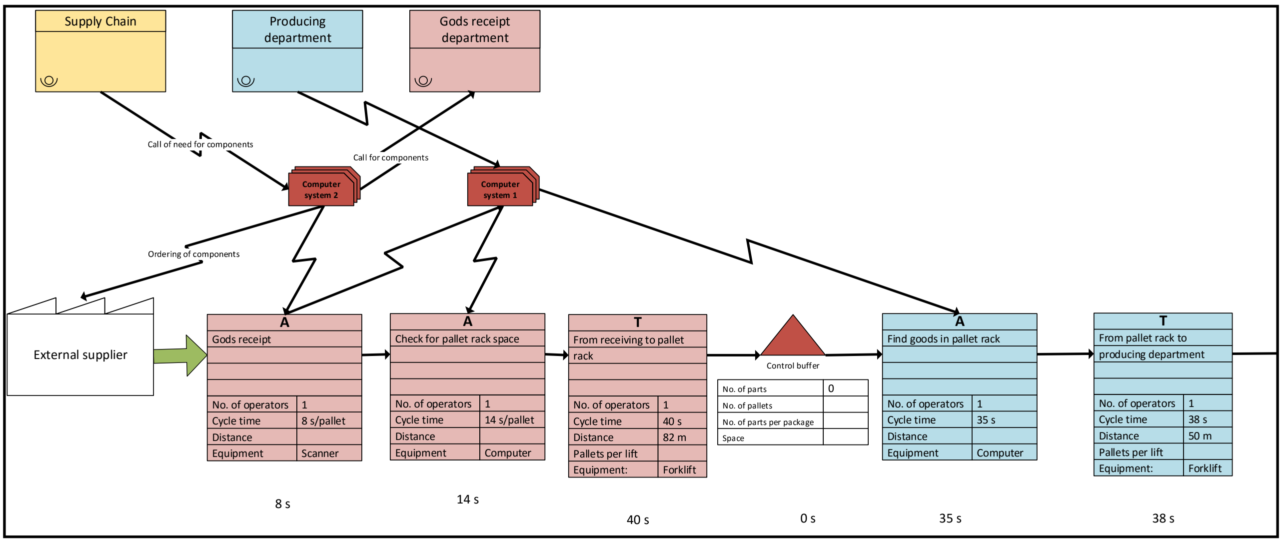

Comparison of Static and Dynamic Analysis Tools for Material Flow

A study at SKF's D-factory

Master's thesis in Production Engineering

SIMON KJERSTADIUS
ANDREAS LARSSON

Department of Product and Production Development
Division of Production Systems
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ANDREAS LARSSON

Department of Product and Production Development
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 (0)31-772 1000

Cover:
The cover illustrates a part of an example Current Material Flow Map from p 13

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Summary

This thesis covers a comparison between the methods Material Flow Mapping and Discrete Event Simulation when applied to a material flow. The Material Flow Mapping method was tested in a case study at SKF in Gothenburg. The comparison was performed based on the case study and of theoretical knowledge of the methods. The methods were compared in four areas: Needed data, Time and effort, Level of detail and Theoretical results. Time and effort consisted of four subcategories for a total of seven areas of comparison. Both methods were then evaluated in each of these areas to see which was better based on the case study. The results were then summarized to see which method excelled in the most areas. Material Flow Mapping was the best in four areas, Discrete Event Simulation in two and one was a draw. The result of the comparison was that Material Flow Mapping was the better method when performing the case study. Both methods have different strengths where the Material Flow Mapping looks at the activities performed and the Discrete Event Simulation looks at the buffer capacity and bottleneck analysis.

Keywords: Material Flow Mapping, Discrete Event Simulation, Material Flows, Lean production.

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Simon Kjerstadius
Andreas Larsson

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1 Introduction

This report covers a project carried out as a master thesis performed with the SKF's D-factory in Gothenburg as a case study. The material flow of the factory was mapped, analyzed and improvements suggested.

The analysis of the material flow has been performed using the tool Material Flow Mapping (MFM) to identify problems within the flow, also an initial analysis with the tool Value Stream Mapping has been performed. The two methods, MFM and Discrete Event Simulation (DES), was compared to analyze the differences between static and dynamic analysis tools and how they contribute to the problem analysis of the system and also how they can be used to complement each other. This thesis will also cover some improvements of the Material Flow Mapping method.

1.1 Background

The production industry has changed greatly since the introduction of the Toyota Production System and the development of lean production. The goal of lean production being the removal of any action that can be seen as wasteful and not adding any value for the customer to the finished product. The original application of the lean methodology was the production lines but it have now spread to other areas of application such as services and product development. An area where the lean production methods have not been applied to any large extent is the supply chain area even if it has a close connection to production. (Finnsgård, Medbo, & Johansson, 2011).

One of the tools from the lean toolbox to evaluate and improve production is Value Stream Mapping (VSM). This is a method developed to quickly map and evaluate the current state of a production system with the purpose of identifying what is waste and what is value adding as well as mapping the information flow. The final goal of the method being a future state where waste is removed and only value adding activities remain while still being able to meet customer demand. (Liker, 2004)

As the application of lean methods has spread to other areas of application there is also a need for adaption of the methods. One such adaption to make VSM better suited for the analysis of supply chains resulted in the development of Material Flow Mapping (MFM). While VSM considers transportation as a sometime necessary action and tries to remove any unnecessary transportations it does not provide any tools for further analysis of the transportation of material.

