Time		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
1.	Ordering of materials (Assembly plant)	3	3	3
External Warehouse (Logistics Centre)				
2.	Forklift	72	72	72
3.	MAFI train before departure	288	288	288
4.	Mark goods	12	66	120
5.	MAFI train departure every 20 mins	190	190	190
6.	MAFI train before unloading	60	60	60
7.	Forklift	30	375	720
8.	Truck before departure	120	120	120
9.	Truck departure every 20 mins	420	420	420
Engine Assembly Plant				
10.	Truck before unloading	120	120	120
11.	Forklift unload Truck and place it on the roller bed	180	690	1200
12.	Roller bed	180	690	1200
13.	Forklift pick up pallets and sort based on destination	60	750	1440
14.	Buffer/sorting area	21600	32400	43200
15.	Forklift deliver to platform	47	47	47
16.	Pallet buffer location	180	180	180
17.	Forklift	13	13	13
18.	Platform	300	300	300
19.	Pick part from pallet and place it on the tugger train	10	35	60
20.	Tugger train before departure	180	270	360
21.	Tugger train	236	472	708
22.	Disconnect cart at assembly station	30	30	30
Lead Time		24331	35791	50851

Table 9 Lead Time - Pallet Flow (Replenishment from external warehouse)

Table 9 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer (Disconnect cart at assembly station) from the external warehouse for one pallet of Fan Ring. From the calculation, it is found that the minimum throughput time is 24331 seconds (6.75 hours) and the maximum throughput time is 50851 seconds (14.12 hours). Therefore, the average throughput time of the specific part number is calculated to be 35791 seconds (9.94 hours).

4.1.2.2. Box flow

In this flow, the box materials are stacked on pallets. The pallets contacting stacks of boxes are unloaded from the truck and placed onto a tugger train at the unloading area by means of a forklift. The tugger trains the transports the pallet of boxes to the external warehouse. Once the pallets of boxes reach the external warehouse, it's placed in the buffer area before its loaded onto a roller conveyor by a forklift. Subsequently, the pallets of boxes are given new labels. Then the boxes are transferred to a cassette and transported to the storage area, where they are placed in the storage racks according to the part number. When a pull signal is received from the assembly plant, the boxes with the required part number are fetched from the storage rack and transported in cassettes to the shipping area in the external warehouse. At the shipping area, the cassettes are loaded onto a truck by a forklift and is transported to the assembly plant. Once the truck reaches the assembly plant, the cassettes are unloaded from the truck by a forklift and placed in a buffer. The boxes are taken from the cassettes at the buffer and transported to the specific assembly location. The boxes are again kept in a buffer before it reached the final assemblers.

The Material Flow Map (MFM) for the box flow is illustrated in Figure 5 below.

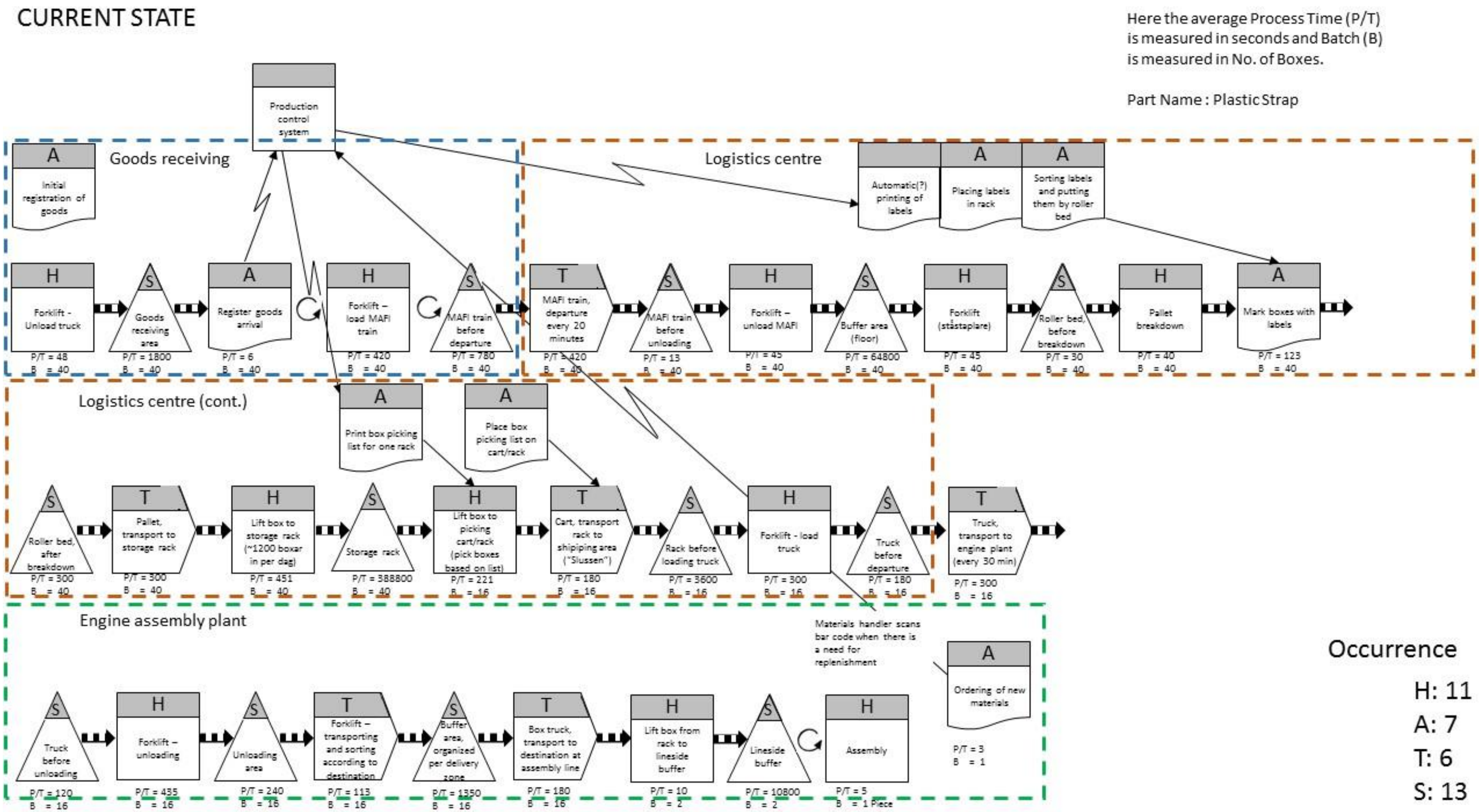


Figure 5 Material Flow Map - Box Flow

Measurement of throughput time and lead time

In box flow, we have considered a specific part called plastic strap which is one of the highly-consumed parts in this automotive industry and delivered every day from the supplier. Every day the company receives 2 pallets of plastic straps. Each pallet contains 20 boxes and each box has 1000 plastic straps. The batch size considered as a number of boxes throughout the flow. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is calculated. The table below describes the minimum, average and maximum process time for each activity. And based on these process times the throughput time and lead are calculated for the pallet flow.

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Goods Receiving				
1.	Forklift unload trucks	32	48	64
2.	Goods Receiving area	1800	1800	1800
3.	Register goods arrival	4	6	8
4.	Forklift load MAFI train	360	420	480
5.	MAFI train before departure	720	780	840
Throughput Time (Goods Receiving)		2916	3054	3192
External Warehouse (Logistics Centre)				
6.	MAFI train departure every 20 mins	420	420	420
7.	MAFI train before unloading	13	13	13
8.	Forklift unload MAFI	30	45	60
9.	Buffer area (Floor)	21600	64800	43200
10.	Forklift	30	45	60
11.	Roller bed before breakdown	30	30	30
12.	Pallet breakdown	20	40	60
13.	Mark boxes with labels	6	123	240
14.	Roller bed after breakdown	300	300	300
15.	Pallet transport to storage rack	300	300	300
16.	Lift box on to storage rack	22	451	880
17.	Storage rack	345600	388800	432000
18.	Lift box to picking cart or rack	26	221	416
19.	Cart, transport rack to shipping area	180	180	180
20.	Rack before loading truck	1800	3600	5400
21.	Forklift load truck	300	300	300
22.	Truck before departure	180	180	180
23.	Truck transport to engine plant	300	300	300
Throughput Time (External Warehouse)		371157	460148	484339
Engine assembly plant				
24.	Truck before unloading	120	120	120
25.	Forklift unloading	180	435	690
26.	Unloading area	180	240	300
27.	Forklift transporting and sorting according to destination	75	113	150

28.	Buffer area organized per delivery zone	900	1350	1800
29.	Box Truck, transport to destination at assembly line	120	180	240
30.	Lift box from rack to lineside buffer	10	10	10
31.	Lineside buffer	7200	10800	14400
Throughput Time (Engine assembly plant)		8785	13248	17710
Throughput Time		382858	476450	505241

Table 10 Throughput Time - Box Flow

Table 10 describes the throughput time of one box of plastic strap. From the calculation, it is found that the minimum throughput time is 382858 seconds (106.35 hours) and the maximum throughput time is 505241 seconds (140.34 hours). Therefore, the average throughput time of the specific part number is calculated to be 476450 seconds (132.34 hours).

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
1.	Ordering of new materials	3	3	3
Logistics Centre				
2.	Lift box to picking cart or rack	26	221	416
3.	Cart, transport rack to shipping area	180	180	180
4.	Rack before loading truck	1800	3600	5400
5.	Forklift load truck	300	300	300
6.	Truck before departure	180	180	180
7.	Truck transport to engine plant	300	300	300
Engine assembly plant				
8.	Truck before unloading	120	120	120
9.	Forklift unloading	180	435	690
10.	Unloading area	180	240	300
11.	Forklift transporting and sorting according to destination	75	113	150
12.	Buffer area organized per delivery zone	900	1350	1800
13.	Box Truck, transport to destination at assembly line	120	180	240
14.	Lift box from rack to inside buffer	10	10	10
Lead Time		4374	7232	10089

Table 11 Lead Time - Box flow

Table 11 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the external warehouse for one box of plastic strap. From the calculation, it is found that the minimum lead time is 4374 seconds (1.21 hours) and the maximum lead time is 10089seconds (2.80 hours). Therefore, the average lead time for the specific part number is calculated to be 7232 seconds (2 hours)

4.1.3. Case 3 – Car Assembly

The main difference, in this case, is that the material flow between the external warehouse and the assembly plant is carried out by a third party logistic provider. There is three type of material flows in this case which is materials in pallets, boxes and repacking of the materials from pallets to boxes. The third party logistic provider and assembly plant use the same IT system for a better information flow. The distance between the external warehouse and the assembly plant is around 2.5km, therefore the transportation of materials between the two location is involved with regular traffic on the road.

4.1.3.1. Pallet flow

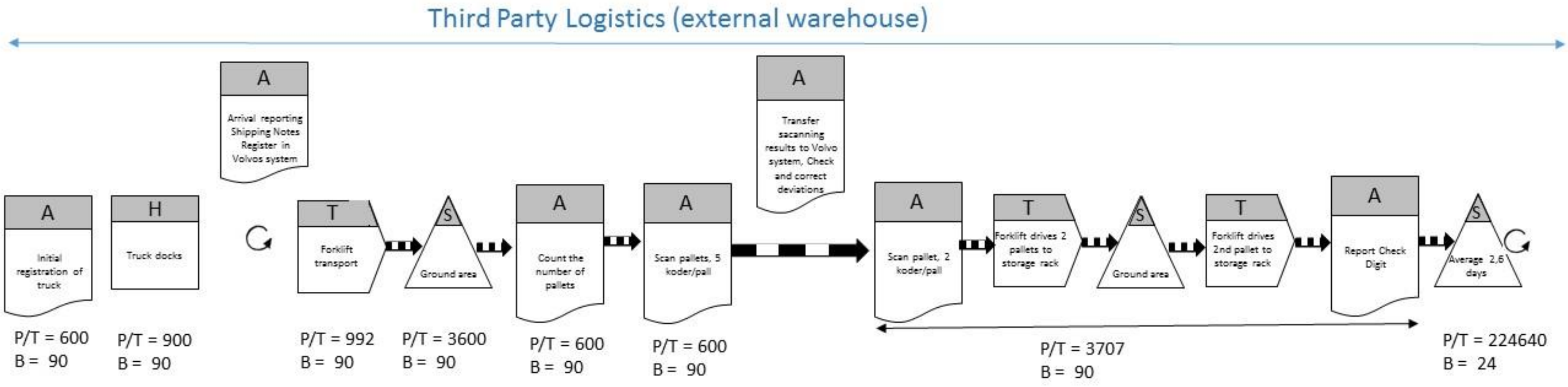
The pallet of materials arriving from the supplier is unloaded at the receiving area in the external warehouse by a forklift. The pallets are placed in a buffer area before it's transported to the storage area where it is loaded onto the storage racks. A moving floor conveyor is installed in the external warehouse, trucks delivering assembly and at the assembly plant. The moving floor conveyor helps in achieving an automatic loading and unloading of the materials and eliminates the need for a forklift to do so. When a pull signal is received from the assembly plant for material replenishment, the pallets are fetched from the storage racks and then placed onto the moving floor conveyor which further loads the pallets onto the truck. The truck leaves the external warehouse with pallets in fixed intervals of 30 minutes carrying around 70 pallets. When the truck reaches the assembly plant, the pallets are emptied onto a moving floor conveyor which takes them to the storage area. At the storage area, a forklift is used to pick the pallets and place it onto the storage racks. When the pull signals are received from the assembly, the pallets of required part number are fetched from the storage racks by a forklift onto a tugger train. The tugger train transports the pallets from storage area to the point of use at the assembly.

The Material Flow Map (MFM) for the pallet flow Figure 6 is illustrated below

CURRENT STATE

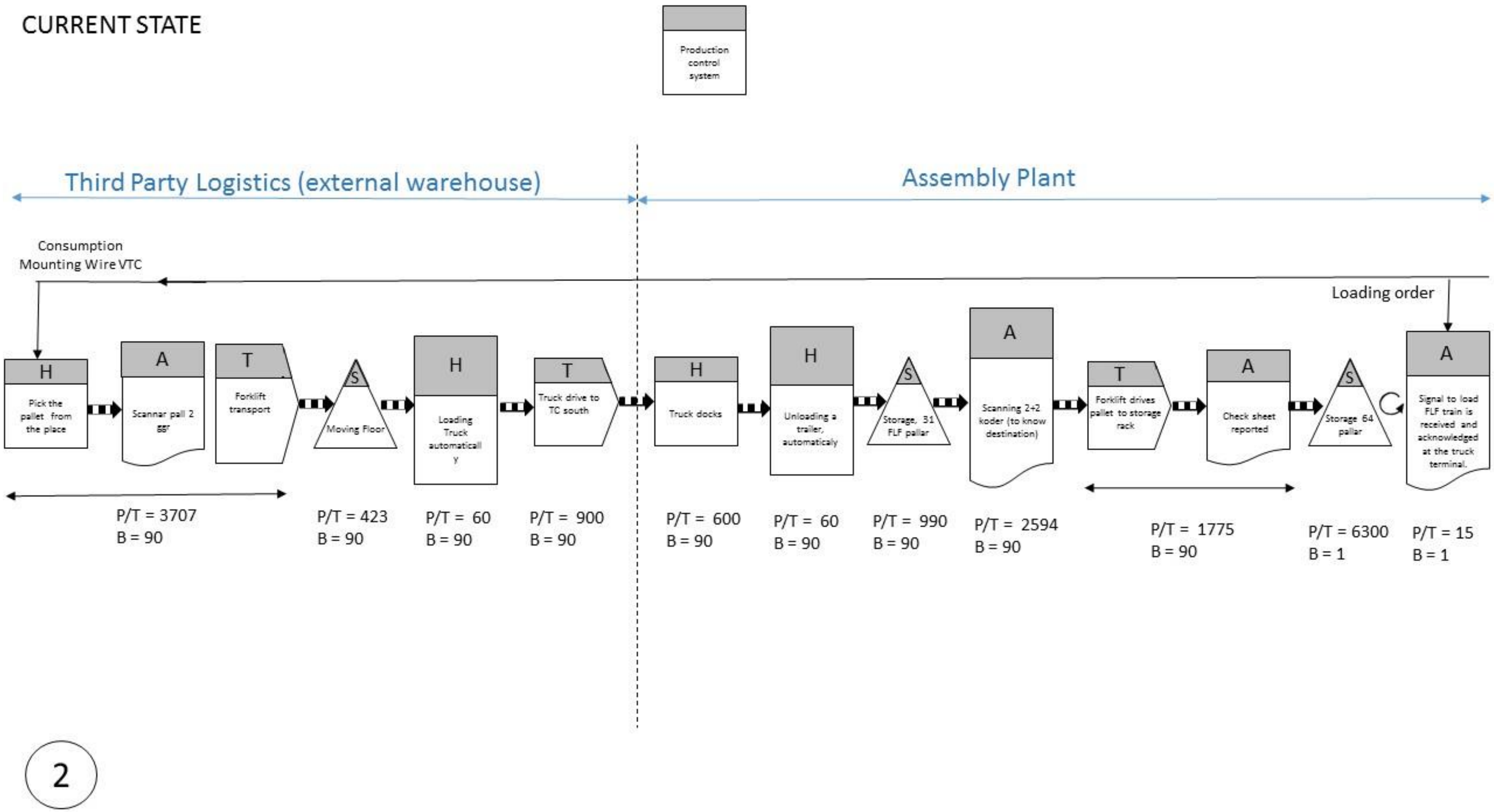
Here the average process time (P/T) is measured in Seconds and Batch (B) is measured in Number of palettes

Part Name : Battery Box



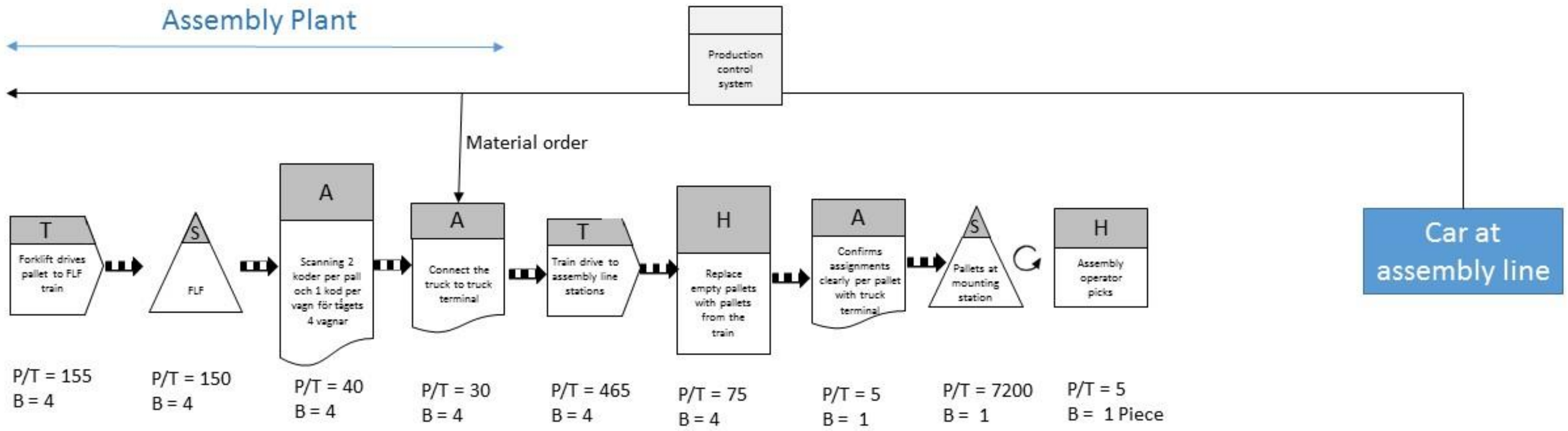
1

Figure 6 Material Flow Map - Pallet Flow



Material Flow Map - Pallet Flow (Continued)

CURRENT STATE



Total Occurence

H: 7
A: 14
T: 8
S: 8

3

Material Flow Map - Pallet Flow (Continued)

Measurement of throughput time and lead time

In Pallet flow, we have considered a specific part called Battery box, which is one of the high consuming part with this automotive industry. A pallet consists of 72 pieces of the Battery box and received twice a week to the external warehouse from the supplier. On a whole, the company receives 48 pallets per week

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Third Party Logistics (External Warehouse)				
1.	Initial Registration of Trucks	600	600	600
2.	Truck docks	600	900	1200
3.	Forklift transport	64	992	1920
4.	Ground area	1800	3600	5400
5.	Count the number of pallets	600	600	600
6.	Scan pallets	600	600	600
7.	Scan pallet 2 codes per pallet	213	3707	7200
8.	Forklift drives two pallets to storage rack			
9.	Ground area			
10.	Forklift drives two pallets to storage rack			
11.	Report check digit			
12.	Average 2,6 days	224640	224640	224640
13.	Pick the pallet from the place	213	3707	7200
14.	Scan two pallets			
15.	Forklift transport			
16.	Moving floor	423	423	423
17.	Loading truck automatic	60	60	60
18.	Truck driving to TC south	600	900	1200
Throughput time		230413	240729	251043
Assembly Plant				
19.	Truck docks	600	600	600
20.	Unloading the train automatically	60	60	60
21.	Storage 31 FLF pallets	180	990	1800
22.	Scanning two codes	57	2594	5130
23.	Forklift drive pallets to storage rack	39	1775	3510
24.	Check sheet reported			
25.	Storage 64 pallets	3600	6300	9000
26.	Signal to load FLF train	15	15	15
27.	Forklift drive pallets to FLF train	62	155	248
28.	FLF	120	150	180
29.	Scanning two codes	40	40	40
30.	Connect the truck to truck terminal	30	30	30
31.	Train drive to the assembly line station	180	465	900
32.	Replace empty pallets with pallets from the train	30	75	120

33.	Confirm assignment	5	5	5
34.	Pallet at mounting station	7200	7200	7200
Throughput time Assembly Plant		12218	20454	28838
Total throughput time		242631	261183	279881

Table 12 Throughput Time - Pallet Flow

Table 12 describes the throughput time of one pallet of the Battery box. From the calculation, it is found that the minimum throughput time 242631 seconds (67.39 hours) and the maximum throughput time is 279881 seconds (77.74 hours). Therefore, the average throughput time of the specific part number is calculated to be 261183 seconds (72.55 hours).