MFM have the same goal as VSM, identifying and removing wasteful actions and creating a future state map, but goes into detail to identify the different activities that are performed in the supply chain. The different activities are divided into Handling, Administration, Transportation and Storage (HATS). Both VSM and MFM are static evaluation tools and only capture the system at one point in time. (Finnsgård, Medbo, & Johansson, 2011)

Another method used in the analysis of production systems is Discrete Event Simulation (DES). In DES a computer model of a system is created based on collected data. This could either be an existing or a theoretical production system. The goal of the model is to be similar enough to the original system as to be a good representation of the system. The finished model can then be analyzed to discover problems such as bottlenecks in the real production system. One of the main benefits is that it is also possible to try out different solutions to the problems found and develop a future model of the production system. DES is a dynamic tool that describes how a system works over time. (Dahl & Eliasson, 2011), (Matthew, 2013)

Both VSM and DES are methods used frequently in industry today but they are quite different and possess different strengths and weaknesses. These differences have also made researchers interested in how and if these methods could be combined and it is suggested that the combination of them could result in a method that compensates for their individual weaknesses. (Gullander & Solding, 2009).

To evaluate and test the methods a case study in a factory at the company SKF in Gothenburg has been performed. In the case study the material flow to the production lines in one of the factories has been analyzed using MFM and then compared with theoretical knowledge about DES.

1.2 Purpose

The purpose of this project is to see how a material flow can be analyzed using the method MFM and also to compare the MFM to a DES-simulation with concerns for the material flow analysis. The purpose of the case study at SKF was to map the material flow to discover potential improvement areas and suggest improvements to the current system.

1.3 Limitations

The production lines in the factory will not be analyzed.
The time for this project is 20 weeks from the start date.
The focus of the thesis work is the transportation and the buffers of the material flow.

1.4 Clarification of the problem

This thesis aims to investigate how the different methods MFM and DES can be used to analyze and improve a material flow and if they are suitable methods to use when analyzing a material flow without value adding activities. Further it aims to see how the methods compares to each other and what benefits of using them both can yield. This is summarized in the two questions:

How can the performance of a logistic material flow without value adding activities be analyzed?

How can data from static analysis and dynamic simulation be used together to enhance analytics? Graphical representation can be seen in Figure 1. (Focus on arrows 3, 4 and 5).

Figure 1 describes the relationship between a MFM, a static tool, and a Discrete Event Simulation, a dynamic tool. Both of these methods can be used to analyze a material flow but the methods uses different approaches to analyze and describe a material flow. The second research question focuses on how the two methods can be used together and how they can enhance and improve each other.

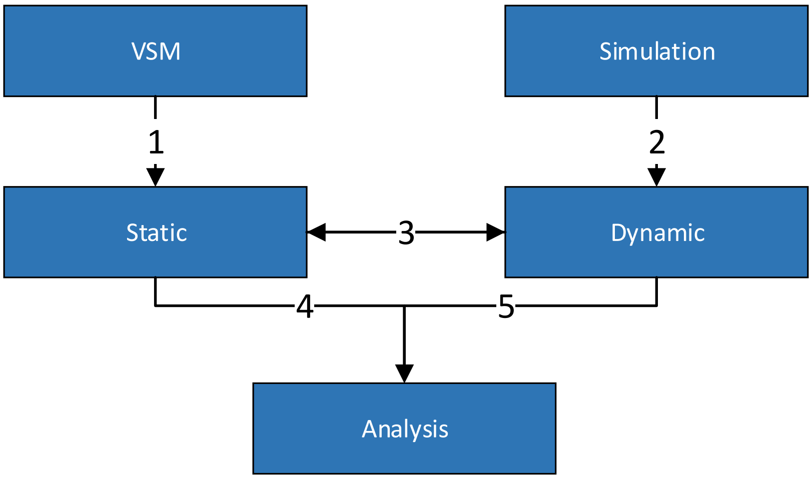

Figure 1: A flowchart over the collaboration between static and dynamic tools

1.5 SKF-Case

The SKF production facility in Gothenburg produces medium and large bearings distributed to the whole world. The bearings that are produced consist of inner and outer rings, cages, rollers and guide rings.

The Gothenburg site produces rollers themselves but the rest of the parts are bought and delivered to the assembly site. The Gothenburg site consists of the RK-factory where rollers are produced, the E-factory where large bearings are produced and the D-factory where large and medium bearings are produced. The factory that will be analyzed in this thesis is the D-factory where bearings are assembled from delivered parts. The rings are also grinded in the assembly line.

The material flow in the D-factory consists of forklift drivers that load and unload trucks and also distributes the material in the factory to the producing units. This thesis will only look at the material flow from the arrival of the material to the production site until it reaches the assembly line. In SKF each producing or assembly line is called a channel.

The material flow in the D-factory has some issues that the supply chain wanted analyzed in a scientific manner. The supply chain stated that the material flow had problems and one big problem was when pallets went missing in the logistic flow from ordering to delivery at the channel.

2 Theory

This chapter covers the theoretical background for the project and methods used which is performed through a literature study.

2.1 Production flow

A production flow is a chain of actions that in the end will result in a finished product. The production flow can be composed of different parts to create the finished product. These parts are:

- Material handling
- Processing
- Storing
- Resource

The material handling is used when something needs to be moved from point A to point B. What has to be moved can differ but it can for example be raw material for the product, packing material or the finished product. Examples of material handling can be a forklift, a conveyor or a person moving the part by hand.