In this flow, when the material is ordered from the assembly plant the signal is sent to the storage area in the assembly plant as well the storage area in the external warehouse. The replenishment to lineside buffer (pallets mounting station) in the assembly plant takes place by transferring the material from the storage area in the assembly plant. Since this case has two storage points, two lead time calculations had been made. Table 13 shows the lead time of material replenishment from the storage area in the assembly plant and Table 14 shows the lead time of material replenishment from the storage area in external warehouse

Process No.	**Process**	**Process Time**		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
Assembly Plant				
1.	Forklift drive pallets to FLF train	62	155	248
2.	FLF	120	150	180
3.	Scanning two codes	40	40	40
4.	Connect the truck to truck terminal	30	30	30
5.	Train drive to the assembly line station	180	465	900
6.	Replace empty pallets with pallets from the train	30	75	120
7.	Confirm assignment	5	5	5
Lead time		467	920	1523

Table 13 Lead Time - Pallet Flow (Replenishment from local storage area)

Table 13 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the local storage in the assembly plant for one pallet of the Battery box. From the calculation, it is found that the minimum lead time 467 seconds (0.12 hours) and the maximum lead time is 1523 seconds (0.42 hours). Therefore, the average lead time for the specific part number is calculated to be 920 seconds (0.25 hours).

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Third Party Logistics (External Warehouse)				
1.	Pick the pallet from the place	213	3707	7200
2.	Scan two pallets			
3.	Forklift transport			
4.	Moving floor	423	423	423
5.	Loading truck automatic	60	60	60
6.	Truck driving to TC south	600	900	1200
Assembly Plant				
7.	Truck docks	600	600	600
8.	Unloadding the train automatically	60	60	60
9.	Storage 31 FLF pallets	180	990	1800
10.	Scanning two codes	57	2594	5130
11.	Forklift drive pallets to storage rack	39	1775	3510
12.	Check sheet reported			
13.	Storage 64 pallets	3600	6300	9000
14.	Signal to load FLF train	15	15	15
15.	Forklift drive pallets to FLF train	62	155	248
16.	FLF	120	150	180
17.	Scanning two codes	40	40	40
18.	Connect the truck to truck terminal	30	30	30
19.	Train drive to the assembly line station	180	465	900
20.	Replace empty pallets with pallets from the train	30	75	120
21.	Confirm assignment	5	5	5
Lead time		6314	18344	30521

Table 14 Lead Time - Pallet Flow (Replenishment from external warehouse)

Table 14 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from external warehouse for one pallet of the Battery box. From the calculation, it is found that the minimum lead time 6314 seconds (1.75 hours) and the maximum lead time is 30521 seconds (8.47 hours). Therefore, the average lead time for the specific part number is calculated to be 18344 seconds (5.09 hours).

4.1.3.2. Box flow

In box flow, the pallet of boxes arriving in trucks is cross-docked at the external warehouse. The pallets of boxes are unloaded and placed in the buffer area. The pallets of boxes are registered and sorted at this area before it is transported to the shipping area. The pallets with boxes are then loaded onto a truck by a forklift and transported to the assembly plant. When the pallets with the boxes reach the assembly plant, it is unloaded by a forklift and placed onto a tugger train. The tugger train transports the pallets of boxes to a box storage in the assembly plant after receiving a pull signal. Upon reaching the box storage, the boxes which have to be repacked to a different box size and the boxes which have to be transported in the existing boxes to the assembly line are sorted and separated.

The boxes which don't have to be repacked are placed in the storage racks at the assembly plant in pallets itself. Once the re-order point has reached, the box of required part number is loaded on to flow racks from the pallets. The boxes stay in queue till the pull signal from assembly has arrived for replenishment. Upon pull signal, the boxes are fetched from the flow racks one by one and loaded onto cassettes. The boxes are then transported to the buffer closer to the point of use at the assembly.

The materials which have to be repacked to different boxes are stored in a different storage rack in the assembly plant in pallets itself. Upon re-order point, the boxes are fetched and transported to the repacking area. When the repacking is done, the new boxes are stored in the same storage rack and transported to the point of use at the assembly in a similar way as other boxes.

The Material Flow Map (MFM) for the pallet flow Figure 7 is illustrated below

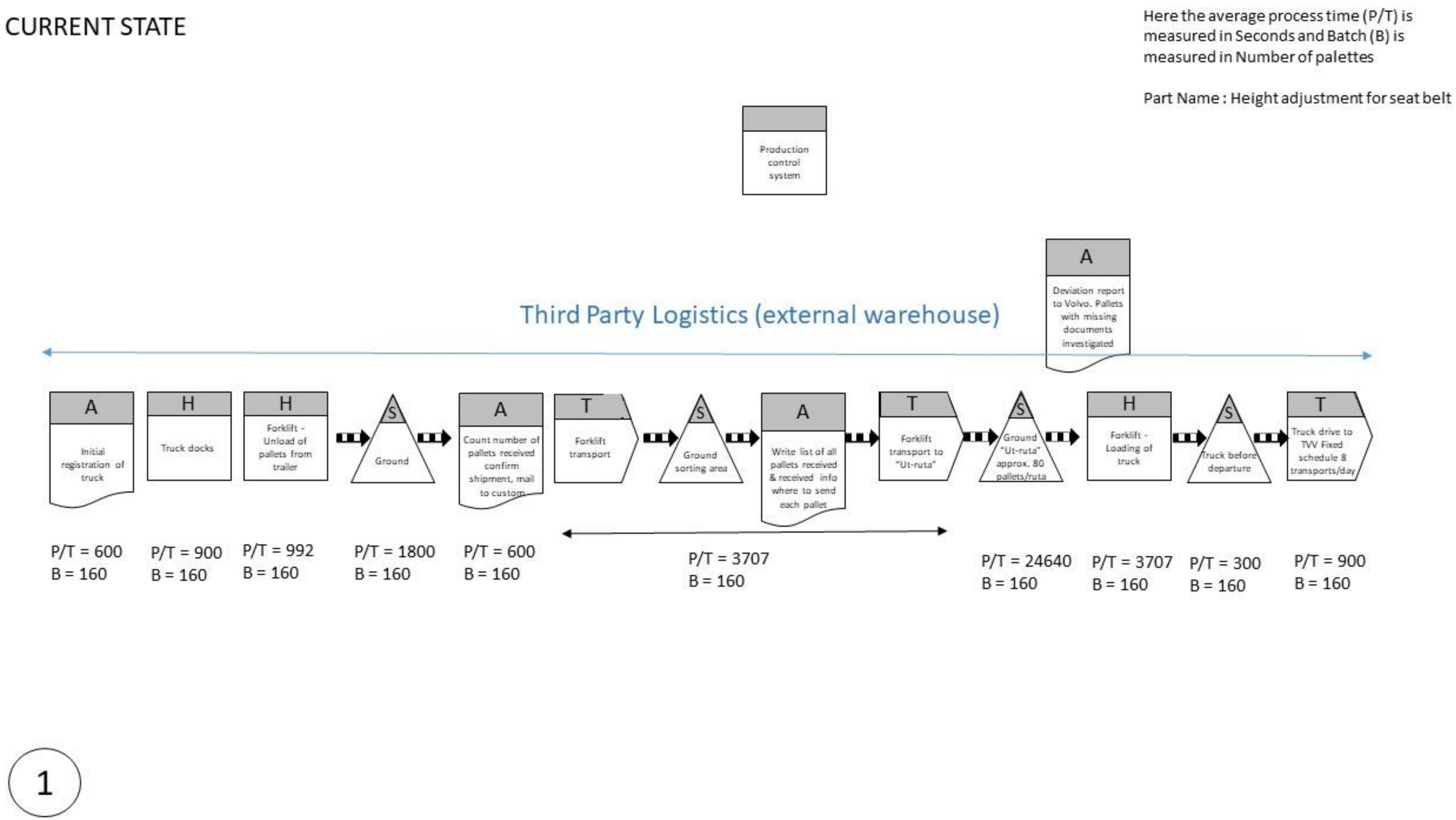
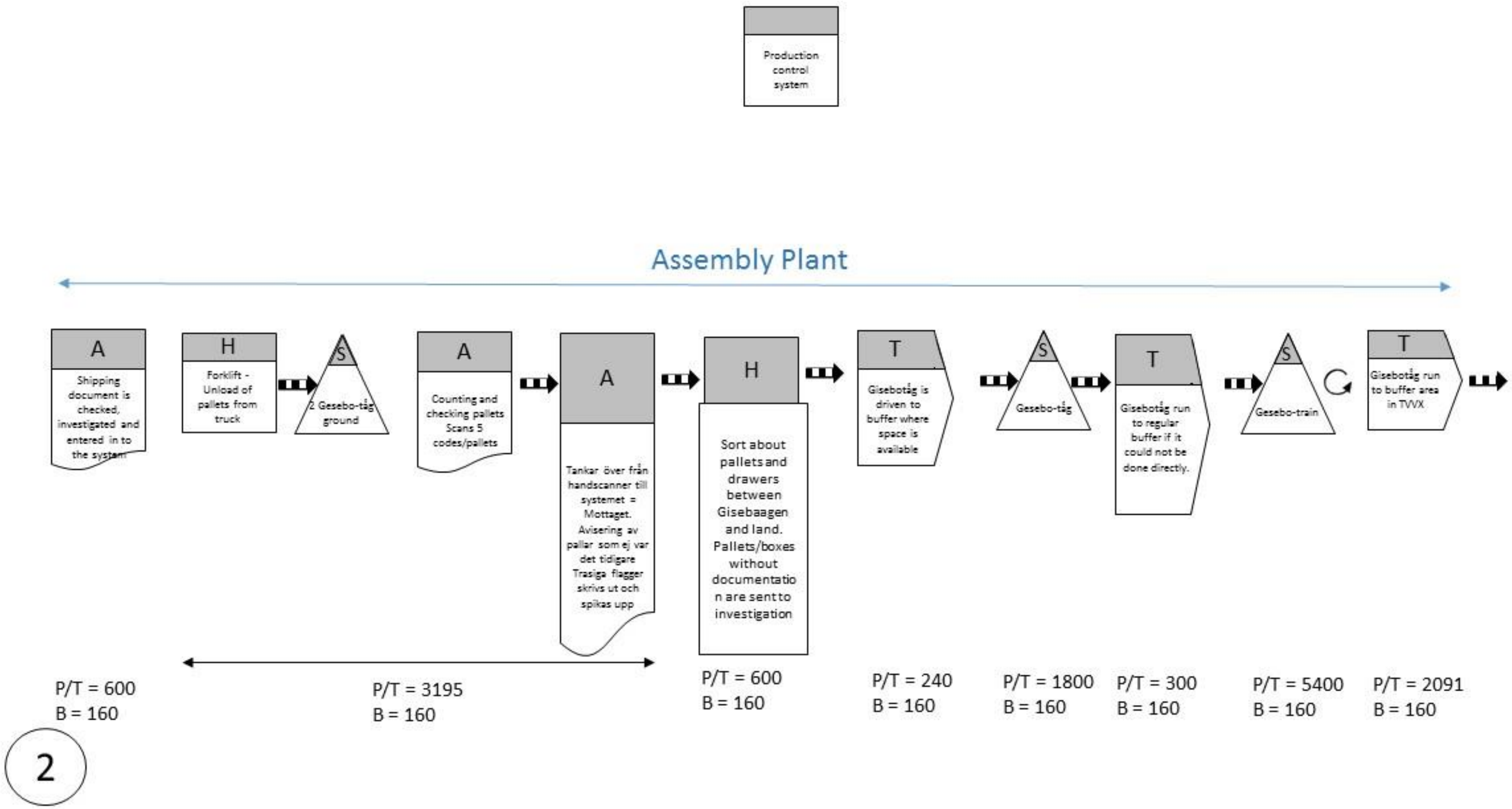
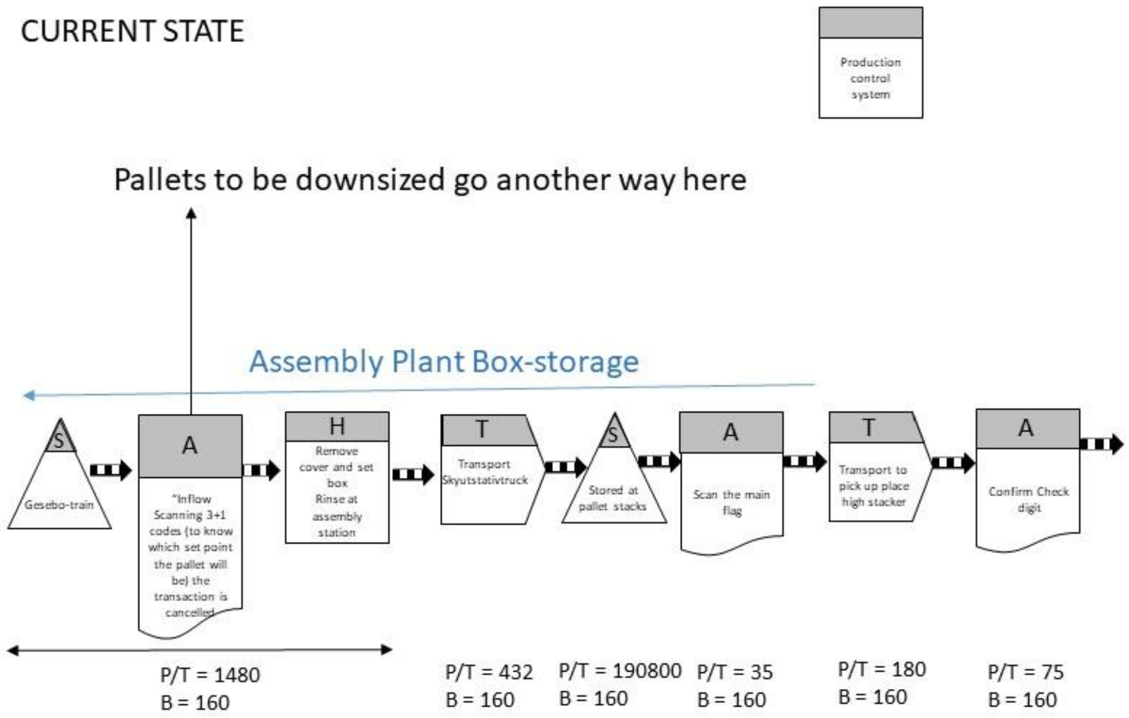


Figure 7 Material Flow Map - Box Flow

CURRENT STATE



Material Flow Map - Box Flow (Continued)



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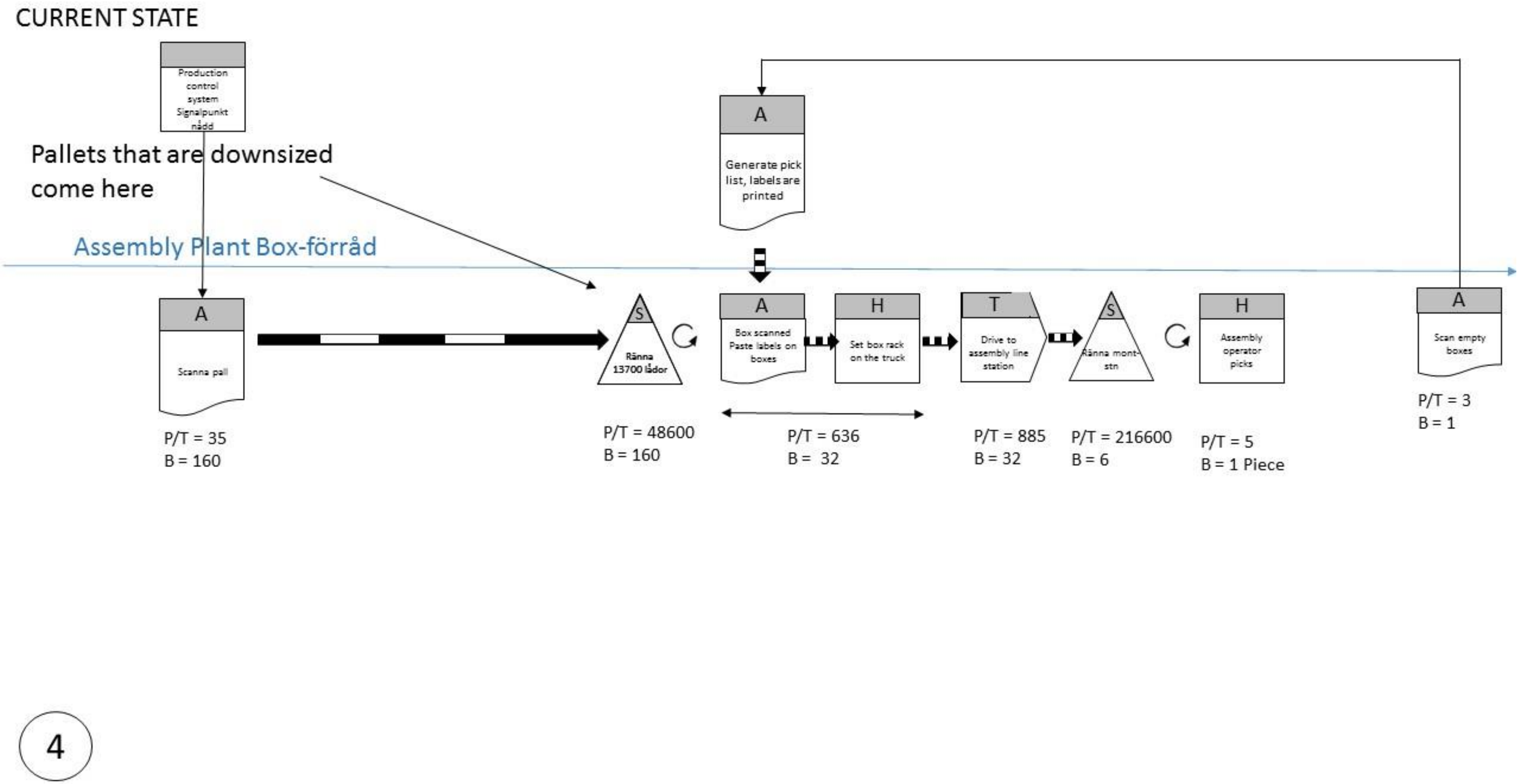
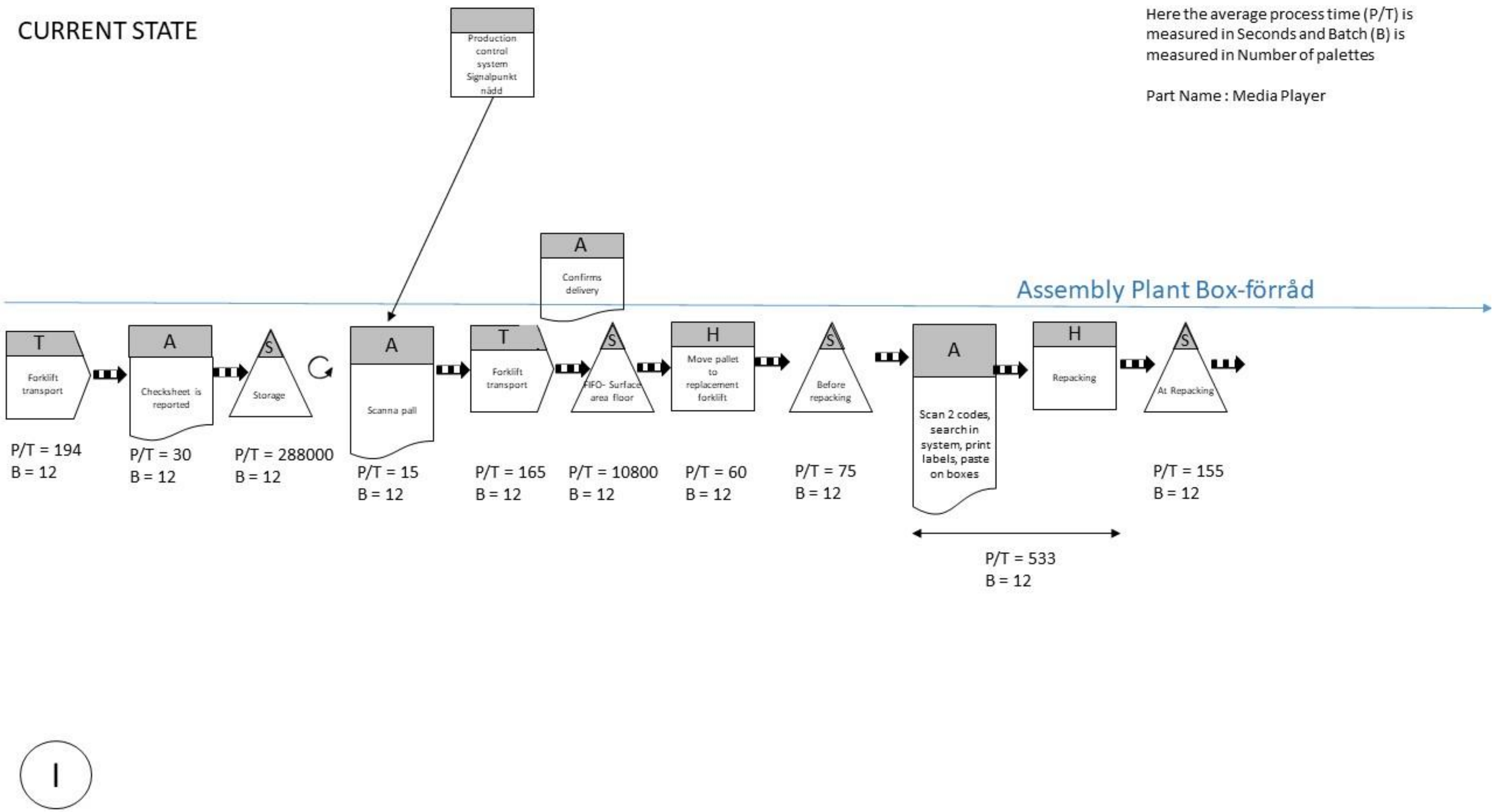
Material Flow Map - Box Flow (Continued)

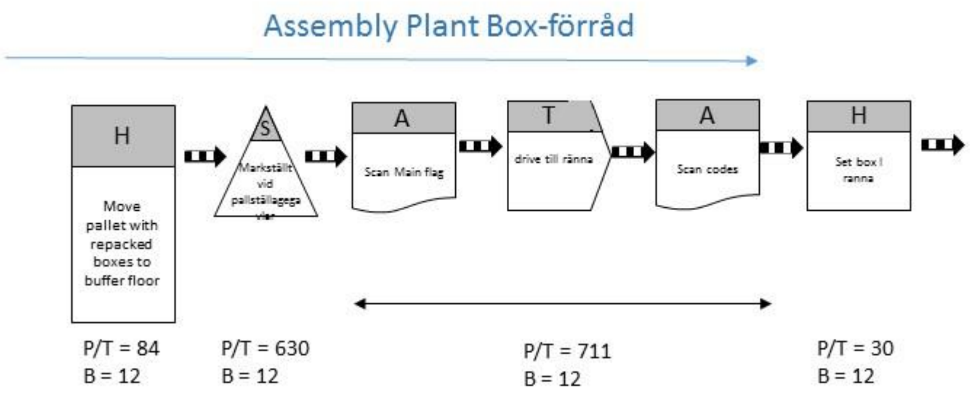


Material Flow Map - Box Flow (Continued)



Material Flow Map - Box Flow Repacking

CURRENT STATE



II

Total occurences without downsizing	Total occurences with downsizing
H: 8	H: 12
A: 11	A: 16
T: 9	T: 10
S: 11	S: 14

Material Flow Map - Box Flow Repacking (Continued)

Measurement of throughput time and lead time (Box Flow without repacking)

In box flow, we have considered a specific part called Height adjustment for seat belt, which is one of the high consuming part with this automotive industry. A pallet consists of 32 boxes and each box consist of 20 pieces of Height adjustment and received twice a week to the external warehouse from the supplier. On a whole, the company receives 9 pallets per week

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Third Party Logistics (External Warehouse)				
1.	Initial Registration of Trucks	600	600	600
2.	Truck docks	600	900	1200
3.	Forklift unload pallets from trailer	64	992	1920
4.	Ground	1800	3600	5400
5.	Count the number of pallets	600	600	600
6.	Forklift transport	213	3707	7200
7.	Ground sorting area			
8.	Write list of pallets received			
9.	Forklift transport ut-ruta			
10.	Ground ut-ruta	224640	224640	224640
11.	Forklift loading of truck	213	3707	7200
12.	Truck before departure	300	300	300
13.	Truck drives to TVV	600	900	1200
Throughput Time External Warehouse		229630	239946	250260
Assembly Plant				
14.	Shipping document checked	300	600	900
15.	Forklift unload pallets from truck	71	3195	6318
16.	Two Gesebo train ground			
17.	Counting and checking the pallets			
18.	Scanning pallets			
19.	Sorting of pallets and drawers	600	600	600
20.	Gesebo tag driven to buffer	120	240	360
21.	Gesebo tag (Storage)	1800	1800	1800
22.	Gesebo tag run to regular buffer	300	300	300
23.	Gesebo tag (Storage)	3600	5400	7200
24.	Gesebo tag runs into buffer area in TVVX	113	2091	4068
Throughput Time Assembly Plant		6904	14226	21546
Assembly Plant Box Storage				
25.	Gesebo tag	80	1480	2880
26.	Inflow			
27.	Remove cover and set box			
28.	Transport	144	432	720
29.	Stored at pallet stacks	72000	190800	309600
30.	Scan the main flag	35	35	35
31.	Transport to pick up place at high stacker	180	180	180
32.	Confirm check digit	75	75	75
	Throughput Time Assembly Plant Box Storage	72514	193002	313490

Assembly Plant Box-Forrad				
33.	Scan pallets	35	35	35
34.	Ranna	28800	48600	68400
35.	Box scanned, Paste labels on boxes	636	636	636
36.	Set box racks on the truck			
37.	Drive to assembly station	672	885	1098
38.	Ranna mont station	1200	4200	7200
Throughput Time Assembly Plant Box storage		31343	54356	77369
Total Throughput time		340391	501530	662665

Table 15 Throughput Time - Box Flow (Without repacking)

Table 15 describes the throughput time of one box of Height adjustment for the seat belt. From the calculation, it is found that the minimum throughput time 340391 seconds (94.55 hours) and the maximum throughput time is 662665 seconds (184.07 hours). Therefore, the average throughput time of the specific part number is calculated to be 501530 seconds (139.31 hours).

Process No.	**Process**	**Process Time**		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
Assembly Plant Box-Forrad				
1.	Scan empty boxes (ordering new materials)	3	3	3
2.	Box scanned, Paste labels on boxes	636	636	636
3.	Set box racks on the truck			
4.	Drive to assembly station	672	885	1098
Lead Time		1311	1524	1737

Table 16 Lead Time - Box Flow (Without repacking)

Table 16 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the storage area in the assembly plant for one box of Height adjustment for the seat belt. From the calculation, it is found that the minimum lead time 1311 seconds (0.36 hours) and the maximum lead time is 1737 seconds (0.48 hours). Therefore, the average lead time for the specific part number is calculated to be 1524 seconds (0.42 hours)

Measurement of throughput time and lead time (Box Flow with repacking)

In this box flow, we have considered a specific part called Media Player, which is one of the parts that goes through the procedure of repacking/downsizing with this automotive industry. A pallet consists of 12 boxes and each box consist of 8 pieces of Media Player and received twice a week from the supplier. On a whole, the company receives 2 pallets per week

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
Third Party Logistics (External Warehouse)				
1.	Initial Registration of Trucks	600	600	600
2.	Truck docks	600	900	1200
3.	Forklift unload pallets from trailer	64	992	1920
4.	Ground	1800	3600	5400
5.	Count the number of pallets	600	600	600
6.	Forklift transport	213	3707	7200
7.	Ground sorting area			
8.	Write list of pallets received			
9.	Forklift transport ut-ruta			
10.	Ground ut-ruta	224640	224640	224640
11.	Forklift loading of truck	213	3707	7200
12.	Truck before departure	300	300	300
13.	Truck drives to TVV	600	900	1200
Throughput Time External Warehouse		229630	239946	250260
Assembly Plant				
19.	Shipping document checked	300	600	900
20.	Forklift unload pallets from truck	71	3195	6318
21.	Two Gesebo train ground			
22.	Counting and checking the pallets			
23.	Scanning pallets			
24.	Sorting of pallets and drawers	600	600	600
25.	Gesebo tag driven to buffer	120	240	360
26.	Gesebo tag (Storage)	1800	1800	1800
27.	Gesebo tag run to regular buffer	300	300	300
28.	Gesebo tag (Storage)	3600	5400	7200
29.	Gesebo tag runs into buffer area in TVVX	113	2091	4068
Throughput time Assembly Plant		6904	14226	21546
Assembly Plant Box- forrad				
30.	Forklift transport	129	129	129
31.	Check sheet is reported	30	30	30
32.	Storage	180000	288000	396000
33.	Scan pallets	15	15	15
34.	Forklift transport	165	165	165
35.	FIFO surface area floor	7200	10800	14400
36.	Move pallets to replacement forklift	60	60	60

37.	Before Repacking	75	75	75
38.	Scan two codes	82	533	984
39.	Repacking			
40.	At repacking	10	155	300
41.	Move pallet with repacked boxes to buffer floor	84	84	84
42.	Storage	60	630	1200
43.	Scan main flag	222	711	1200
44.	Drive to Ranna			
45.	Scan codes			
46.	Set box in Ranna	30	30	30
47.	Ranna	28800	48600	68400
48.	Box scanned, Paste labels on boxes	636	636	636
49.	Set box racks on the truck			
50.	Drive to assembly station	672	885	1098
51.	Ranna mont stattion	1200	216600	432000
Throughput time Assembly Plant Box forrad		219470	568154	916806
Total throughput time		456004	822310	1188612

Table 17 Throughput Time - Box Flow (With repacking)

Table 17 describes the throughput time of one box of the Media player. From the calculation, it is found that the minimum throughput time 456004 seconds (126.66 hours) and the maximum throughput time is 1188612 seconds (330.17 hours). Therefore, the average throughput time of the specific part number is calculated to be 822310 seconds (228.41 hours).

Process No.	**Process**	**Process Time**		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
Assembly Plant Box-Forrad				
1.	Scan empty boxes (ordering new materials)	3	3	3
2.	Box scanned, Paste labels on boxes	636	636	636
3.	Set box racks on the truck			
4.	Drive to assembly station	672	885	1098
Lead Time		1311	1524	1737

Table 18 Lead Time - Box Flow (With repacking)

Table 18 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the storage area for one box of the Media player. From the calculation, it is found that the minimum lead time 1311 seconds (0.36 hours) and the maximum lead time is 1737 seconds (0.48 hours). Therefore, the average lead time for the specific part number is calculated to be 1524 seconds (0.42 hours)

4.1.4. Case 4 – Truck Engine Assembly (No external warehouse)

In this case, the warehouse is centralized within the assembly plant. Two type of flow has been considered for this case. In each of the flows, the throughput time and the lead time has been calculated.

4.1.4.1. Pallet flow

The pallet of materials is coming in a truck from the suppliers. An initial registration of the goods is done at the beginning before it reaches the unloading area. The forklifts unload a stack of 4 pallets from the truck and place it on a roller bed. The stack of 4 pallets is then broken down into single pallets at the roller bed by the forklift operator. The pallets are then registered by an automatic barcode scanner while they are moved on the conveyor to an automatic storage location. While receiving a pull signal from the assembly station, the pallet of the required part number was conveyed to the drop zone in the shop floor from the storage. The pallets are then lifted onto a tugger train which is then transferred to the area which is near the assembly line. When the tugger train reaches the line side buffer, the driver disconnects the particular cart of pallets after taking out the empty bin. At the assembly station, two bin system is followed and the reorder point for the two-bin system is one full pallet. When the first bin is emptied in the lineside buffer, the kitting operator at the station exchange the second bin and pushes back the first bin. During this process, the kitting operator must scan the barcode of the first bin indicating the need for material replenishment.

The Material Flow Map (MFM) for the pallet flow Figure 8 is illustrated below.

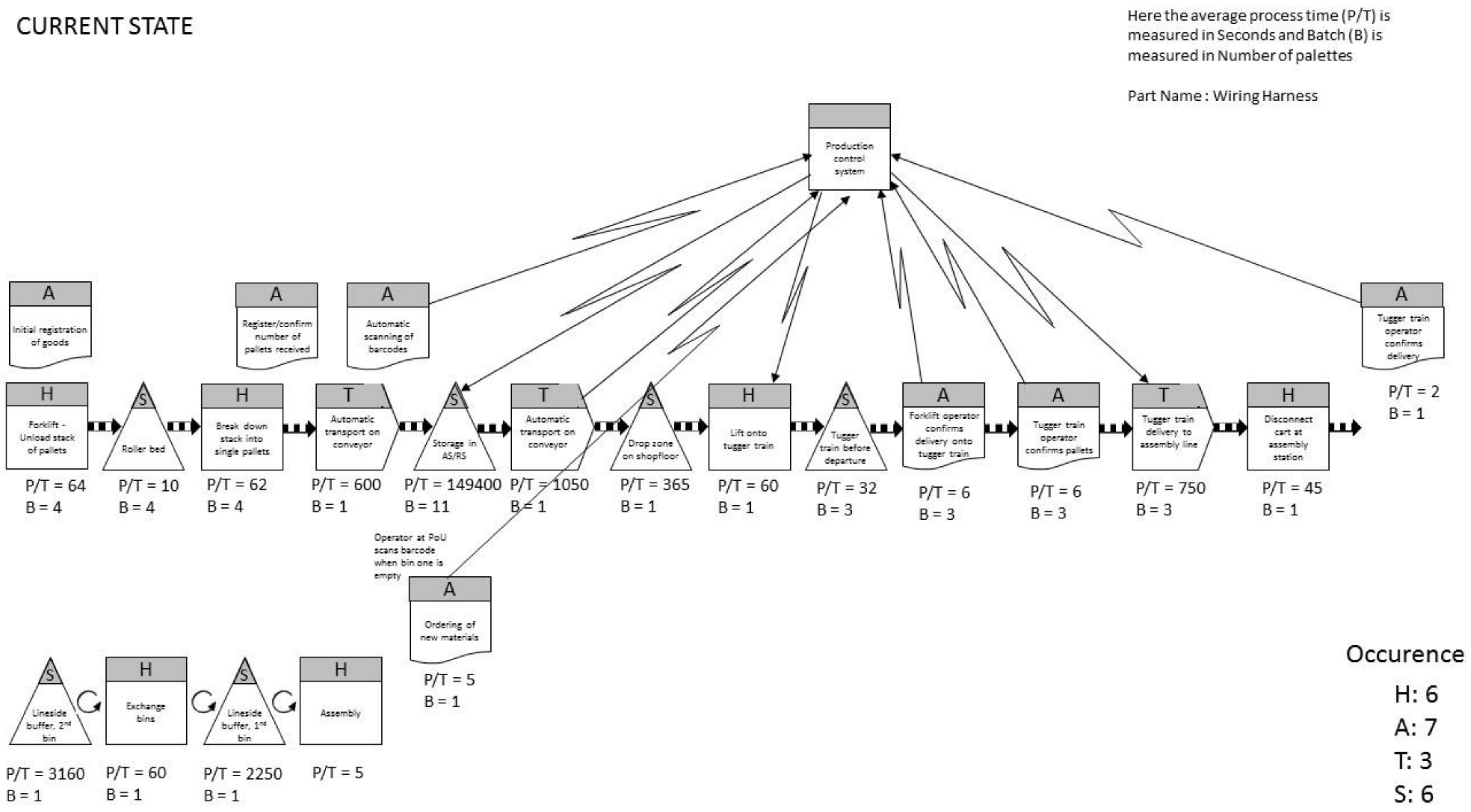


Figure 8 Material Flow Map - Pallet Flow

Measurement of throughput time and lead time

In pallet flow, we have considered a specific part called Wiring harness, which is one of the highly-consumed parts in this automotive industry and delivered every day from the supplier. A pallet consists of 24 pieces of the Wiring harness. Every day on an average, the company receives 12 pallets of the Wiring harness from the supplier. The process time for the first pallet to flow through the specific activity as in pallet flow map is considered as the minimum process time and the time is taken for the final pallet to flow through the specific activity is considered as the maximum process time. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is considered.

Process No.	**Process**	**Process Time**		
		Min (Sec)	**Avg (Sec)**	**Max (Sec)**
1.	Forklift unload stack of pallets	32	64	96
2.	Roller Bed	5	10	15
3.	Break down stacks into single pallets	31	62	93
4.	Automatic transport on conveyor	600	600	600
5.	Storage in AS/RS	97200	149400	201600
6.	Automatic transport on conveyor	900	1050	1200
7.	Drop zone on shop floor	10	365	720
8.	Lift onto tugger train	30	60	90
9.	Tugger train before departure	2	32	62
10.	Forklift operator confirms delivery onto tugger train	6	6	6
11.	Tugger train operator confirms pallets	6	6	6
12.	Tugger train delivery to assembly line	300	750	1200
13.	Disconnect cart at assembly station	45	45	45
14.	Tugger train operator confirms delivery	2	2	2
15.	Lineside buffer, 2nd bin	3160	3160	3160
16.	Exchange bins	60	60	60
17.	Lineside buffer, 1st bin	180	2250	4320
Throughput Time		102569	157922	213275

Table 19 Throughput Time - Pallet Flow

Table 19 describes the throughput time of one pallet of the Wiring harness. From the calculation, it is found that the minimum throughput time is 102569 seconds (28.5 hours) and the maximum throughput time is 213275 seconds (59.2 hours). Therefore, the average throughput time of the specific part number is calculated to be 157922 seconds (43.86 hours).

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
1	Ordering of new materials	5	5	5
2.	Automatic transport on conveyor	900	1050	1200
3.	Drop zone on shop floor	10	365	720
4.	Lift onto tugger train	30	60	90
5.	Tugger train before departure	2	32	62
6.	Forklift operator confirms delivery onto tugger train	6	6	6
7.	Tugger train operator confirms pallets	6	6	6
8.	Tugger train delivery to assembly line	300	750	1200
9.	Disconnect cart at assembly station	45	45	45
10.	Tugger train operator confirms delivery	2	2	2
Lead Time		1306	2321	3336

Table 20 Lead Time - Pallet Flow

Table 20 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer from the warehouse for one pallet of the Wiring harness. From the calculation, it is found that the minimum lead time is 1306 seconds (0.36 hours) and the maximum lead time is 3336 seconds (0.92 hours). Therefore, the average lead time for the specific part number is calculated as 2321 seconds (0.64 hours).

4.1.4.2. Box flow

In this flow, the boxes which are arriving from the suppliers in pallets are unloaded. Before placing the pallets of boxes on a roller conveyor, the pallets of boxes are sorted based on the destination at the storage. The sorting is done on the ground and after that, the forklift places them onto the roller bed. Roller bed takes the pallets of boxes into the factory where the forklift operators do various administrative process such as scanning and registering of pallets and deliver it to the storage area based on the destination of the respective pallet of boxes. And in the plant with the help of a forklift, the boxes with pallets are picked up and placed in a buffer location in a storage rack. Once the reorder point has reached, a pallet of required part number was transferred to the labelling area and each box was given a new label by the removing old one provided by the supplier. Then the boxes are transferred to a new storage location. At the new storage location, two bin system is followed and the boxes after labelling are placed in the second bin. When an order comes from the assembly line the boxes are picked up from the first bin and then transferred to the assembly station by a tugger train. The tugger train operator confirms the delivery of the boxes to the lineside buffer by means of ring scanner. At the assembly station, the kitting operator scans the empty box by means of barcode scanner which gives a signal for replenishment to the production control system.