The processing is when the raw material is moved one step closer to the finished product and this is usually where value is added to the product. Examples of processing can be: a mill that transforms a raw steel block into a part needed for assembly and the assembly where parts are put together to become a product, either a sub part for the finished product or the finished product itself.

The storing is where raw material, semi processed parts and the finished product is stored when waiting for a processing action to process it or to be stored before the finished product leaves the factory. Examples of storing can be pallet rack, empty floor space, a shelf, just anything that can hold and store the parts that needs storing.

The resource is something needed for the processing or material handling to be able to work, it can be a worker needed to operate the processing action, it could be a forklift that is needed to move material in the factory or a robot used in an automated production cell. For some processes both the process and the resource have to be free and have time to be able to produce something. All of these parts are combined into a production flow where raw material is entered into the flow and at the end a finished product will exit. (Matthew, 2013)

Some terminology that is used in production flow:

- Work in Process (WIP): This is the amount of goods currently within the production flow, both raw material as well as finished goods.
- Downstream: This is a direction in the production flow, when starting at the beginning of the flow where the raw material enters and then moving along the flow and finally ending up at where the finished product is stored, this is called moving downstream.
- Upstream: The opposite of Downstream.
- Lead time: The time it takes from when the first raw material arrives at the factory until the final product leaves the factory.
- Up, Down and Idle: This is the states that processes and resources can be in, when Up it will be working with a product, Down it will be broken and cannot work on a

product and Idle is when it waits for products to work on. (Skoogh, Lecture: Production development tools, 2013-10-10) (Matthew, 2013)

To analyze production flows there are many methods available and some will be presented below:

- Line balancing – In a production line the same operation might be performed at different machines or assembly station and line balancing is a way to analyze and divide the operations to different stations so that it will be performed effective.
- Theory of Constraint – This theory analyzes and develops production flows according to the constraining processes in the flow. This is performed from the following steps
    - Identify the constraining process
    - Decide how to use this process in the best way
    - Since this is the constraint, plan all production so that this process always can be Up.
    - Improve the process so that it no longer is a constraint.
    - When a constraint is broken start from step one
- Value Stream Mapping – A tool from the Lean toolbox where a production flow easily is analyzed in a static manner, a snapshot of reality, and then analyzed for improvements.
- Discrete Event Simulation – A model of the real production flow is created in a computer environment where the current production flow can be analyzed and new improvements can be tested.

(Skoogh, Lecture: Production development tools, 2013-10-10)

A production flow can usually be described either to be a pushing flow or a pulling flow. A pushing flow is when the decision of what to be produced is performed at the start of a production line and then the product will be pushed through the rest of the flow until it is finished.

A pull system will use an ordering system where the production control is later in the production line and the product is ordered from a producing unit or a supermarket downstream to a producing unit or supermarket upstream to start the production of the right product. A good example is when a finished goods supermarket is used, in a supermarket a certain amount of a product should always be present in the store. If a product is bought by a customer and the amount of products are below a certain amount new products need to be added to the supermarket. This is performed by an order from the supermarket to start a new batch of the sold product so that the supermarket can be restocked.

2.2 Material Flow

According to Ghiani, Laporte and Musmanno (2013, pp. 1-4) the definition of logistics is the discipline that studies the material flow. In Figure 2 an example of a logistic system can be seen, this covers a whole distribution system from raw material to the final customer. This thesis work will focus on the internal logistics and material handling in the D-factory at SKF and will be limited to the arrival of semi-processed material at the Central Distribution Center (CDC) and a customer that will be the producing unit in the factory.

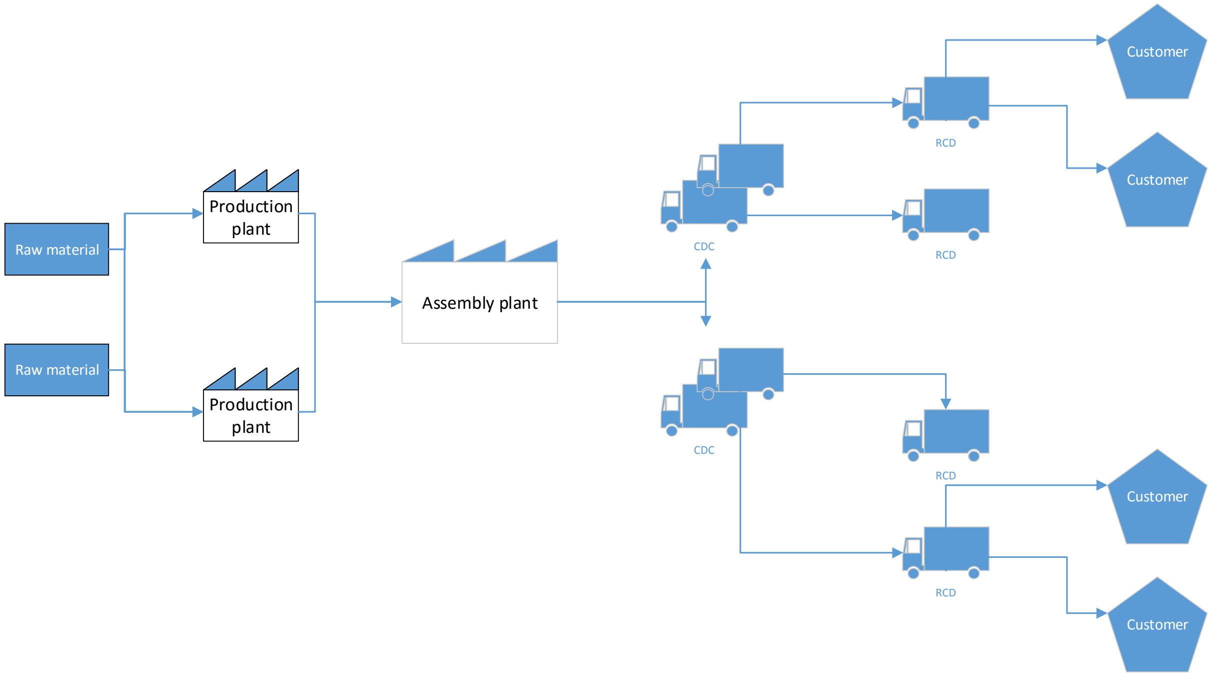

Figure 2: An example of a logistic system.

An important measurement in logistics is the lead time, the time it takes from the arrival of material until it arrives at the customer and this is in lean terms an important value for the customer since a shorter lead time means that the customer receives the goods faster. Another important value is the state of the goods when it arrives, if a goods is delivered fast but it is damaged then the value of a fast delivery will lower drastically.

The material flow will usually also contain an information flow that travels in the opposite direction to the produced parts where an order from the customer will result in a shipping order from the raw material supplier. The type of production system will determine how far the customer order will travel, in a Make To Order system the information will travel all the way to the raw material supplier but in a Make To Stock system the order will only travel to the distributor of the product. (Ghiani, Laporte, & Musmanno, 2013).

2.2.1 Material Handling

Material handling is the actions that moves and administer the material for and of production in the factory. Bartsch, Saleh and Steen (2008) says that material handling covers the moving, storing, protecting and controlling of material. Tompkins et al. (2003) define material handling as "*providing the right amount of the right material, in the right condition, at the right place, in the right position, in the right sequence and for the right cost, by the right method(s)*"

2.2.1.1 <u>Analyzing and improving material flows</u>

A static method of analyzing a material flow is a simple Material Flow Analysis that consists of a map of the factory where all material handling is drawn as arrows to get an overview of how the transports are handled. After this a new map can be created where a more efficient flow can be achieved. This method only covers the transportation of material and to some extent the storing of material. (Skoogh, Lecture: Production development tools, 2013-10-10)

Bartsch, Saleh and Steen (2008) present ten principles to analyze and improve material handling systems:

1. Planning – To plan the movements and storage in advance can improve the material handling.
2. Standardize – Less variation in regard to methods, equipment, controls and software.
3. Work Principle – Reducing unnecessary transports and handling.
4. Ergonomic principle – Ensure safe and efficient activities.
5. Unit load – Batching the material so that more material is moved with one transport.
6. Space utilization principle – Use the space in an efficient and effective way.
7. System principle – Integrate information flow with the physical material flow.
8. Automated – Use digital systems to combine information.
9. Environmental – Energy consumption, recycling and reuse of equipment.
10. Life cycle cost – Counting total cost of equipment.

2.3 Static and Dynamic

This thesis will use the definitions of static and dynamic from the Cambridge online dictionary:

- Static – "staying in one place without moving, or not changing for a long time"
- Dynamic – "continuously changing or developing"

(Cambridge, 2015)

A dynamic model will be dependent on different changing variables for example time and different amount of received raw material. A static model will use constants for all calculations and will only look at the material flow in a certain given time.

2.4 Value Stream Mapping

Value Stream Mapping (VSM) is a tool from the lean manufacturing toolbox which is used to quickly analyze a production flow for a product family from incoming material to finished goods (Gullander & Solding, 2009). VSM explains the relationship between production flow and communication in the factory as well as the product flow. The analysis is used to identify problem areas and wastes in the value stream, waste being processes that do not add any value to the product for the customer. (Rother & Shook, 2001)

The value stream method is divided into two parts: a current state map and a future state map. The current state map maps the state of the production flow as it is. When the current state map has been analyzed a future map should be created. The future map is created based on the current state map, eight questions are answered and the current state map is transformed to the future state map. A current state map can be seen in Figure 3.