The Material Flow Map (MFM) for the box flow Figure 9 is attached below.

CURRENT STATE

Deliveries of boxes should be made to the assembly line within 2 hours after order from the line

Here the average process time (P/T) is measured in Seconds and Batch (B) is measured in Number of boxes

Part Name: Coolant Pipe

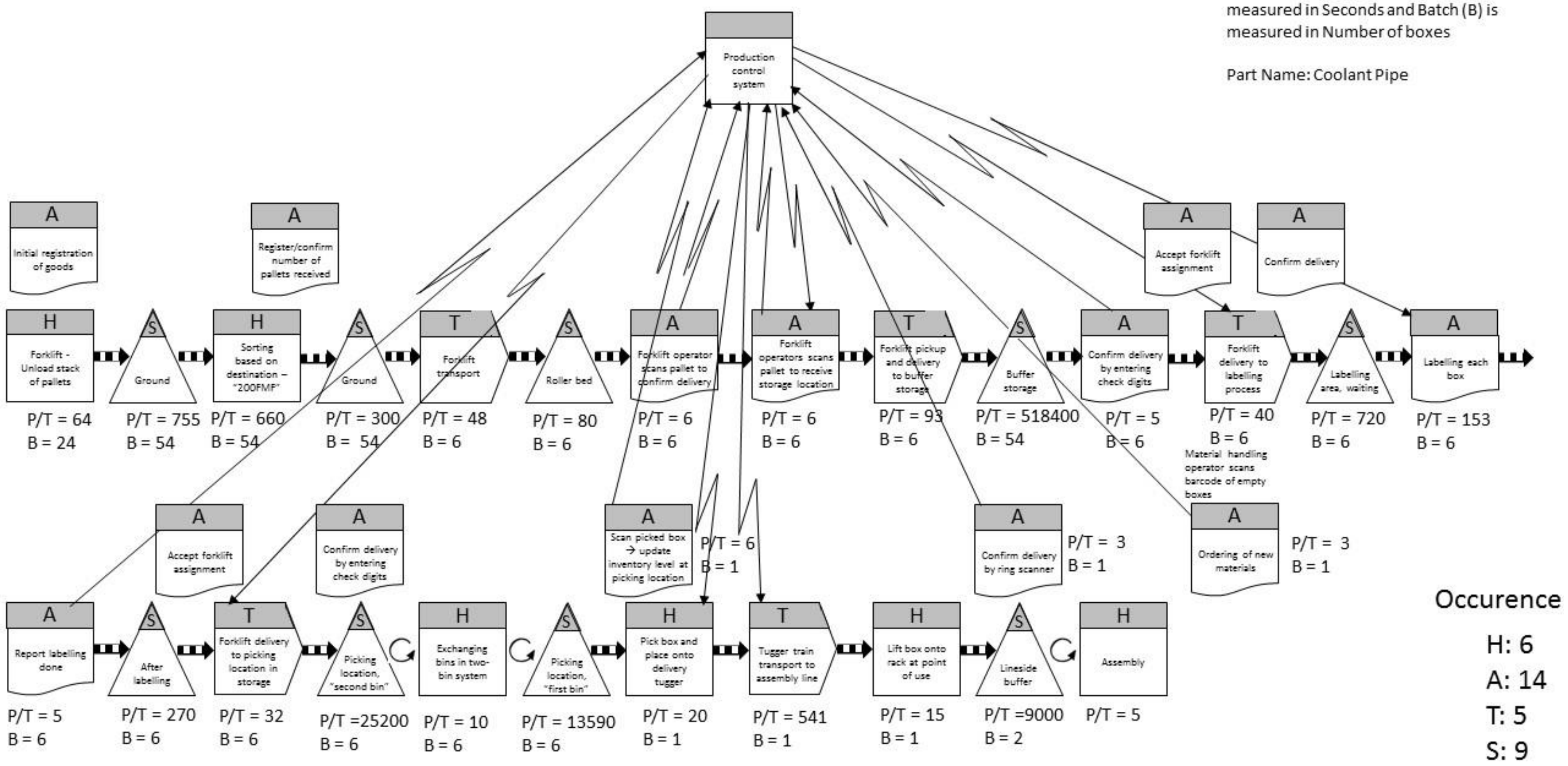


Figure 9 Material Flow Map - Box Flow

Measurement of throughput time and lead time

In box flow, we have considered a specific part called Coolant Pipe, which is also a highly-consumed part by the automotive industry in this case. A pallet consists of 6 boxes of Coolant Pipe and each box consist of 25 pieces. The company receives 9 pallets of Coolant Pipe (54 boxes) every week from the supplier. The process time for a first pallet (6 boxes) to flow through the specific activity as in box flow map is considered as the minimum process time and the time is taken for the final pallet (6 boxes) to flow through the specific activity is considered as the maximum process time. To calculate the appropriate lead time and throughput time, the average of the minimum and the maximum process time is considered. From the picking location 1st bin, the tugger train operator picks up one box of Coolant Pipe from the pallet when the order is made from the lineside buffer. |In lineside buffer, two boxes of Coolant Pipe are maintained as a buffer. As the kitting operator picks up one piece of Coolant Pipe for every 180 seconds, the first piece of the box has minimum process time and the final piece of the box takes the maximum process time to reach the assembly.

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
1.	Forklift unload stack of pallets	32	64	96
2.	Ground	311	755	1200
3.	Sorting based on destination	660	660	660
4.	Ground	300	300	300
5.	Forklift Transport	24	48	72
6.	Roller Bed	40	80	120
7.	Forklift operator scans pallet to confirm delivery	6	6	6
8.	Forklift operator scans pallet to receive storage location	6	6	6
9.	Forklift pickup and delivery to buffer storage	44	93	143
10.	Buffer storage	86400	518400	950400
11.	Confirm delivery by entering check digits	5	5	5
12.	Forklift delivery to labelling process	40	40	40
13.	Labelling area waiting	240	720	1200
14.	Labelling a pallet of box	153	153	153
15.	Report labelling done	5	5	5
16.	After labelling	120	270	420
17.	Forklift delivery to picking location in storage	32	32	32
18.	Picking location 2nd bin	25200	25200	25200
19.	Exchange bins in two bin system	10	10	10
20.	Picking location 1st bin	180	13590	27000
21.	Pick box onto delivery tugger	20	20	20
22.	Update inventory level	6	6	6
23.	Tugger train transport to assembly line	182	541	900
24.	Lift box onto rack at point of use	15	15	15
25.	Confirms delivery by ring scanner	3	3	3

26.	Lineside buffer	4500	9000	13500
Throughput Time		118534	570022	1021512

Table 21 Throughput Time - Box Flow

Table 21 describes the throughput time of one box of Coolant Pipe. From the calculation, it is found that the minimum throughput time is 118534 seconds (32.92 hours) and the maximum throughput time is 1021512 seconds (283.75 hours). Therefore, the average throughput time of the specific part number is calculated as 570022 seconds (158.34 hours).

Process No.	Process	Process Time		
		Min (Sec)	Avg (Sec)	Max (Sec)
1.	Ordering of new materials	3	3	3
2.	Pick box and place onto the delivery tugger	20	20	20
3.	Update inventory level	6	6	6
4.	Tugger train transport to assembly line	182	541	900
5.	Lift box onto rack at point of use	15	15	15
6.	Confirms delivery by ring scanner	3	3	3
Lead Time		229	588	947

Table 22 Lead Time - Box Flow

Table 22 describes the lead time between ordering of material from the assembly plant till the material reaches the lineside buffer for one box of Coolant Pipe. From the calculation, it is found that the minimum lead time is 25651 seconds (0.06 hours) and the maximum throughput time is 53189 seconds (0.26 hours). Therefore, the average lead time for the specific part number is calculated as 39420 seconds (0.16 hours).

5. Cross-Case Analysis

In this Chapter, two types of cross-case analysis have been made between the four cases considered. The first cross-case analysis focus on comparing the activities such as handling, administration activities, transportation and storage as per Material Flow Map between the four cases considered. The second Cross case analysis focus on comparing throughput time and lead time between the four cases considered

5.1. Cross-Case Analysis - Activities

Cross-case analysis has been made on comparing the process time taken for four different activities such as handling, administration activities, transportation and storage as per Material Flow Map. In each case from the flow map, the sum of average process time corresponding to handling, administration, transportation and storage are calculated and listed in Table 23. In addition to average process time, a number of occurrences taking place in handling, administration, transportation and storage are made in Table 24 and comparison are made based on that as well.

Case	Flow Type	Handling Time (Hours)	Administration Time (Hours)	Transportation Time (Hours)	Storage Time (Hours)
Case 1	**Pallet Flow**	0.20	0.18	0.48	19.78
	Box Flow	0.77	0.25	0.61	121.55
Case 2	**Pallet Flow**	0.66	0.07	0.49	83.51
	Box Flow	0.56	0.03	0.41	131.3
Case 3	**Pallet Flow**	1.50	1.44	3.25	67.58
	Box Flow	2.41	1.01	2.23	193.45
	Box Flow - Downsize	2.44	1.05	2.31	223.27
Case 4	**Pallet Flow**	0.09	0.005	0.66	43.11
	Box Flow	0.21	0.006	0.20	157.86

Table 23 Cross Case Analysis - Activities Time

Case	Flow Type	Handling Occurrences	Administration Occurrences	Transportation Occurrences	Storage Occurrences
Case 1	**Pallet Flow**	5	7	5	8
	Box Flow	14	9	6	12
Case 2	**Pallet Flow**	9	8	7	14
	Box Flow	11	7	6	13
Case 3	**Pallet Flow**	7	14	8	8
	Box Flow	8	11	9	11
	Box Flow - Downsize	12	16	10	14
Case 4	**Pallet Flow**	6	7	3	6
	Box Flow	6	14	5	9

Table 24 Cross-Case Analysis - Activities Occurrences

5.1.1. Handling

Compared to other cases, case 4 with no external warehouse has a minimum number of occurrences of handling. This, in turn, leads to minimum handling time of 329 seconds (0.09 hours) for pallet flow and 774 seconds (0.21 hours) for box flow. The pallet flow of case 1 also found to have similar or less occurrence of handling as in case 4. This is because the material is directly transferred to lineside buffer in the assembly plant from the external warehouse, which reduces the handling activities and time. When we compare, pallet flows of case 1 and 2 which is the same company has a significant difference in the handling process. This is due to the fact that the case 1 has external warehouse within the premises of the assembly plant whereas, Case 2 has the external warehouses few hundred meters away from the assembly plant. This leads to the involvement additional transportation by trucks which increases the handling process in the case 2. In addition to that, case 2 (pallet flow) stores the material both in assembly plant as well as in external warehouse, which doubles the work of loading and unloading pallets to the storage rack and thus increases the occurrences of handling activity and time. Case 1 of box flow has the highest number of occurrence of handling activities as well as the handling time. The handling time is found to be 2781 seconds (0.77 hours). In this case of box flow, there is an additional process of repacking/downsizing which increases the number of handling activities and time. In addition to repacking, the number of buffers within the assembly plant increases the handling activities such as the use of a forklift to load roller bed and tugger train. Similar to that of box flow in case 1, both pallet and box flow of case 2 found to have a high number of handling occurrence and time. The use of external warehouse which is away from the assembly plant leads to the involvement of additional activities such loading and unloading of trucks which in turn increases the handling occurrences. In addition to that, the high number of storage buffers also increases the number of handling occurrences and time. Flows in Case 3 seems to have highest handling time when compared to other cases. The industry dealing with case 3 uses the third-party logistics as their external warehouse, where they store the material primarily that are received from the supplier. In addition, the material is stored in the storage racks of the assembly plant. Both together increases the handling time and occurrences for this case. However, among the different flows in Case 3, box flow of downsizing seems to have the highest handling time because the material has to go through the process of repacking and different storage point involves loading and unloading by means of the forklift which increase the handling activity and time greatly.

5.1.2. Administration

When we analyse all the cases, Case 3 has the highest number of administrative activities as the pallet or box is scanned so many times such as during initial counting of pallets, obtaining the location in external warehouse for the forklift to transfer the material from truck, transferring the materials from storage rack of external warehouse to outbound delivery area, number of pallets loaded in the truck, number of pallets that are unloaded in the assembly plant, forklift operator scanning the pallets before loading the tugger train from the truck, Tugger train confirming the delivery of materials by scanning the pallets. The scanning takes place throughout the flow to update the IT system that the material has passed through the certain process which increases the administration activities and time (Pallet - 1.44 hours, Box - 1.01 hours & Box downsized – 1.05 hours) greatly. Similarly, box flow of case 4 with no external warehouse, the reason behind having a high number of administration process is due to the labelling activity that the boxes have to go through. This additional labelling process is carried out to ensure a proper information flow between the production control system and the different process in the material flow. However, the high number of occurrence doesn't increase the administration time, because most of the administrative process are happening simultaneously with other processes in the flow. But in the same case, the pallet flow found to have the minimum administration activities since there is no additional activity of labelling which leads to slightly lesser administration time when compared to box flow. Comparing box flow of Case 1 & 2 which is of the same automotive manufacturer, case 1 found to have higher administration time. This is because the goods are initially provided with yellow labels in goods receiving area which is replaced by another label after downsizing in the external warehouse which consumes more time. In addition to this, printing of labels is not done parallelly which further increases the administration time. Whereas in case 2, only one label is provided for the box throughout the flow and printing of the labels takes place in parallel to another process which reduces the administration time. Comparing the pallet flow of case 1 & 2, Case 2 found to have less administration time because they are provided with one label throughout the flow and printing of labels are done parallel to another process. Whereas the case 1, labelling is done in both goods receiving area and in the external warehouse which increases the administration time. Comparing pallet flow of Case 1&2 (external warehouse) with case 4 (no external warehouse), case 4 found to have less administration time (0.005 hours). This is because the automotive manufacturer dealing with case 4 scans the label that is provided by the supplier itself and the scanning activities are activities are carried out in parallel. Whereas the automotive manufacturer of Case 1&2 prints their own labels for the incoming materials which increase the administration time greatly. In addition to the labels, in case 4, the material is stored and retrieved from the warehouse that is within the assembly plant. Hence the administration occurrences are less and further reducing the administration time.

5.1.3. Transportation

In case 4, where there is no external warehouse, found to have a minimum number of occurrence of transportation for both pallet and box flow. This is due to the fact that the warehouse is located within the assembly plant and only conveyor, forklift and tugger trains are used for in-plant transportation activities. However, the pallet flow of this case has the maximum transportation time compared to other cases. The pallet flow uses roller conveyor from the unloading area till the storage to transfer the materials. The speed of the roller conveyor is slow and also have a long distance to travel until it reaches the storage buffer. Hence, it takes a lot of transport time. Whereas the transportation time for box flow is significantly less compared to the pallet flow since the transfer of material from unloading area to storage is done by forklift. In addition, box flow has a different storage location which is close to the unloading area and the tugger trains used for transporting the material from storage to the assembly line is very efficient as each tugger train follows a specific route in the assembly plant which further reduces the transportation distance and time. In pallet flow, all tugger trains are used to transfer materials to the three-different assembly line which increases the transportation time whereas, in box flow, each assembly line has been provided with a dedicated tugger train which follows a specific route. This helps in a smooth flow of materials from storage to point of use with less transportation time.

Case 1 and 2 are the same company where they have external warehouse but in case 2, regular trucks are used to transfer the materials from external warehouse to the assembly plant which increases the transportation occurrence and time compared to case 4. In case 2 both tugger trains and trucks are used to transfer the materials from external warehouse to the point of use assembly which increases the transportation time. But in case 1, no trucks are used to transfer the material since the external warehouse is located within the premises of assembly plant which in turn reduces the transportation time. Whereas, the box flow of case 1 uses box truck within the assembly plant which has to travel a long distance to transfer the materials to the point of use leading the box to flow this case to have high transportation time compared to case 2 and 4.

All three flows in case 3 have the highest number of occurrences as well as the transportation time. When we compare the pallet flow of case 3 with case 1 and 2 pallet flow, we can see that the number of transportation occurrence is almost similar but the transportation time is high in case 3 pallet flow. In case 1 and 2, the external warehouse is within the premises of the assembly plant which reduces the time to transport the material since the distance is less as well as no interaction with regular traffic. But in the case 3, the external warehouse is far from the assembly plant, encounters the regular traffic and is also operated by a third party logistic service. So, it becomes an obvious reason in an increase in time. When it comes to box flow of case 3, the large number of buffer storage involves a lot of transportation activities in the flow increases the transportation time.

5.1.4. Storage

The pallet flow of case 1 has the minimum process time though the supplier delivers the specific part number every alternative day. Similarly, in case 4, the supplier delivers the specific part number every day but the material is stored for one day in the company's storage buffer. This leads to having slightly higher storage time when compared to case 1 pallet flow. The box flow of case 1, the specific part is received once in a week and the material has to go through a process of repacking and has to wait for a long period after repacking before it is transferred at the point of use in the assembly plant. In the box flow of case 4, the company receives the material from the supplier in bulk quantity once in a week. Since the material has to be stored in the buffer for an average of half a week, the storage time is high compared to all the other cases. In Case 2, the logistic center of pallet flow maintains the stock of materials required for 3 days and the logistic center of box flow maintains the stock of materials required for 4-5 days. This increases the storage time significantly compared to case 4 (pallet flow).

In case 1 and 2, the number of storage buffers is more since the company has an external warehouse. In addition, both the cases, the materials are stored in the external warehouse as well as in the assembly plant which increases the number of storage buffer and storage time compared to case 4. In case 4, there is no external warehouse which reduces the number of storage buffers and storage time.

The number of occurrences need not necessarily increase the storage time. When we compare case 1 and 2 with case 3, we can see that the number of occurrences in the case 1 and 2 is more than case 3 but the sum of average storage time for pallet and box is higher for case 3. The increase in storage is due to a large number of buffers in the flow, sometimes buffers are created due to the waiting caused due to delay in transporting the material from one process to the other. The delay could be caused due to unavailability of the truck or forklifts for transferring the materials. And in all three cases (1,2,3), there is a fixed time interval for the trucks and forklifts to do the cycle of transportation. So, this creates a buffer in the flow and increases the storage time.

5.2. Cross-Case Analysis - Throughput Time and Lead Time

Similarly, cross-case analysis has been made based on throughput time and lead time for each flow of different cases. The average throughput time and lead time of all the 4 cases has been used to make the comparative analysis. The Throughput time and Lead time are listed in Table 25

Case	Flow Type	Throughput Time (Hours)	Lead Time (Hours)
Case 1	**Pallet Flow**	20.64	1.52
	Box Flow	124.24	0.46[*]
			23.82[**]
Case 2	**Pallet Flow**	84.73	0.24[*]
			9.94[**]
	Box Flow	132.34	2.00
Case 3	**Pallet Flow**	72.55	0.25[*]
			5.09[**]
	Box Flow	139.31	0.42
	Box Flow (Downsizing)	228.41	0.42
Case 4	**Pallet Flow**	43.86	0.64
	Box Flow	158.34	0.16

Table 25 Cross-Case Analysis - Throughput Time & Lead Time

[*] Replenishment from local storage area
[**] Replenishment from external warehouse

Comparing the throughput time for all the cases pallet flow of Case 1 & 4 found to be comparatively less. In both the cases the materials are delivered from the supplier frequently hence there is no need for storing the material in the storage for long period. Since the storage time has greatly reduced both the cases found to have less throughput time. In addition to that, for case 1, the material is stored only in the external warehouse and not in assembly plant. This makes the possibility of replenishing the lineside buffer directly from external warehouse which reduces the throughput time greatly. Even though the pallet flow of case 4 has less throughput time, box flow for this case seems to have high throughput time. This is due to the fact that, the material is supplied only once a week from the supplier and hence the material has to stay for longer time in the storage which increases the throughput time. Further to the storage time, a high number of administration activities increases the throughput time. Among the different flows, box flow (downsizing) of case 3 found to have higher throughput time of 228.41 hours. This is because the materials in the boxes are stored in the external warehouses as well as in the assembly plant which increases the throughput time. In the case of downsizing, the material has to go through the process of repacking. Since the material has to travel through different storage points and repacking, time involved in traveling, handling, storing, transporting and repacking altogether increases the throughput time greatly. In case 2 pallet flow though the company receives the material every day, the company practice the method of storing the material in an average of 3 days in their external warehouse which increases the throughput time. But in Case 1 pallet flow which is of the same company as case 2 uses the method of Just-In-Time principle. Due to JIT principle, the company doesn't store the material for a longer period resulting in less throughput time.