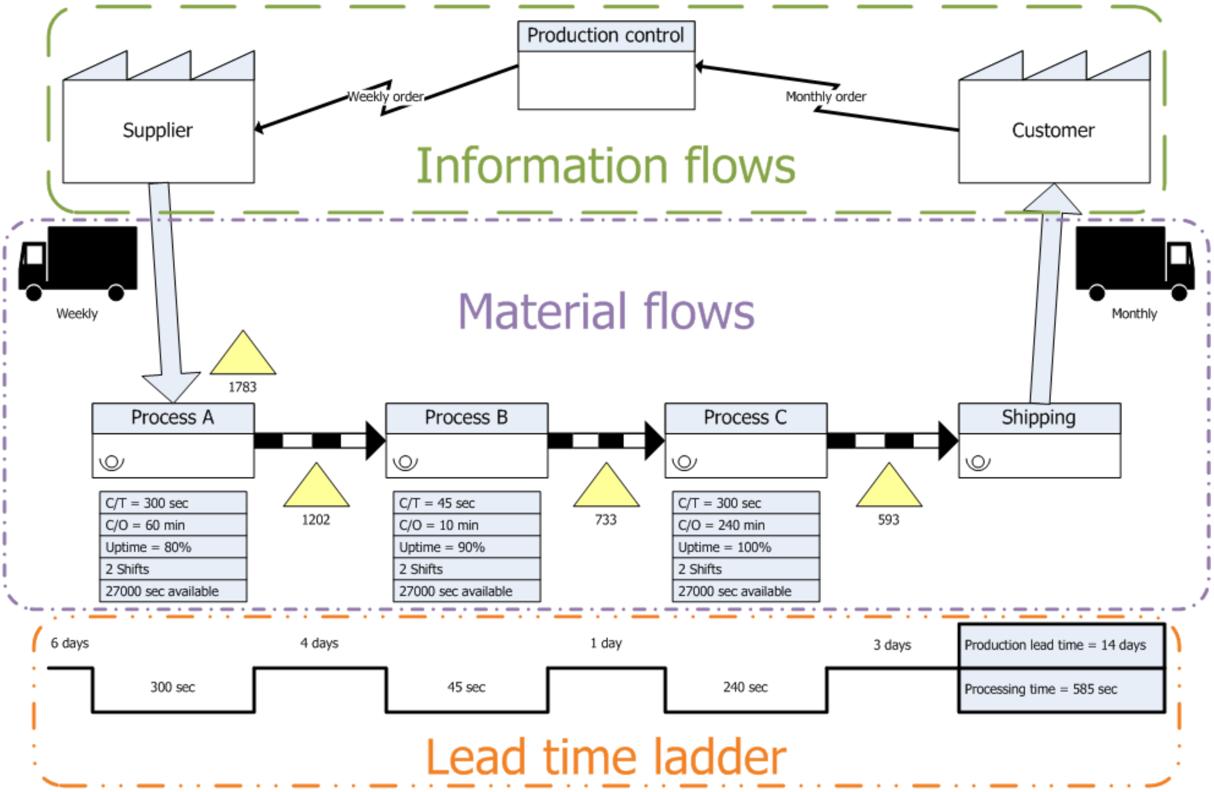

Figure 3: A VSM current state map. [Picture](#) by Daniel Pennfield/ [CC BY-SA 3.0 US](#)

2.4.1 Mapping the current state

To analyze a current state of a material flow, Value Stream Mapping can be used. The analysis is performed by a team that should consist of people working in the production flow, walking through the flow upstream and recording information such as, cycle times, buffer sizes, number of operators, number of shifts and other information that might be useful in a rough value stream map. Already in this state a sketch for a future state map is created with the improvement ideas that occur during the walk. (Rother & Shook, 2001)

The next step is to use the recorded data and a rough sketch to draw the actual current state value stream map and use that map to get an understanding of the value flow. The information flow of the factory should also be included in the map, starting with the ordering of products from the customer and work upstream in the map from customer to planning department of the own company to supplier of material to the factory. Also add the information flow from the planning department to the production flow. (Rother & Shook, 2001)

The last step of the mapping is to calculate the lead time and value adding time for a product. This is a summation of the time spent in buffers (Equation 1) and the processing time of each process. The value adding time of the flow should also be calculated and this is the summation of the total time where value is added to the product.

$$\frac{Products\ in\ the\ buffer}{Daily\ customer\ need} = Time\ spent\ in\ buffer \qquad \text{(Equation 1)}$$

2.4.2 *Mapping the future state*

Using the VSM of the current state as basis, a map of the future state can be created. The future state map shows a possible future state of the factory with improvements of the value flow. This future state map is created by answering eight questions.

The goal of the future state value stream map is to eliminate wastes, minimizing non-value-adding processes in the value stream. According to Liker (2004) the eight wastes that occur in any company with customers are:

1. Overproduction. Producing goods that have no order connected to it, this is producing to stock.
2. Waiting. Any kind of waiting for the employees should be considered a waste.
3. Unnecessary transports. Moving goods for long distances, unnecessary paths or in and out of storage will increase the work in process (WIP).
4. Overprocessing. Not producing the part in an efficient way but doing unnecessary steps or processes.
5. Excess inventory. All kind of inventory costs money and will use space. Too much inventory might hide problems in the production line such as late deliveries from suppliers, long setup times, downtime for the machines etcetera.
6. Unnecessary movement. All movements that have to be performed by the worker that gives nothing to the product, such as looking for tools or material, reaching etcetera.
7. Defects. Not correct parts, production problems or corrections of a product or production.
8. Unused employee creativity. Not to use or give the opportunity to share the employee's experience or ideas for improvement.

The eight questions for the future VSM are:

1. What is the takt-time for the product? This value is a constant and will be an important value throughout the creation of the future state map and represents how many seconds each product can be processed to meet the demand of the customer. It is calculated as:

   $$Takt\ time = \frac{Available\ worktime\ (in\ seconds\ per\ shift)}{Customer\ need\ (in\ products\ per\ shift)} seconds/product \qquad \text{(Equation 2)}$$

   The customer need is the number of products the customer wants for the duration of that shift and the available work time is the time that the factory is up and producing during one shift, hence it is:

   $$Available\ worktime = Total\ work\ time - time\ for\ breaks \qquad \text{(Equation 3)}$$

2. Should the company use a supermarket for finished goods or should there be direct delivery to the customer? Do the company have such a good relationship and close proximity to the customer that the needed products can be delivered when they are finished then the direct delivery should be used.