As the company uses both external warehouse and assembly plant to store the materials, the controlling of material flow is different for each case and hence analysis regarding to lead time is made based on two kinds of replenishment. Replenishment to lineside buffer is either from the storage point in assembly plant or directly from the external warehouse.

Comparing the lead time for all the cases, case 4 box flow has the minimum lead time of 0.16 hours. This is because the warehouse and the lineside buffer are quite near and the dedicated tugger trains used to transport box from warehouse to lineside buffer is really efficient as they follow the specific route. However, in the same case pallet flow seem to have high lead time because the distance covered by the tugger train from storage point to the lineside buffer is high which increases the lead time. Case 2 box flow (2.00 hours) and Case 1 pallet flow (1.52 hours) found to have high lead time. This is because the materials are transferred from the external warehouse to the assembly line directly which increases the lead time. Similarly, Case 1 box flow (0.46 hours), Case 2 pallet flow (0.24 hours) and Case 3 pallet flow(0.25 hours) too have an external warehouse but the materials are stored in the assembly plant as well which is used for replenishing the lineside buffer and thus reducing the lead time.

When comparing the replenishment of material from external warehouse between box flow of Case 1(23.82 hours) and pallet flow of case 2 (9.94 hours), box flow of case 1 seems to have higher lead time. It is because the material has storage time in different storage point which increases the lead time greatly. Case 3 pallet flow (5.09 hours) found to have minimum lead time when compared with the cases involving the replenishment of material from the external warehouse. This is because the loading and unloading of materials from the truck is made by means moving conveyor which reduces the time greatly and transportation time for transferring the material from warehouse to the assembly plant is very less resulting in reduced lead time.

6. Results

In this chapter, the results obtained from the analysis has been explained in depth

From the flow maps and the empirical data obtained for this thesis work, it is identified that each automotive industry has a different approach in controlling the flow of material from their warehouse to the point of use in assembly i.e., replenishing material to lineside buffer either from the storage point in assembly plant or from the external warehouse. The approaches made by the automotive industry had both positive and negative aspects. From the cross-case analysis, the authors of this thesis have come up with the below-mentioned results.

The automotive industry that focused in having their external warehouse within the company premises showed to have comparatively less throughput time for their material flow between their external warehouse and assembly line. The external warehouse within the company premises helped the manufacturer to transport the material directly to assembly line without having any storage point in assembly plant. Though it increases the lead time for replenishment, it eliminates the need of storing the materials in the assembly plant in addition to their external warehouse. Since the number of storage points gets reduced in the supply chain, the number of handling involved in the supply chain was also found to be reduced. It also showed that occurrences of different activities such as handling, administration, transportation and storage are less and time consumed in those activities are also less and thus achieving short throughput time.

The automotive manufacturers who practiced the method of storing the material in both external warehouse and assembly plant succeeded in achieving short lead time for replenishing the lineside buffer from the storage point in the assembly plant, but increased the occurrence of handling, administration, transportation and storage activities and time involved in those activities which directly influenced the throughput time greatly.

Companies with external warehouse or not that received material on frequent basis from the supplier found to have lesser storage time. However, inbound materials from the supplier were not part of this thesis work but the time frequency that materials were received from the supplier greatly influenced the storage time. This in turn reflected the throughput time of the material. Companies those receiving the material from the supplier almost on daily basis found to have comparatively less throughput time.

The companies that used the same labels in the pallet or box of materials provided by the supplier for their administration activity showed that the administration activity becomes easier and consumes less time for the company to record the details of the incoming material. It also helped in making clear understanding between of availability of materials between supplier and the automotive manufacturer.

The automotive industry with no external warehouse found to have comparatively less number of occurrence for the different activities considered and shorter throughput time and lead time. Since the materials are directly delivered to the assembly line from the storage, it reduced the handling and lead time. Hence the automotive industries with external warehouse can achieve short lead time and throughput like that of companies with no external warehouse by controlling their flow of material by having their external warehouse within the company premises. In addition to that, the company following the principle of Just-In-Time for receiving the material from the supplier will reduces the throughput time and lead time greatly.

7. Discussion and Future studies

In this Chapter, the authors have discussed some suggestions about how the considered companies could change their current activities which could reduce their lead time and throughput time in the future. The authors also made some proposal how this research work could be carried out further in the future

7.1. Discussion

While studying the different flow for this thesis work, we have identified that the use of external warehouses has increased the different activities and storage time greatly. Automotive manufacturer of Case 2 stored the material both in their external warehouse and the assembly plant in spite of getting materials from their suppliers frequently. The company could focus on implementing Just-In-Time purchasing which would eliminate the storage of materials in large quantity for long period and thus reducing the throughput time of the material. In addition, the companies follow the method of adding labels to their incoming materials from the supplier in different stages of the material flow adds up the administration activities and time. The company could come up with a solution of encouraging the suppliers to provide the labels to the materials that could be used directly by the automotive manufacturer similar to that of Case 4. This helps in eliminating the administration activities and time greatly which have the consequence of reducing throughput time for the material. In case 2, the company uses the truck to transfer material from their warehouses to the assembly plant which goes through regular traffic. Due to the reason of uncertainty in traffic which might slightly delay the arrival of the truck, the company needs to store material in their assembly plant as well. Here the company might think of having their external warehouse within the premises of the assembly plant which could reduce the transportation time as well as avoid the method of storing a lot of materials. However, in Case 1 which is of the same automotive manufacturer as Case, 2 have their external warehouse within the premises of assembly plant which reduced the transportation time when compared to Case 2. In addition, the company does not store the material in both external warehouse and assembly plant, which reduced the storage time leading to having less throughput time when compared to Case 2. Even this company follows the same procedure of labelling as Case 2. On eliminating this process and following the same suggestion as suggested to Case 2, the company can reduce the lead time and throughput time further. In addition, the company also attains an environmental sustainability as the use of paper for labelling process is eliminated.

Case 3 found to have high administration activity and time when compared to all the other cases. In spite of using same IT system by the third-party logistics and the assembly plant, the administration time found to be higher in this case. This is because of the materials are scanned every time to ensure that the materials are delivered to the correct location. This increases the administration activities and time greatly. In addition, the materials are stored in the external warehouse (third-party logistics) in an average of 2.6 days which increases the throughput time. Further, the materials are stored within the assembly plant as well which adds up to the throughput time. The company could focus on purchasing the materials based upon the actual demand which eliminates the waiting time for the material in the storage area.

Out of all the cases, case 4 with no external warehouse found to be efficient in most of the aspects considered within the study. Since the company has their warehouse within the company handling and transportation time reduced greatly. In addition, the Pallet flow of Case

4, receives material every day that is of required quantity only. Hence, they have comparatively less throughput time. If the company concentrates more on transferring the material from the storage area to assembly line with dedicated tugger trains, the transportation time and the lead time for the material will reduce further. Though the pallet flow follows the method of scanning to register their incoming materials, box flow follows the method of labelling process. The labelling process adds up the administration activities and time which lead to increased throughput time. The box flow of this company should focus on following the similar method as pallet flow which will reduce the throughput time. In addition to this, the company should also receive their box materials at least twice a week instead of getting the entire material on the same day from the supplier. This will reduce the storage time and throughput time greatly. To attain economic and environmental sustainability, either it is necessary to encourage the same supplier to provide different parts required for the company which helps in transporting the material together thus reducing the transportation cost and time or have suppliers around the company locality and develop a method to use same transport to collect material from different suppliers which again reduces the transportation cost.

In general, all the companies involved in our thesis work could use stop watch display for takt time for each activity could enable the constant process time for the respective activity. For example, the truck transfers material from one point to the another with fixed interval of time could use this stop watch display and alerts the truck driver to drive the truck at correct time without any delay. This in turn, ensure the supply of material at the right time without increasing the lead time.

From the plant visit to four different manufacturers, the authors of this thesis work identified that the company was only focused on lead time and throughput time for their manufacturing process. The thesis work which is a part of the research project has enlightened the manufacturers that, the time involved in replenishing the material to lineside buffer from the storage point also influences the lead time and throughput time in production and delivering the product to the customer. The delay or increase in replenishment time will further delay the production time. The results obtained for the individual case by calculating lead time and throughput time from this thesis work could be used by the respective companies to generalize their replenishment lead time and throughput time. Further the companies could think of improving their material flow which would attain them short lead time and throughput time.

7.2. Future Studies

The focus of this thesis is on control of material flow from external warehouse to assembly plant. The results obtained from this thesis work could be used in removing or reducing certain activities to reduce the lead time and throughput time as a matter of efficient flow. It would be interesting to know the economic aspects of reduction of process or activities. In addition, the study could also consider the economic effects of having an external warehouse and internal warehouse.

It is also interesting to know if eliminating some process in the Material Flow Map or performing some changes in layout of the assembly plant or external warehouse could reduce the lead time or throughput time. So, future studies can be done on each case separately from the output from this thesis to make proposal for change of layout (future state) of the plant to achieve efficient material flow.

The current study is focussing on the control of material flow from external warehouse to the assembly plant. It would also be interesting to do similar study to analyse, how the lead time and throughput time is affected due to the time frequency of receiving the materials from the supplier.

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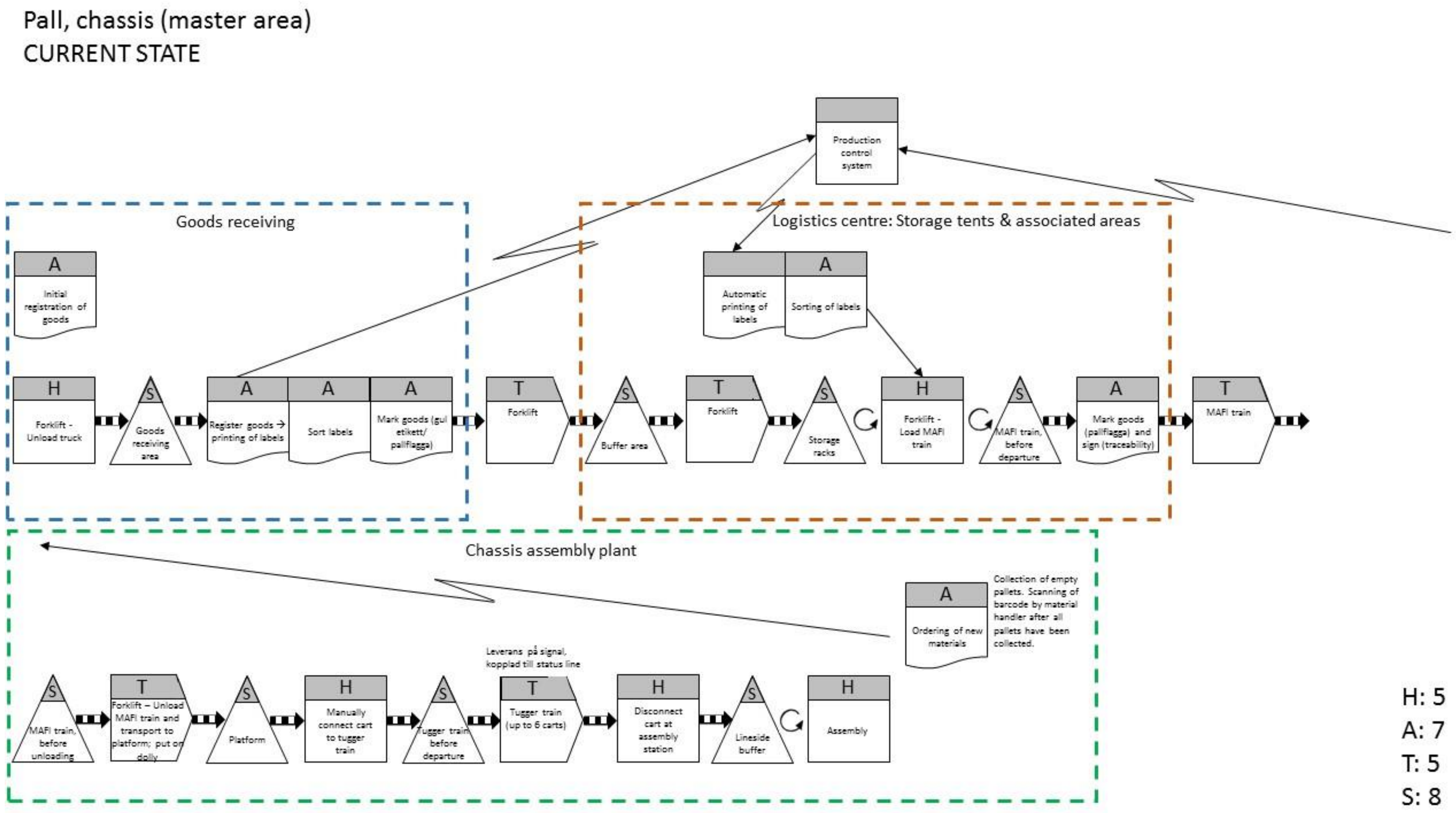
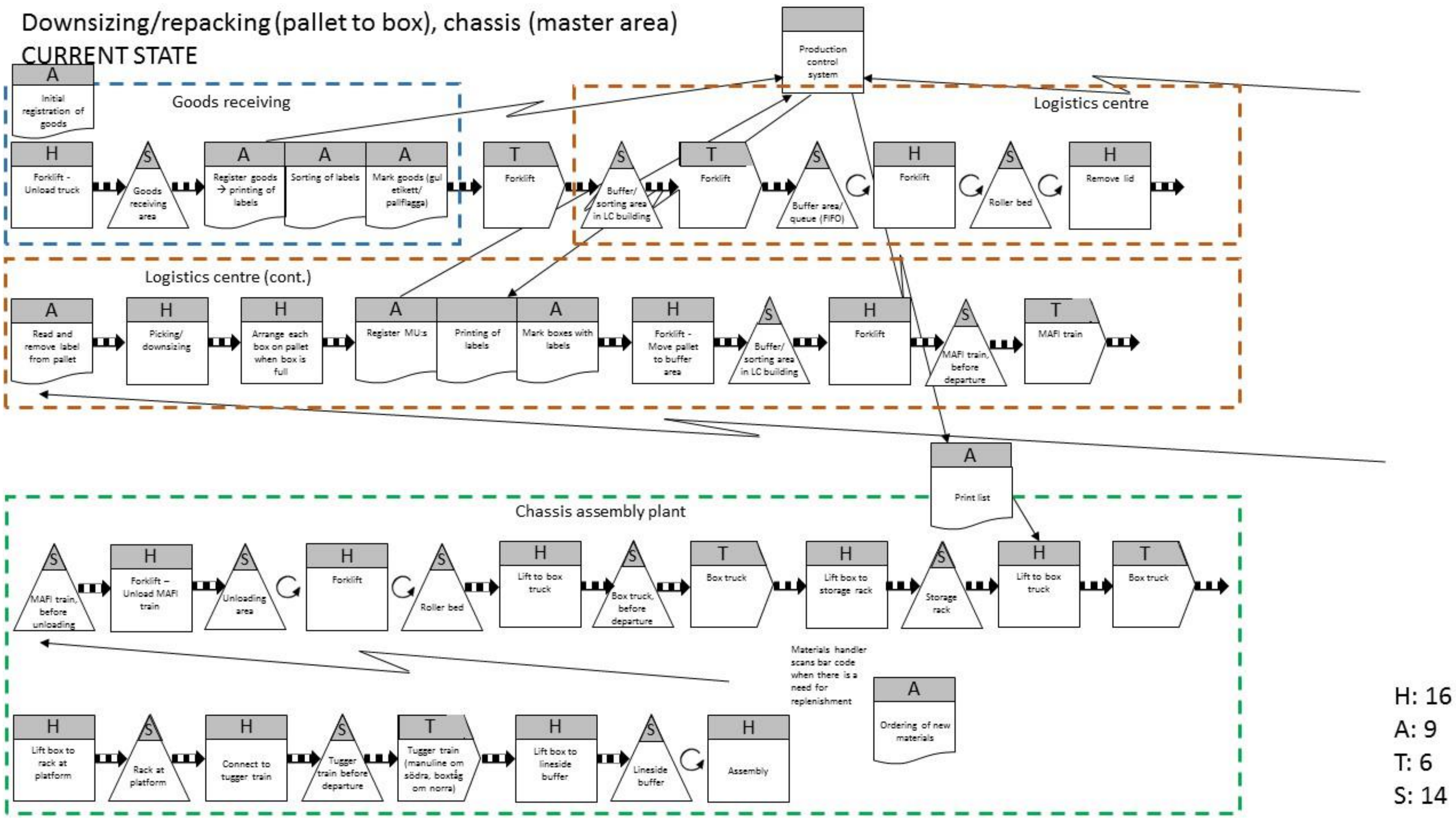
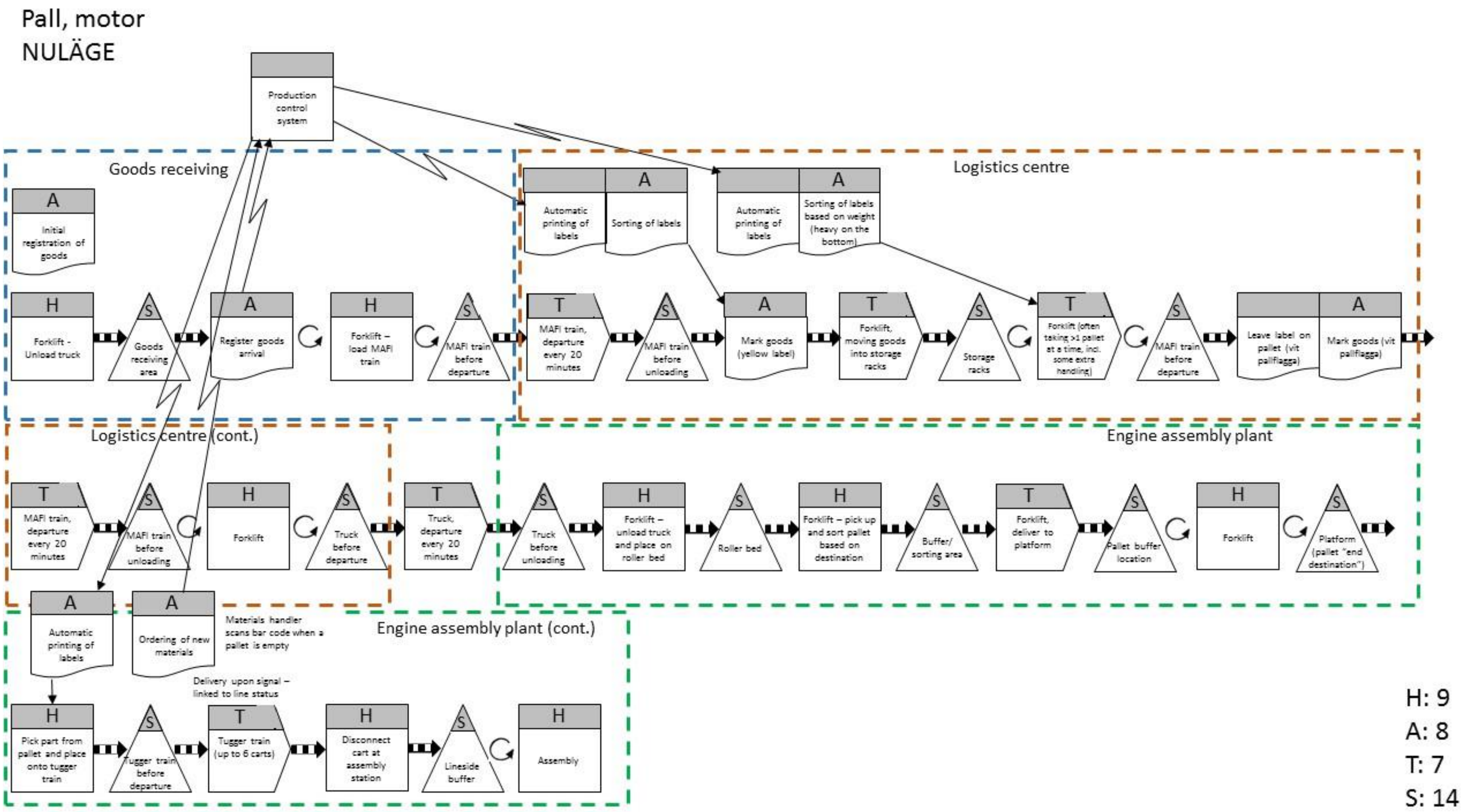
Appendix A – Material Flow Maps made for all 4 cases



Case 1 – Pallet Flow

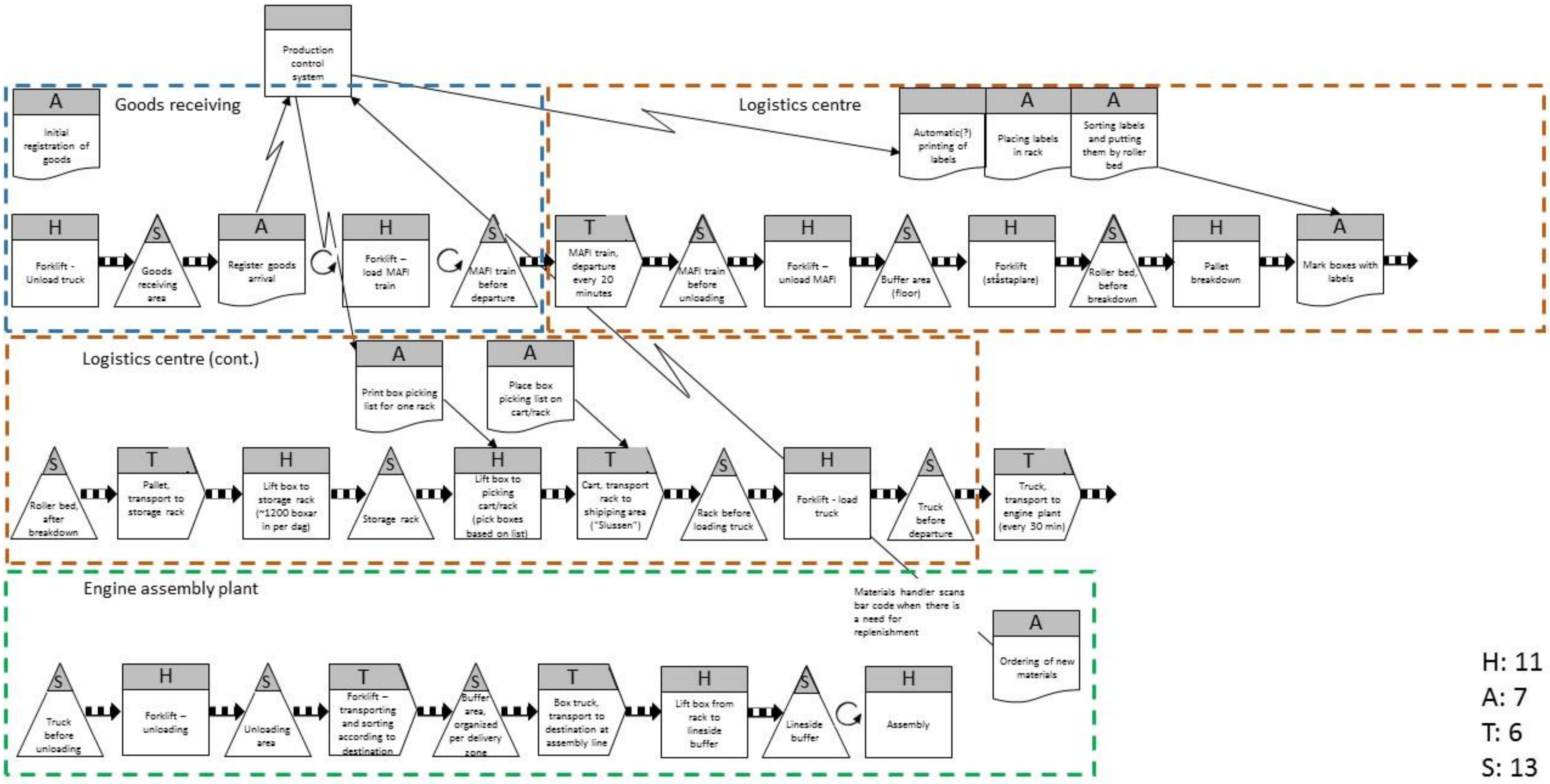


Case 1 – Box Flow



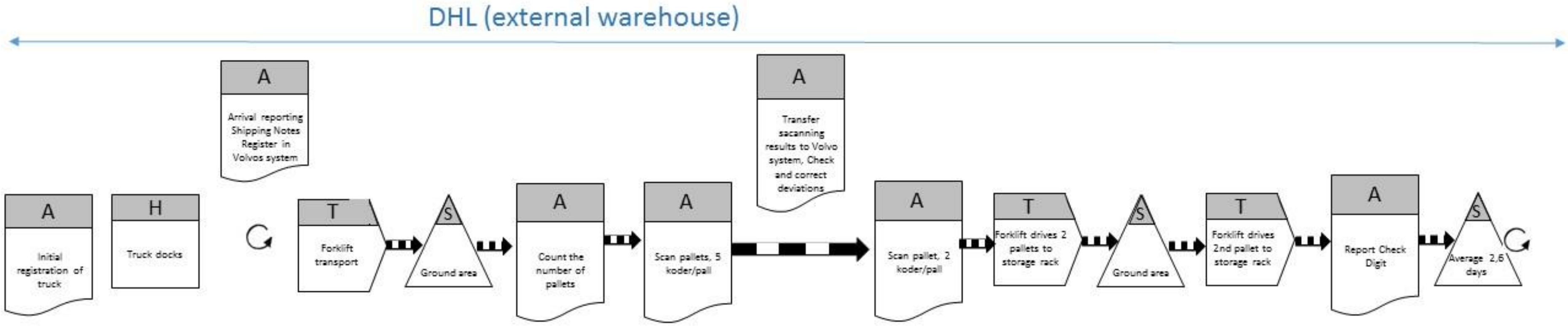
Case 2 – Pallet Flow

Box, motor
NULÄGE



Case 2 – Box Flow

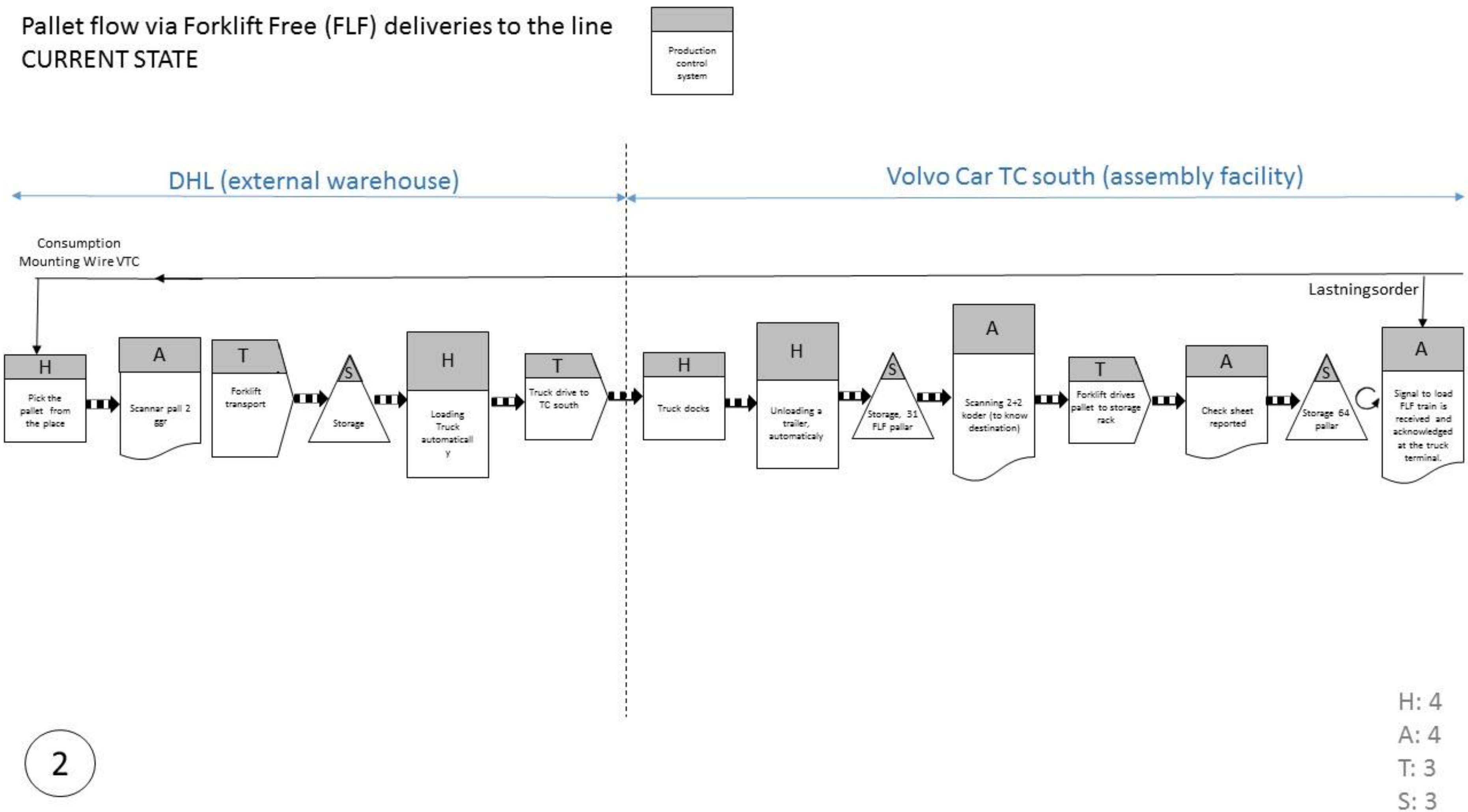
Pallet flow via Forklift Free (FLF) deliveries to the line
CURRENT STATE



1

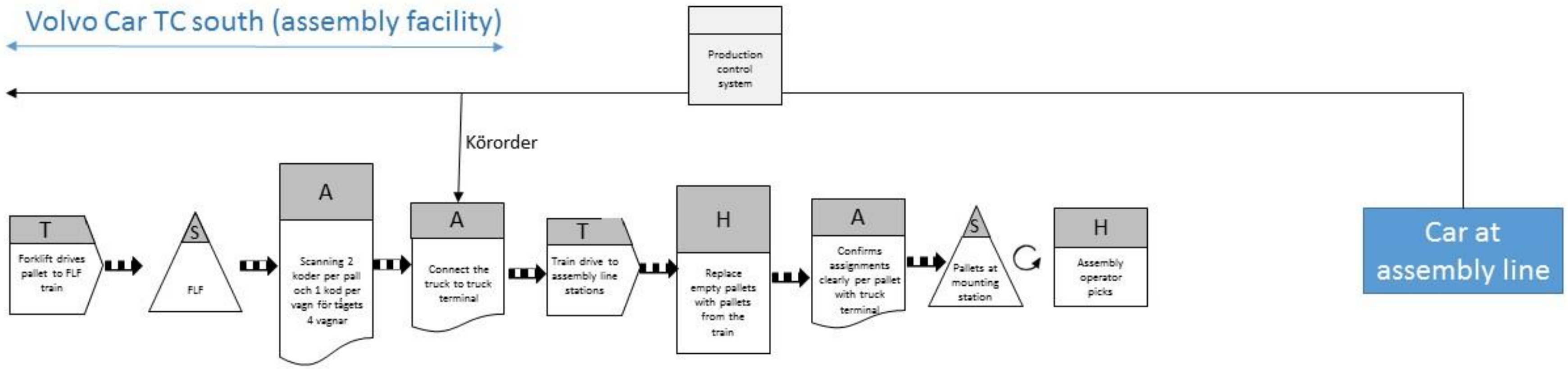
H: 1
A: 7
T: 3
S: 3

Case 3 – Pallet Flow



Case 3 – Pallet Flow (Continued)

Pallet flow via Forklift Free (FLF) deliveries to the line
CURRENT STATE



H: 2
A: 3
T: 2
S: 2

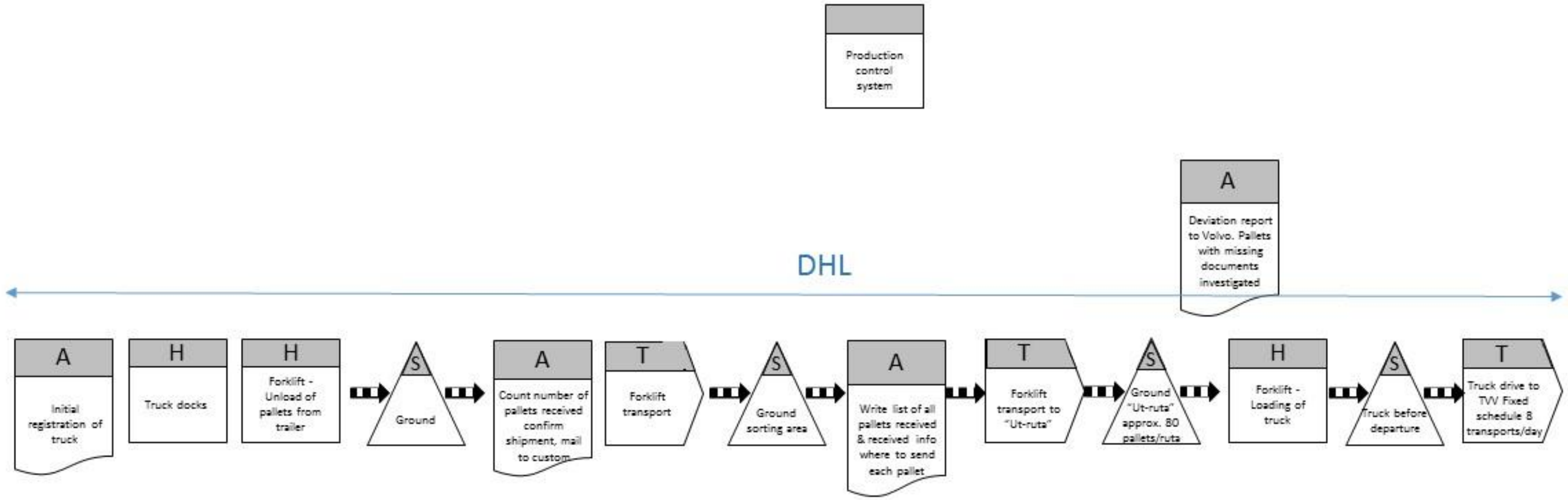
DHL	VCC	Totalt
H: 3	H: 4	H: 7
A: 8	A: 6	A: 14
T: 5	T: 3	T: 8
S: 4	S: 4	S: 8

3

Case 3 – Pallet Flow (Continued)