3. Where can the company introduce continuous flows? To introduce continuous flows the number of buffers is reduced and hence the work in process can be reduced. A continuous flow will also result in a more controllable flow of products and give a

better and faster reaction to problems and scraped products.

4. Where in the process are supermarkets needed in the pull system? A pull system is when the products are pulled through the system instead of pushed. This means that for example when a customer buys a product from the supermarket a production order of that product type will be sent to the producing flow. A supermarket can also be added in the middle of the production system and then the downstream producing unit will be considered the customer.

5. At what point can the production flow be controlled, which unit is the pacemaker? This point will regulate the flow of the whole production and will set the orders in motion in the production flow.

6. How can the production be leveled out? To make sure that the supermarkets are evenly stocked the production must be leveled out so that the flow of products is varied. However due to set-up times the flow might not be so easy to level out.

7. What batch size should be used when producing? How many products can be bundled together for a good production result?

8. What improvements have to be implemented? To reach the future state map, what improvements have to be performed?

(Rother & Shook, 2001)

While answering the questions above a new, future value stream map is created and finally the new lead time and value adding time is calculated. VSM have both strengths and weaknesses, Gullander and Solding (2009, pp. 436-437) have identified and listed these as follows:

"Strengths with VSM

- Fast and easy to carry out.
- Cheap, since no special tools or computer programs are needed. Only man hours are spent during initial work.
- Simple – Easy to learn and understand.
- All tools needed are pen and paper.
- Gives a good basis for discussions and decisions.
- Increases the understanding for the customer, the product and information flow and losses.
- Can often be performed with people directly involved in the system with aid from a VSM experienced person.

Weaknesses with VSM

- Only the flow of one product or product type is analysed per VSM analysis.
- The VSM gives only a snapshot of the situation on the shop floor at one specific moment.
- The VSM map is a rough simplification of the real situation.
- It is difficult to experiment with suggested new systems and layouts."

2.5 Material Flow Mapping

Material Flow Mapping (MFM) is a method based on VSM but focuses on the material flow from supplier until it reaches the assembly line where as VSM focuses on the production flow. It is meant to be used to assess and describe the material flow process. The method was developed at Chalmers University of Technology by Finnsgård, Medbo and Johansson (2011) and presented in a case study report.

While VSM is a great tool for analyzing and improving production it does not offer as much possibilities to analyze the material flow into the production. This is because transportation is classified as a non-value adding activity and thus considered waste. In MFM the material flow is analyzed by identifying the different activities that makes up the material flow, Handling, Administration, Transport and Storage (HATS).

MFM is performed in a similar manner as a VSM, following the flow upstream from production to supplier. However there might be problems doing the analysis this way because there might be several different ways for the material to move as non-value adding activities often are less controlled than value adding activities. (Finnsgård, Medbo, & Johansson, 2011) Therefore it might be easier to follow the flow downstream. While following the flow identification of HATS-activities is performed. The times for different activities, distances and buffer sizes are measured along with determining the resources needed to perform the activities. All the data is then collected in a finished map, the finished MFMs of the current state can be seen in Appendix A

Examples of the activities:

- Handling can be packing a pallet with the parts or putting frames on a pallet.
- Administration could be filling out transport lists or registering goods in the computer system
- Transport is just moving something from point a to point b
- Storage is buffers and other types of storage.

Based on the eight questions of VSM a set of seven questions for MFM have been developed.

“1. What is the real customer demand?

2. To what degree can we achieve a continuous material flow?

3. How can we achieve a pull controlled material flow?

4. How can a levelled material flow be achieved?

5. How can the material flow be synchronised with the takt of customer production flow?

6. Which process improvements are needed (training reductions of disturbances, quality improvements, reduction of changeover time etc.)

7. How can the material flow be further improved?”

(Medbo, 2015)

In the first question customer demand could be the number of parts needed to be delivered to an assembly line to reach the production goal. With question number two the goal is to reduce the number of HATS-activities and also consider if there is a way to make a one piece flow and if not, can the batch sizes be adjusted to a more optimal size. The third question concerns if it is possible to only move goods when they are needed in the next step of the material flow. Question four looks at if it is possible to even out the material flow that is decrease storage by adjusting the amount of deliveries.

The fifth question concerns if it is possible to identify order points where the flow of components upstream can be controlled from an order point downstream. Question six considers what improvements are needed to be able to implement the improvements found by asking the other questions. Question seven covers other improvements that might have been found while doing the analysis that might not have been covered with the other questions. Part of an MFM can be seen in Figure 4.

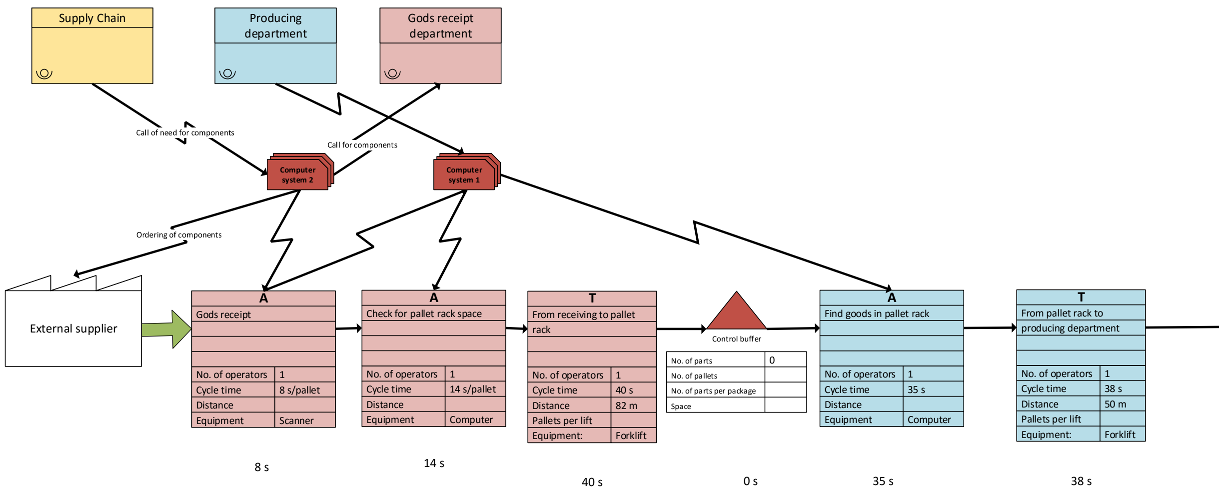

Figure 4: Part of a Material Flow Map

2.6 Discrete Event Simulation

A flow simulation can be performed in a software based on discrete event simulation. Discrete event simulation is a time based jumping event triggered simulation that proceeds with the calculation at the given time points in the code. Discrete event simulation is based on events that trigger a reaction in the simulation. Such an event could be that a work is arriving at a resource and uses it. (Fishman, 2001, pp. 6-7) (Matthew, 2013)

An example of what a DES is and what input data is needed as well as what output it can achieve is shown in a slide from Skoogh (2013-10-10), this slide is shown in Figure 5.

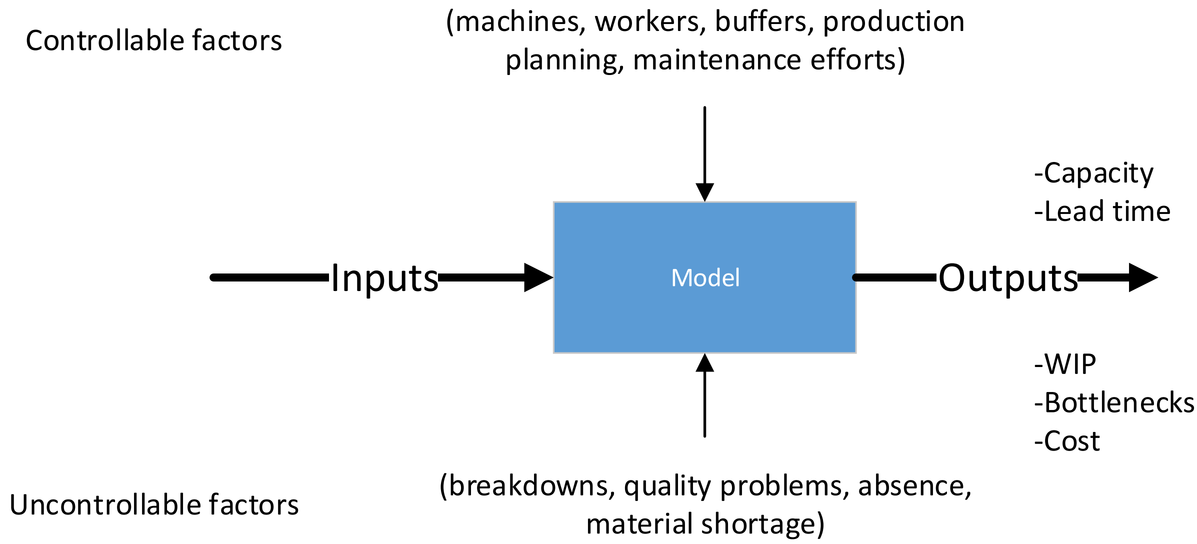

Figure 5: An overview of DES.

An example will be used to explain how a discrete event simulation works. The example is a one buffer and one machine system where a product is stored in the buffer until the machine is ready to process it, when the process is finished the product will disappear from the model.

Every fifth second a new work (product) will arrive to the buffer of the resource (machine) and will wait there until the resource is ready to process the work. The resource will take 8 seconds to process the work and will then send it on to the next buffer in line. At time, t, equal to zero the resource is idle and the buffer is empty, as shown in Figure 6.

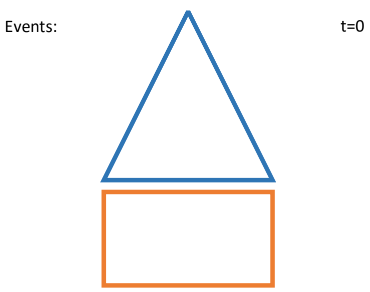

Figure 6: Initial state where the green triangle is the buffer and the orange rectangle is the resource

Nothing will happen in the model until t=5 so the model will simply jump to when the next event occurs. Here the work will arrive to the buffer as shown in Figure 7.

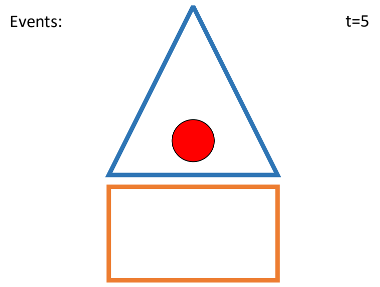

Figure 7: The state at time t=5.