Box

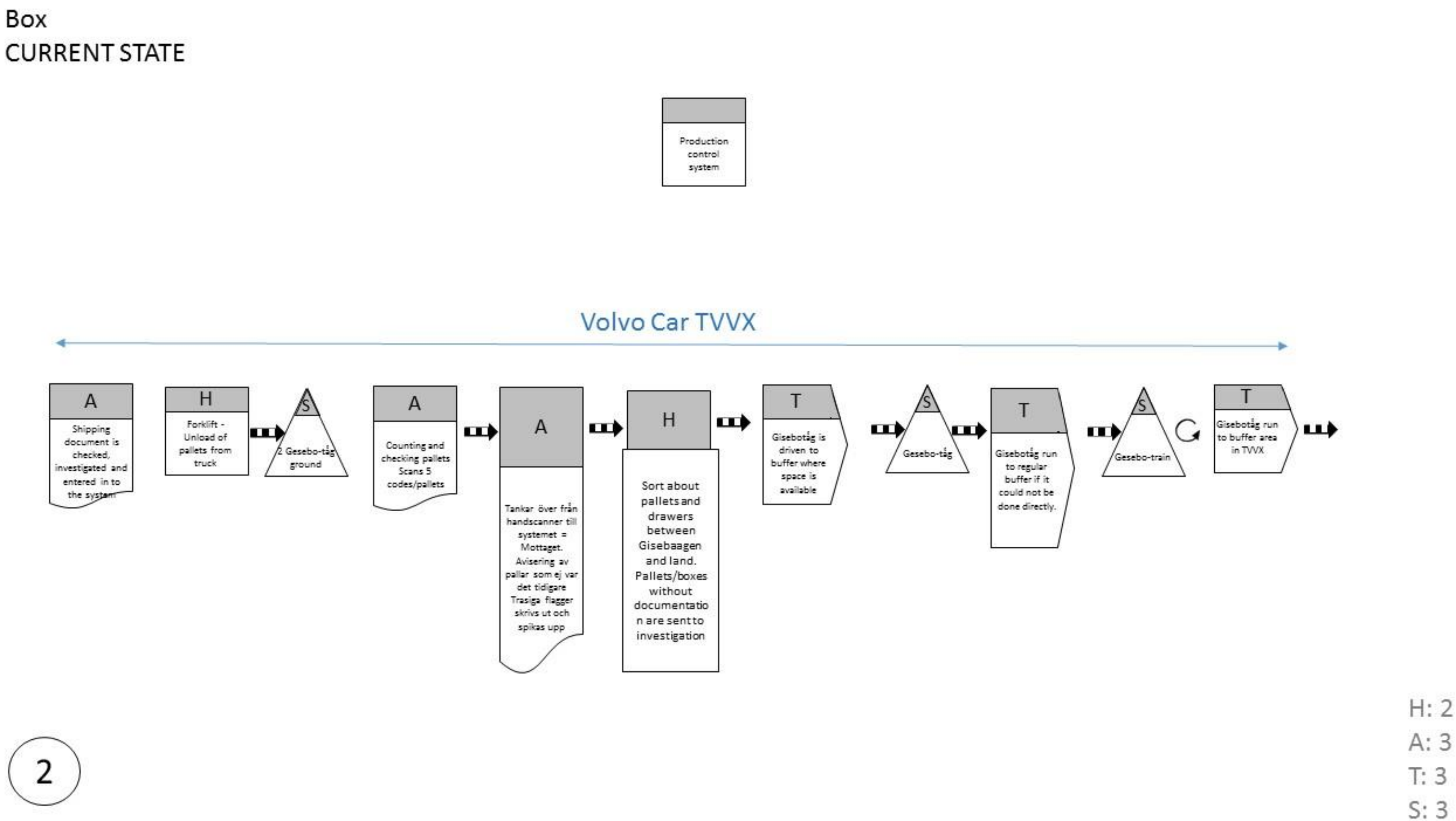
CURRENT STATE



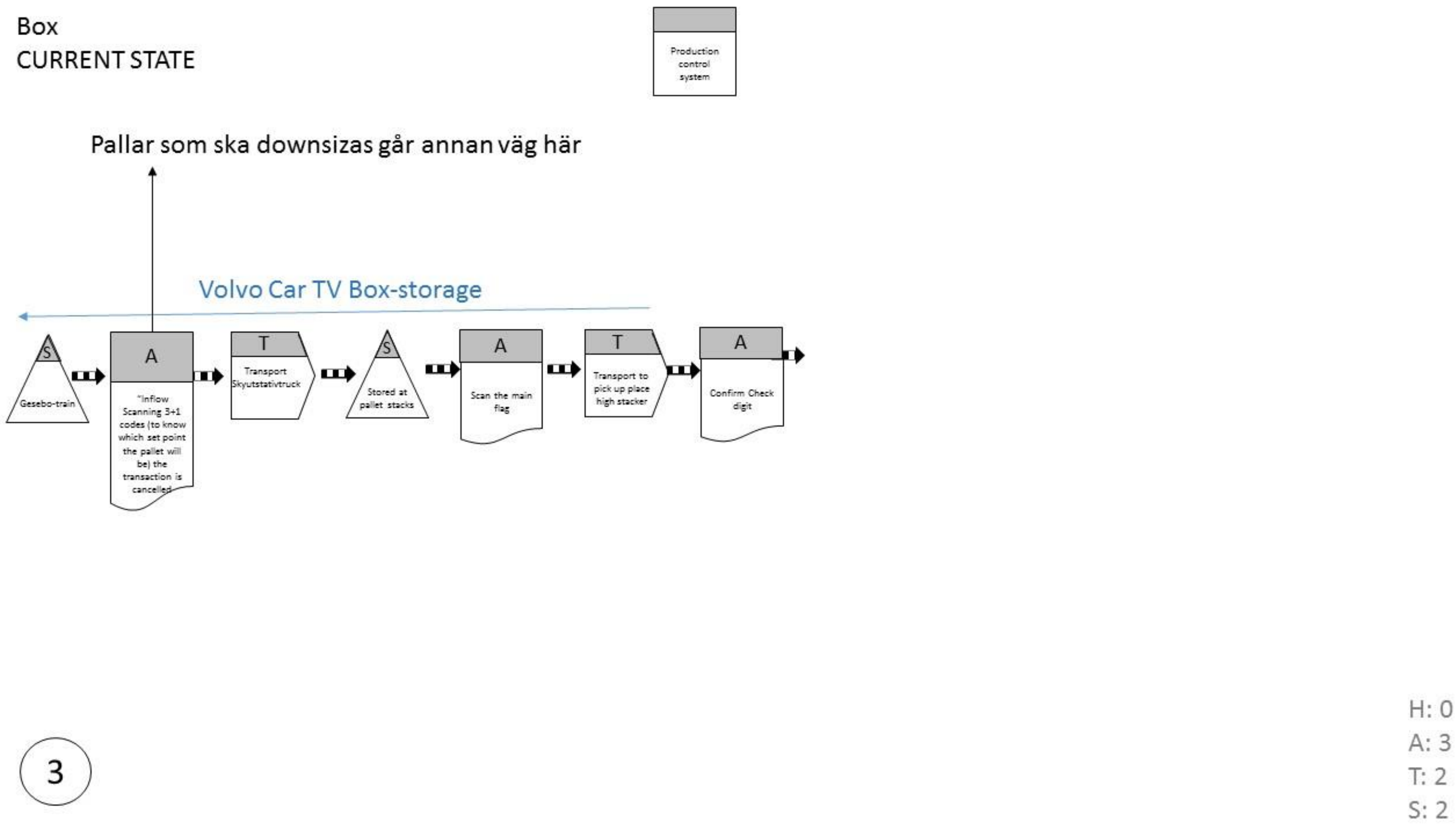
1

H: 3
A: 4
T: 3
S: 4

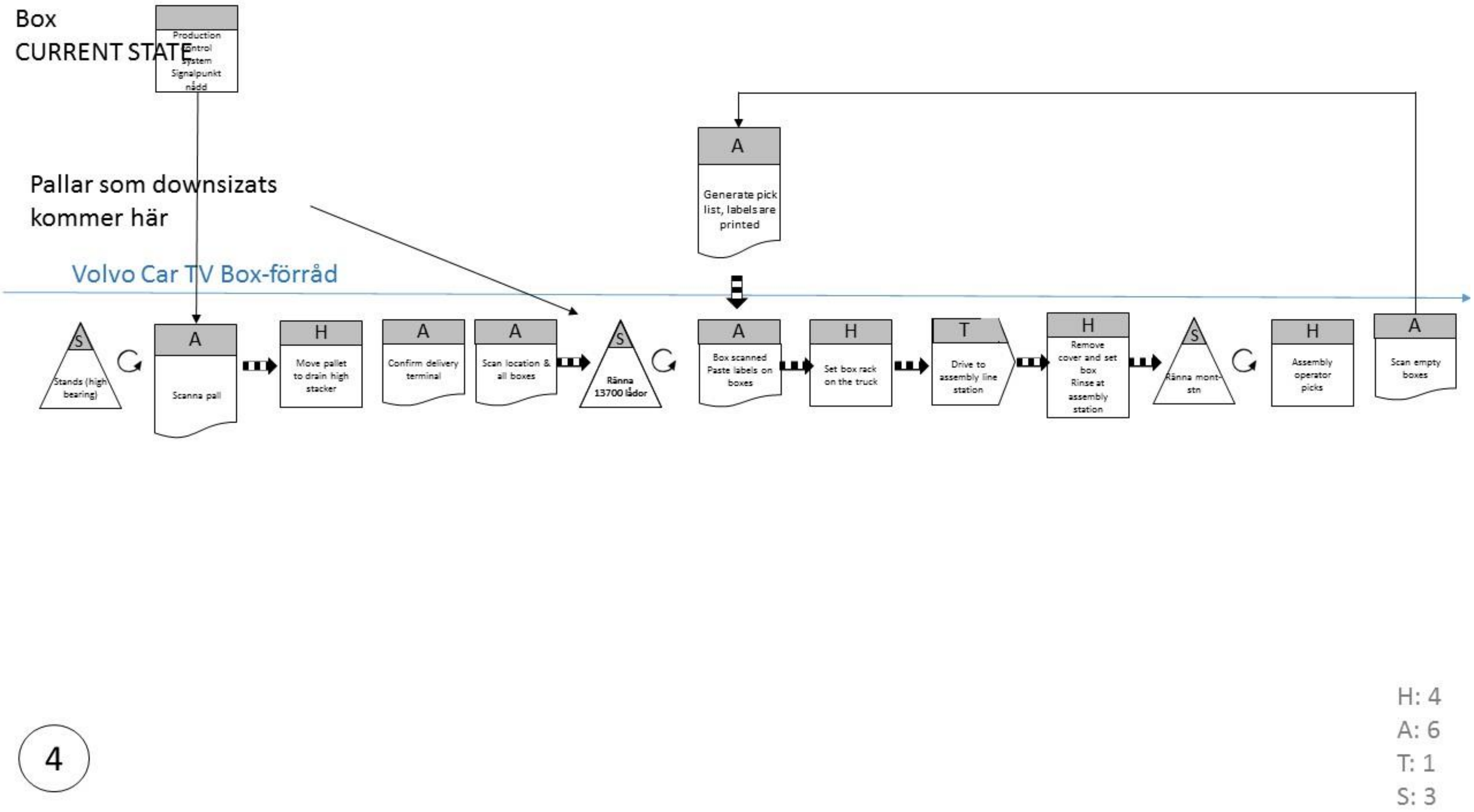
Case 3 – Box Flow



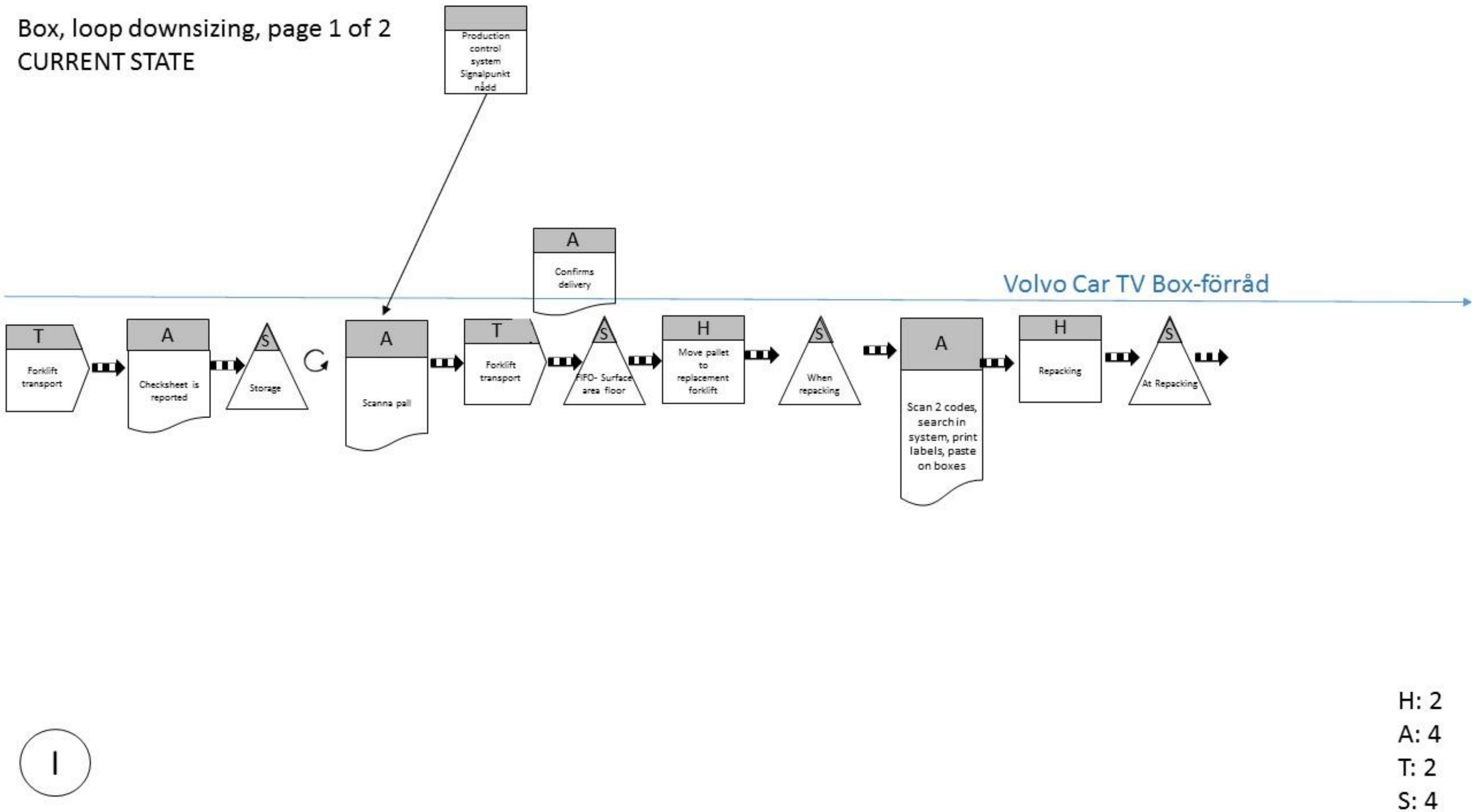
Case 3 – Box Flow (Continued)



Case 3 – Box Flow (Continued)

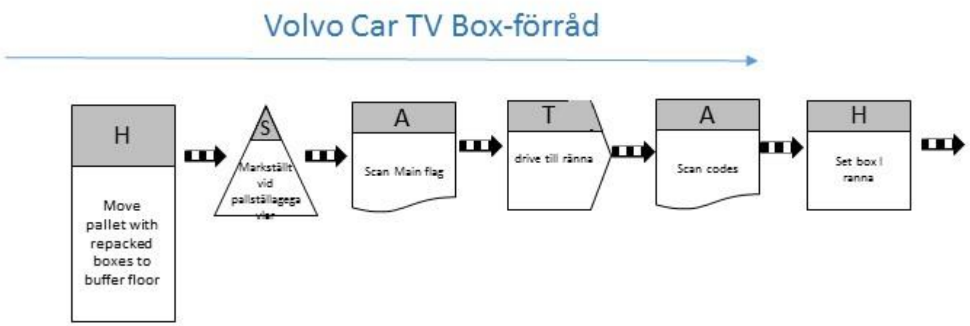


Case 3 – Box Flow (Continued)



Case 3 – Box Flow downsizing

Box, loop downsizing, page 2 of 2
CURRENT STATE



II

H: 2
A: 2
T: 1
S: 1

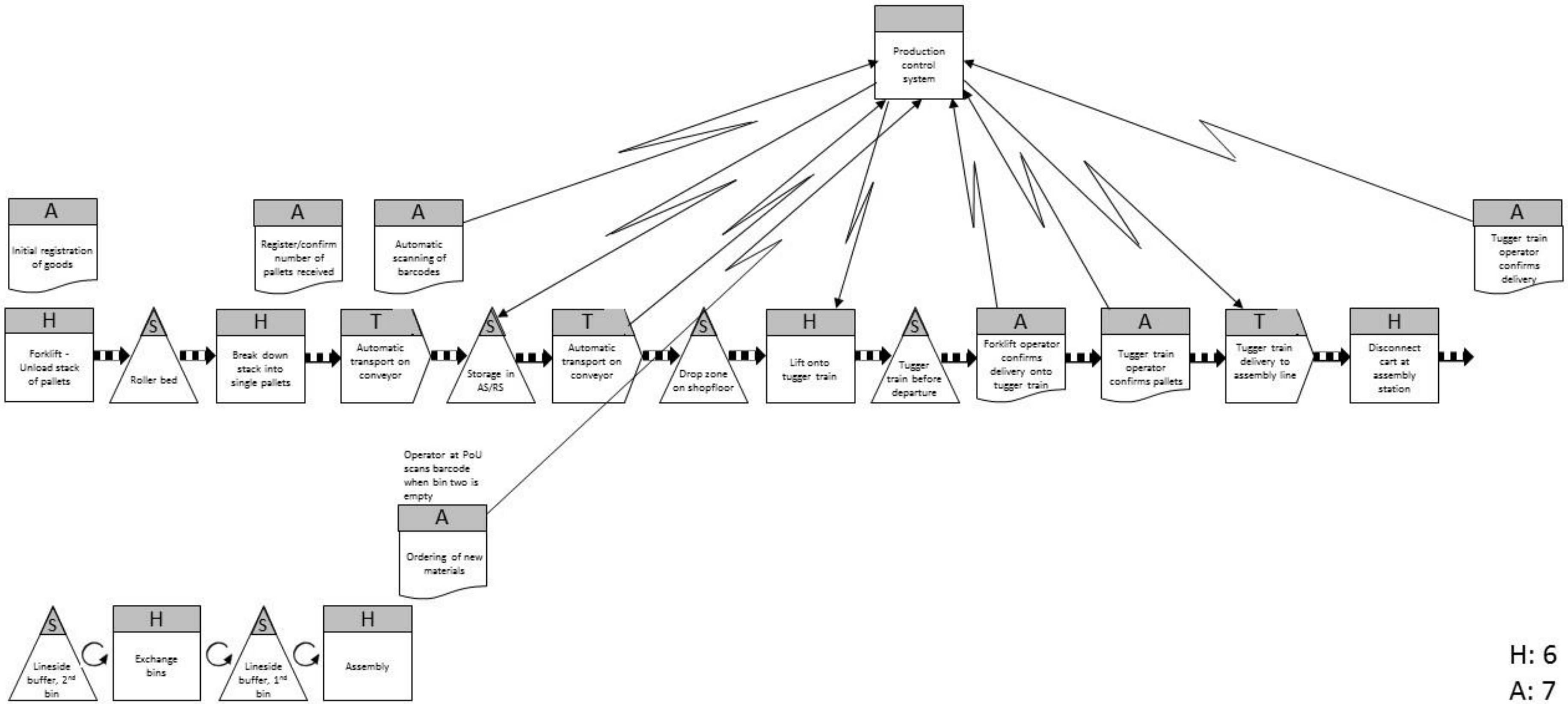
Utan downsizing, DHL	Utan downsizing, VCC	Totalt utan downsizing
H: 3	H: 6	H: 9
A: 4	A: 12	A: 16
T: 3	T: 7	T: 10
S: 4	S: 8	S: 12

H: 6-1+5=10
A: 11-2+6=15
T: 7-2+3=8
S: 8-2+6=12

Med downsizing, DHL	Med downsizing, VCC	Total med downsizing
H: 3	H: 10	H: 13
A: 4	A: 16	A: 20
T: 3	T: 7	T: 10
S: 4	S: 11	S: 15

Case 3 – Box Flow downsizing (Continued)

Pallet flow (tugger train deliveries to line)
CURRENT STATE

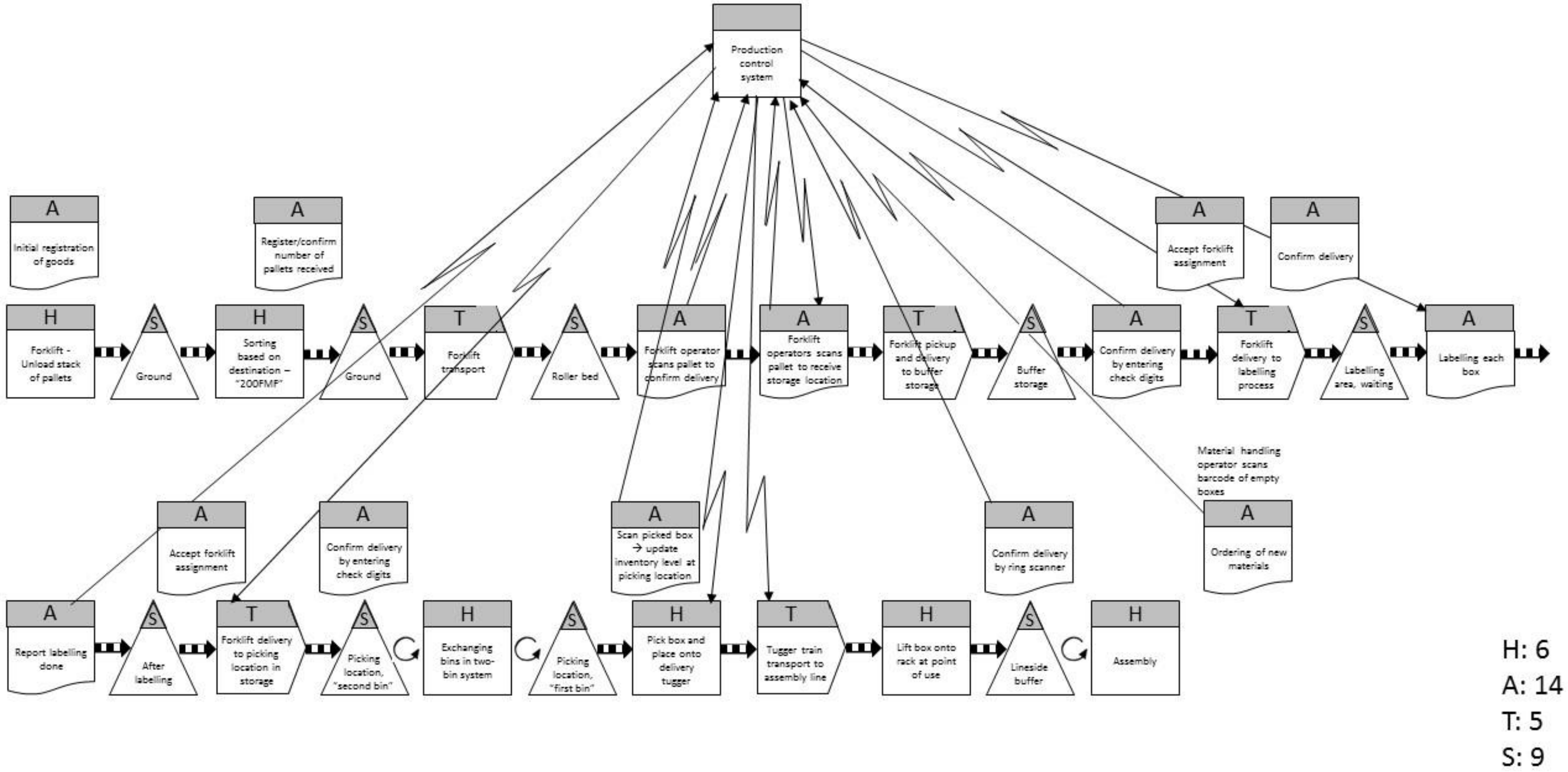


H: 6
A: 7
T: 3
S: 6

Case 4 – Pallet Flow

Box flow (high frequent materials)
CURRENT STATE

Deliveries of boxes should be made to the assembly line within 2 hours after order from the line



Case 4 – Box Flow

Appendix B – Interviews made with the companies

Case 1 – Truck Chassis Assembly

Palette Flow

Goods Receiving

1. What is the quantity of material obtained from the supplier to the external warehouse?
2. What is the time taken for unloading trucks?
3. In what batch size the forklift unloads the material?
4. What is the batch size the palettes are stored in Goods receiving area?
5. How much time the pallets are stored in Goods receiving area?
6. How much time does it take to register the goods (Printing of labels)?
7. How much time does it take to sort the labels?
8. What is the time taken to mark the goods?
9. What is the time taken by the forklift to transfer it to the storage tents?

Storage Tents

10. In what batch size forklift transfer it to the storage tents?
11. How much time the pallets is left in the buffer area?
12. In what batch the pallets are left in the buffer area?
13. What is the time taken by the forklift to transfer it to the storage racks?
14. In what batch size the palettes are transferred to the storage racks?
15. What is the time taken for printing the labels?
16. How is the pull signal made?
17. What is the time taken by the forklift to load MAFI Train?
18. In what batch size the palettes are loaded into MAFI train?

Chassis Assembly Plant

19. How much time MAFI train needs to wait before departure?
20. What is the time taken to marking the goods?
21. What is the time taken for MAFI train to reach assembly plant from the warehouse?
22. What is the waiting time for MAFI Train in the assembly plant before it is unloaded?
23. What is the time taken for a forklift to unload pallets from MAFI Train?
24. In what batch size they are transferred to the platform?
25. What is the time that the palettes are left behind in the platform?
26. In what quantity they are stored in the platform?
27. What is the time taken for connecting the platform to tugger train?
28. How much time should the tugger train wait before departure?
29. What is the time taken for tugger train to transfer the palettes?
30. What is the time taken for disconnecting the cart at the assembly station?
31. How much time the pallets are left in line side buffers?
32. In what batch size they are kept in line side buffers?
33. What is the minimum quantity maintained in line side buffer?
34. How the signaling for ordering new material is made?

Box flow

Goods receiving area

1. What is the time taken for initial registration of goods?
2. What is the time taken by forklift to unload the truck?
3. In what batch size the forklift unloads the pallets from the truck?
4. How long is the pallet kept in the goods receiving buffer?
5. What is the time taken to print the labels?
6. What is the taken to sort the labels?
7. What is the time taken to mark the goods?
8. What is the time taken to transfer the pallets to logistic center by a forklift?
9. What is the batch size of pallets carried by the forklift while transferring to logistics center?

Logistic Centre

10. How long are the boxes kept in the sorting buffer area in the logistics center?
11. What is the time taken by the forklift to transfer the pallet to the buffer area queue?
12. In what batch size the forklifts transfer the pallets to buffer area queue?
13. How long are the pallets kept in the buffer area queue?
14. What is the time taken to transfer the pallets from buffer area due to roller bed by the forklift?
15. In what batch size the forklift transfer the pallets from the buffer area queue to roller bed?
16. How long are the pallets kept in the roller bed buffer?
17. What is the time taken to remove the lid?
18. What is the time taken to read and to remove the label from pallets?
19. In what batch size the picking and downsizing are done?
20. What is the time taken for downsizing and picking?
21. To what batch size the downsizing is done and repacked to the pallets?
22. What is the time taken to arrange the boxes in the pallets?
23. What is the time taken to register MU?
24. What is the time taken to print new labels?
25. What is the time taken to mark labels on the boxes?
26. What is the time taken by the forklift to move pallets to buffer area?
27. In what batch size the forklift transfer the pallets to buffer?
28. How long are the pallets kept in the buffer/sorting area in the logistics center?
29. What is the time taken by the forklift to transfer the pallets from buffer/storage to MAFI train?
30. What batch size the pallets are transferred from storage to MAFI train?
31. What is the time taken by the MAFI train to reach the chassis assembly plant?

Chassis Assembly Plant

32. What is the time that MAFI train needs to wait before unloading?
33. What is the time taken by the forklift to unload MAFI train?
34. In what batch size the forklift unloads from MAFI train?
35. How much time are the boxes left in unloading area and in what batch size they are left?
36. What is the time taken for the forklift to transfer boxes from unloading area to the roller bed?

37. In what batch size they are transferred?
38. What is the time taken for lifting to box truck?
39. In what batch size they are lifted?
40. How much time is the box truck kept before departure?
41. What is the time taken for transferring box truck to storage rack?
42. What is the time taken to put the box truck I storage rack?
43. How much time is the box truck kept in storage rack?
44. In what batch size the storage rack is maintained?
45. What is the time taken to lift the box truck?
46. In what batch size they are lifted?
47. What is the time taken to transfer box truck to the platform?
48. In what batch size they are transferred?
49. What is the time taken to lift the box to rack in the platform?
50. In what batch size they are made?
51. How much time are the rack left on the platform?
52. In what batch size the rack is maintained?
53. What is the time taken for connecting the rack to the tugger train?
54. How much has the tugger train to wait before departure?
55. What is the time taken for tugger train to transfer material?
56. What is the time taken for lifting the box to line side buffer?
57. How much time are the boxes left in the lineside buffer?
58. What is the minimum quantity measured in the lineside buffer?
59. How are the signals made while ordering the new materials?

Case 2 – Truck Engine Assembly

Palette Flow

Goods Receiving

1. In what interval the transportation between external warehouse and assembly plant takes place?
2. What is the time taken for the forklift to unload the trucks?
3. In what batch size they are unloaded from the trucks?
4. How much time are the palettes left in goods receiving area?
5. How much time does it take to register the goods?
6. What is the time taken by the forklift to load MAFI train?
7. In what batch size they are loaded?
8. How much time MAFI train need to wait before departure?

Logistics centre

9. How long has the MAFI train to wait in the buffer before unloading?
10. What is the time taken for automatic printing of labels?
11. What is the time taken for sorting of labels?
12. What is the time taken for marking of goods (Yellow Label)?
13. What is the time taken for automatic printing of labels (2)?
14. What is the time taken for sorting of labels based on the weight?
15. What is the time taken by the by forklift to transfer the pallets to the storage racks?
16. How long the pallets wait in the storage rack buffer?
17. What is the time taken by the forklift to transfer one pallet at a time to the MAFI train before departure buffer?
18. How long does the MAFI train with pallets wait in the buffer?
19. What is the time taken for leaving labels on the pallets?
20. What is the time taken for marking goods in the pallet?
21. What is the time taken by MAFI train to reach the buffer?
22. How long does the MAFI train wait in the buffer before unloading?
23. What is the time taken by the forklift to transfer the pallets to the trucks?
24. How long does the truck wait in the buffer before transporting the pallets?
25. In what batch size the truck carries the pallets?

Engine Assembly plant

26. What is the waiting time of truck before unloading the pallets?
27. What is the time taken by the forklift to unload the truck and place it on the roller bed?
28. What is the waiting time for goods in the roller bed buffer?
29. What is the time taken by roller bed to transfer the goods?
30. What is the time taken by the forklift to pick up and sort the pallets based on the destination?
31. What is the waiting time in the buffer/sorting area?
32. What is the time taken by the forklift to transfer the pallet to the platform?
33. In what batch size the pallets are transferred by the forklift to the platform?
34. How long do the pallets wait in the buffer before the end platform buffer?
35. What is the time taken by the forklift to transfer the materials to the end platform buffer?
36. What is the time taken for automatic printing of labels in the engine assembly plant?

37. What is the time taken to pick parts from pallets and to place onto the tugger train?
38. How are the parts are picked up from the pallets and dropped to the tugger train?
39. What is the waiting time for tugger train before departure?
40. What is the time taken by the tugger train to transport to the assembly station?
41. What is the time taken for disconnecting the carts of tugger train at assembly station?
42. What is the waiting time in the lineside buffer?

<u>Box Flow</u>

Goods Receiving

1. In what interval the transportation between external warehouse and assembly plant takes place?
2. What is the time taken for the forklift to unload the trucks?
3. In what batch size they are unloaded from the trucks?
4. How much time the pallets are left in goods receiving area?
5. How much time does it take to register the goods?
6. What is the time taken by the forklift to load MAFI train?
7. In what batch size they are loaded?
8. How much time MAFI train need to wait before departure?

Logistic Centre

9. What is the time taken by MAFI train to transport materials from Goods Receiving area to Logistic center?
10. What is the waiting time for the MAFI train before unloading?
11. What is the time taken for a forklift to unload MAFI train?
12. How many materials are left in the buffer are and in what batch size?
13. What is the time taken for the forklift to put the materials in the roller bed?
14. In what batch size they are loaded in the roller beds?
15. What is the time taken to break down the palettes?
16. What is the time taken to mark the boxes with labels?
17. After breaking down the palettes how much time it is left in the roller bed?
18. What is the time taken for transporting palettes to the storage rack?
19. How much time taken to lift the boxes to the storage rack?
20. How much time are the the boxes left in the storage rack?
21. What is the quantity maintained in the storage racks?
22. How much time does it take to pick the materials from storage racks based on the list?
23. What is the time taken to transfer those materials to the shipping area?
24. In what batch size they are transferred?
25. How much time are they left in the in the shipping area?
26. What is the time taken by the forklift to load the truck?
27. In what quantity the truck is loaded?
28. How much time has the truck to wait before departure?
29. What is the time taken for the truck to reach the assembly plant?

Engine Assembly Plant

30. How much the truck needs to wait before unloading in the assembly plant?
31. What is the time taken for the forklift to unload the truck?
32. How much time are the the materials left in the unloading area?

33. What is the time taken by the forklift to transfer the materials to required are?
34. How much time are the materials left in buffer zone?
35. What is the time taken by box truck to transport the boxes to the assembly line?
36. What is the time taken to put the box in the lineside buffer?
37. In what batch size they are loaded in the lineside buffer?
38. In what minimum quantity line side buffer is maintained?
39. What is the time taken for assembly to empty the line side buffer?

Signalling

40. How is the signalling made for ordering new materials?

Case 3 – Car Assembly

<u>Pallet Flow</u>

External Warehouse

1. What is the name of the specific part chosen throughout the flow?
2. What is the quantity of the material arriving in the truck and in what time period the supplier sends?
3. How much time does it take for the truck for initial registration?
4. In what batch quantity of pallet the truck arrives?
5. How much time does it take for the truck in docks?
6. What is the time taken to the forklift to transport the pallets from truck to ground area?
7. In what batch size the forklift unloads the pallets from truck each time?
8. How much time is the pallet left in the ground area?
9. How much time does it take to count the number of pallets and scanning those pallets?
10. What is the time taken for the forklift to transfer 2 pallets to storage rack?
11. How much time are the pallets left in the ground area?
12. What is the time taken for the forklift to transfer pallets to storage rack?
13. What is the time taken for reporting the check digit?
14. How much time are the pallets left in storage?
15. In what batch size the pallets are left in storage for specific part chosen?
16. What is the time taken to retrieve the pallet from the storage?
17. In what batch size the pallets are retrieved from the storage?
18. What is the time taken for the forklift to transport the pallet to the spacer?
19. In what batch size the pallets are transferred to the spacer?
20. What is the time taken for loading the trailer?
21. What is the time taken for the truck to drive to TC South?
22. In what batch size of pallets, the truck transfers material to the TC south?

Assembly Facility

23. What is the time taken in truck docks?
24. How much time does it take to unloading the trailer?
25. How much time are the pallets left in the spacer?
26. In what batch size the pallets are left in the spacer?
27. What is the time taken for scanning those pallets?
28. What is the time taken for the forklift to transfer pallets to storage rack?
29. In what batch size the forklift transfers pallets to the storage rack?
30. What is the time taken for reporting the check digit?
31. What is the time that the pallets are left in the storage?
32. In what batch size the pallets are left in the storage?
33. What is the time taken for the forklift to transfer pallets to FLF train?
34. In what batch size the forklift loads FLF train?
35. How much time FLF train needs to wait before it leaves to the assembly stations?
36. What is the time taken for FLF train to deliver pallets to assembly station?
37. What is the time taken to replace the empty pallets with the pallets in FLF train?
38. How much time are the pallets left in lineside?
39. What is the time taken for the assembly operator to pick the single part?

<u>Box flow</u>

1. What is the part number and name of the product?
2. In what quantity the material arrives and how frequent does it come from the suppliers?
3. What is the time taken for initial registration of truck?
4. What is the time taken in truck docks?
5. What is the time taken for unloading the pallets from the trailer by the forklift?
6. In what batch size the pallets are unloaded?
7. How long are the pallets kept in the ground buffer?
8. What is the reason for keeping the pallets for that long time in the buffer?
9. What is the time taken for counting the pallets received and for confirming the shipment?
10. What is the time taken by the forklift to transfer the pallets to the ground sorting area after counting and in what batch size?
11. What is the time taken for writing the list of pallets received?
12. What is the time taken by forklift to transfer after making the list of pallets?
13. In what batch size they are transferred?
14. How long are the pallets kept on the ground before loading on to the trailer?
15. What is the reason for waiting in the ground buffer?
16. What is the time taken by the forklift to transfer the pallets to the trailer?
17. In what batch size they are transferred?
18. What is the waiting time in the buffer before the trailer departure?
19. What is the time taken by the truck to transport the pallets to TVV?

TVVX

20. What is the Time is taken for shipping documentation checking, investigation and feeding to the system?
21. What is the time taken by forklift to unload the pallets from the trailer?
22. In what batch size the pallets are unloaded?
23. What is the waiting time in the storage buffer Gesebo train and land set?
24. What is the time taken for counting, checking and scanning of pallets?
25. What is the time taken by hand scanner to scan the received items?
26. What is the time taken for sorting of pallets?
27. What is the time taken by the Gisebotåg to transfer the pallets to the buffer?
28. In what batch size the Gisebotåg transfer the materials to the buffer?
29. What is the waiting time in Gisebotåg buffer?
30. In what batch size the materials are stored in Gisebotåg buffer?
31. What is the time taken by Gisebotåg to transport the materials to ordinary buffer?
32. In what batch size the materials are transferred by Gisebotåg to ordinary buffer?
33. What is the waiting time in Gesebo-tåg buffer?
34. What batch size is maintained in the Gesebo-tåg buffer?
35. What is the time taken to transfer materials by Gesebo-tåg to TV Box-förråd?
36. IN what batch size they are transferred to the TV Box-förråd?

Box-förråd

37. What is the waiting time in Gesebo-tåg buffer?
38. In what batch size the Gesebo-tåg buffer is maintained?

39. What is the time taken for scanning the pallets?
40. What is the time taken for transporting the materials to marking buffer?
41. In what batch size the materials are transported to the buffer?
42. What is the waiting time in marking buffer storage?
43. What is the batch size maintained at marking buffer?
44. What is the time taken for scanning?
45. In what batch size the scanning and flagging process is carried out?
46. What is the time taken for transporting the materials to racking place?
47. In what batch size the materials are transferred?
48. What is the time taken for confirming the check digits?

Continuation….

49. What is the waiting time in storage rack buffer?
50. In what batch size the materials are stored in the buffer?
51. What is the time taken for scanning pallet?
52. What is the time taken for moving pallets to chute?
53. In what batch size the pallets are moved to chute?
54. What is the time taken for confirming the delivery?
55. In what batch size the confirming delivery process is done?
56. What is the time taken for scanning the location and all the boxes?
57. IN what batch size the scanning process is done?
58. What is the waiting time in Chute buffer?
59. What is the batch size maintained at Chute buffer?
60. What is the time taken for scanning the box and placing the labels?
61. In what batch size scanning and placing labels are done?
62. What is the time taken to set the box on the truck?
63. IN what batch size the boxes are arranged in the truck?
64. What is the time taken to transport the boxes to assembly station by the truck?
65. In what batch size the boxes are transferred to the assembly station?
66. What is the time taken to remove the lid and to set the boxes in the chute at the mounting station?
67. In what batch size the removing the lid and setting the box at the cute in the mounting station is done ?
68. What is the waiting time in the chute mounting station buffer?
69. In what batch size the mounting station buffer is maintained?
70. What is the time taken by the assembly operator to pick up the boxes?
71. In what batch size the assembly operator picks up the boxes?
72. What is the time taken for scanning the empty boxes?
73. IN what batch size the scanning the empty boxes are done?

continuation...

74. What is the time taken by forklift to transfer the boxes to storage racks?
75. In what batch size the forklift transfer the boxes to the rack?
76. What is the time taken for check digit report?
77. In what batch size the check digit reporting is done?
78. How long are the boxes kept in the storage racks?
79. What is the batch size maintained in the storage rack buffer?

80. What is the time taken for scanning pallet?
81. What is the time taken by the forklift to transfer the material to the FIFO floor surface?
82. In what batch size the materials are transferred to the FIFO surface floor?
83. What is the time taken by forklift to move pallets to the omplock station?
84. In what batch size the pallets are transferred to the omplock station?
85. How long are the pallets stored in omplock station buffer?
86. In what batch size the pallets are maintained in the omplock station buffer?
87. What is the time taken for scanning 2 codes, searching system, prinitng and pasting labels on the box?
88. What is the time taken for handling at omplock?
89. In what batch size the handling at omplock is done?
90. How long are the materials stored in the omplock storage buffer?
91. In what batch size the materials are maintained at the omplock storage buffer?

continuation….

92. What is the time for moving the pallet with omplockade boxes to the floor?
93. In what batch size the pallets are moved to the floor?
94. What is the time taken for marking at the buffer storage?
95. In what batch size the marking process is done at buffer storage?
96. What is the time taken for scanning the flag?
97. In what batch size the scanning of the flag is done?
98. What is the time taken to drive till the channel?
99. In what batch size the materials are driven till the channel?
100. What is the time taken for scanning the codes on the channel and to scan 2 codes per 1 box?
101. What is the taken for setting box in the Ranna?
102. In what batch size the setting of the box at Ranna is done?

Case 4 – Truck Engine Assembly

Pallet Flow

1. What is the quantity of the material arriving in the truck?
2. How frequent they arrive?
3. Do the box material and the pallet material come on the same day?
4. How is the signal sent to the Production Control System in ordering the material?
5. What is the minimum safety stock maintained in the inventory?
6. What is the time taken to transfer the pallet from truck to roller bed?
7. In what batch size the forklift picks the material from the truck to the roller bed?
8. What is the time taken in the roller bed buffer till it breaks down into single pallets?
9. What is the time taken for the single palette to reach the storage place in the conveyor?
10. Is the batch size is mentioned in this pallet flow?
11. Time is taken for registering and confirming the number of pallets?
12. A number of people working for that process?
13. Is it possible to combine Automatic scanning/barcode process with registering process?
14. Does the process delay the transferring of pallets in the conveyor?
15. What I the capacity of the materials stored here?
16. How much time is each palette kept in the storage?
17. How frequent are the materials transferred from storage to the shop floor?
18. Time is taken in the automatic conveyor till the material reaches the shop floor?
19. In what batch size they are transferred to the shop floor?
20. How much time are they kept in the drop zone shop floor?
21. Time is taken to load the material in tugger train?
22. What is the batch size the materials are loaded in the tugger train?
23. Time spent in the tugger train buffer before departure?
24. How often the tugger train transfer the material from the drop zone?
25. How is the signal made by the forklift operator confirming about the delivery of material in the tugger train to the production control system and what is the time taken for it?
26. How is the signal made by the tugger train operator confirming about the delivery of material in the tugger train to the production control system and what is the time taken for it?
27. Time is taken by the tugger train to deliver pallets in the assembly line?
28. Time is taken for disconnecting the cart?
29. Time is taken for the tugger train operator to confirm the delivery? Also, how the signaling process is carried out?
30. How much time does it take for a bin to get over completely?
31. What is the safety stock or at which point the replenishment is ordered?
32. How is the exchanging of bins process happening?
33. How is the signal made from assembly to production control system?
34. How is the signal made from production control system to storage in AS/RS?
35. How is the signal made from automatic transport on the conveyor to production control system?
36. How is the signal made from production control system to tugger train?
37. How is the signaling process made from forklift operator to production control system?

38. How is the signaling process done from tugger train operator to production control system?
39. How is the signaling done from production control system to tugger train delivery to assembly lines?
40. How the tugger train operator confirms the delivery to the production control system ?

Box Flow

1. What is the quantity of the material arriving in the truck?
2. How frequent they arrive?
3. How is the signal sent to the Production Control System in ordering the material?
4. What is the minimum safety stock maintained in the inventory?
5. In a Palette how many boxes are present (Batch Size)?
6. What is the time taken to transfer the pallet from truck to the ground?
7. How much time are the box materials placed on the ground? And what is the quantity?
8. What is the time taken for sorting the boxes based on the destination?
9. After sorting the boxes how much time it is placed on the ground?
10. What is the time taken by the forklift operator to transfer the boxes to the roller bed?
11. In what batch size the boxes are transferred to the roller bed by the forklift?
12. What is the time taken to scan the palette to confirm delivery as well as to receive to storage location?
13. What is the time taken to transport the boxes from roller bed to buffer storage?
14. What is the time taken to confirm delivery by checking digits?
15. Time is taken to transport the boxes to the labelling process?
16. What is the waiting time in labelling area?
17. What is the Time taken for labelling the box?
18. What is the Time taking for creating the report after labelling?
19. In what batch size they are sent?
20. How is the labelling report created?
21. What is the waiting time for the boxes in the buffer after labelling?
22. What is the batch size of boxes in the buffer after labelling?
23. What is the transport time for the forklift to deliver the boxes to picking location second bin?
24. In what batches the boxes are transferred to the second bin?
25. What is the waiting time for the boxes in the buffer in “Picking a location in first bin”?
26. In what batches the boxes are stored in the picking location first bin?
27. Is the exchanging process between the two-bin system is automatic or done by the operator?
28. Time for exchanging the boxes between the two bins?
29. What is the time taken for placing the boxes in tugger train?
30. In what batch size the tugger train transports the boxes?
31. What is the time taken for tugger train to transport it to the assembly line?
32. What is the time taken to lift the box and drop it at the point of use?
33. In what batch size they are dropped?
34. Is the lifting process done by the operator or by a forklift? If the operator, How many?
35. What is the buffer size in line side buffer?
36. What is the safety stock maintained?
37. What is the reorder point?

38. How much time does it take to get completed?
39. What is the time taken for the assembly process?
40. In what batch size they are produced?