Since there is no work in the resource the work can at this point continue directly into the resource for processing. The processing will take 8 seconds so an event at time 13 (5+8) seconds can be added to the event list, however a new work is arriving at every five seconds so the next work will arrive at time t=10 seconds so this can also be added to the event list, this can be seen in Figure 8.

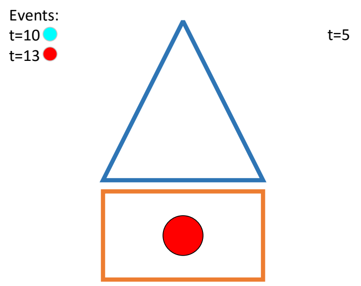

Figure 8: The state at time t=5 with the work in the resource and the events in the event list.

Since nothing will happen in the model until time t=10 seconds the model will jump to this time. Here the new work will arrive to the buffer, however it cannot move into the resource directly since it is occupied by the first work, see Figure 9.

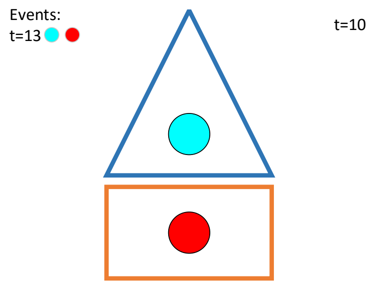

Figure 9: The state at time t=10 where the light blue work has just arrived.

The next event will occur at time t=13 so the model will jump to that occasion in time where the red work will move on and the light blue work will move into the resource. From this knowledge one event that will occur is when the light blue work is finished at the time t=21 (13+8) however a new work will also arrive at the time t=15. This is shown in Figure 10.

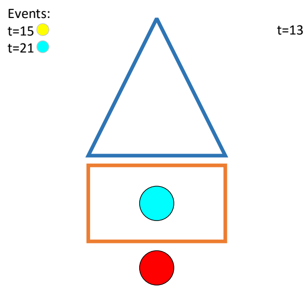

Figure 10: The state at time t=13 where the red work is finished and moves on and the light blue work moves into the resource.

At the time of t=15 a new work will arrive and that is also the next event so the model will jump to t=15. However the new work cannot move into the resource until it is free at the time of t=21. A new work will be created at time t=20, as shown in Figure 11.

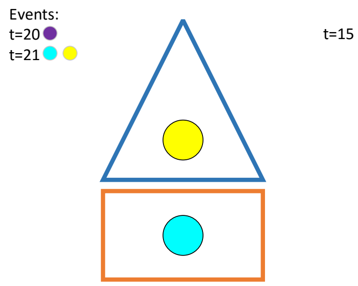

Figure 11: The state at time t=15 where the new yellow work arrives at the buffer

At time t=20 a new work will be added to the model. The next event for that work is when the yellow work is completed t=29 (21+8), this can be seen in Figure 12.

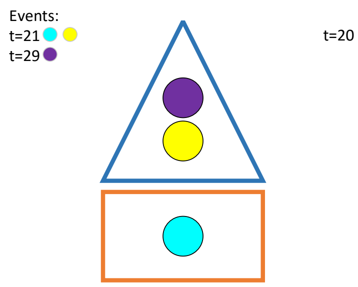

Figure 12: The state at time t=20 where the new purple work arrives at the buffer.

The model will now jump to the next event that is t=21 where the light blue work will be finished and the yellow will move into the resource for processing. The yellow work will be finished at the time of t=29 (21+8). This is shown in Figure 13.

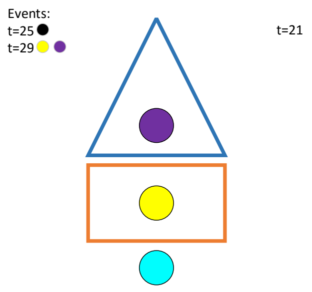

Figure 13: The state at time t=21 where the light blue work moves on and the yellow work moves into the resource.

Next event to occur is that a new work will be created at t= 25 so the model will jump to this time. The next event that will happen for the black work is when the purple work is finished in the resource which is at time t=37 (29+8). A new work will also be created at time t=30. A state representation of the time t=25 is shown in Figure 14.

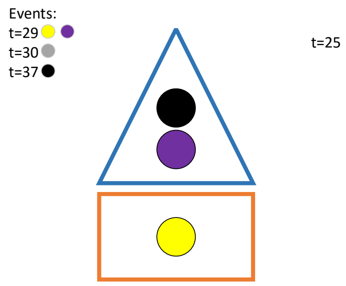

Figure 14: The state at time t=25.

This model is discrete since it is using the time jumping instead of a continuous flow of time and it uses events as triggers for the time jumps. (Fishman, 2001, p. 6) To make the models more realistic different statistical distributions are used to randomly select a value from within the distribution. This statistical distribution should represent the real world case as closely as possible for better results.

The simulation will be a platform where new ideas easily can be tested for a small cost and will give an approximate result as well as give a deeper analysis of the current state. Some possible results from the simulation model is utilization of buffers, machines and personnel, bottlenecks, changes in buffer sizes and standard deviations. (Gullander & Solding, 2009)

3 Method

The workflow that was used is described in the flowchart of Figure 15 and has guided the whole work, it started with a general knowledge of the flow, then a deeper analysis followed by problem identification and finally a list of improvement suggestions.

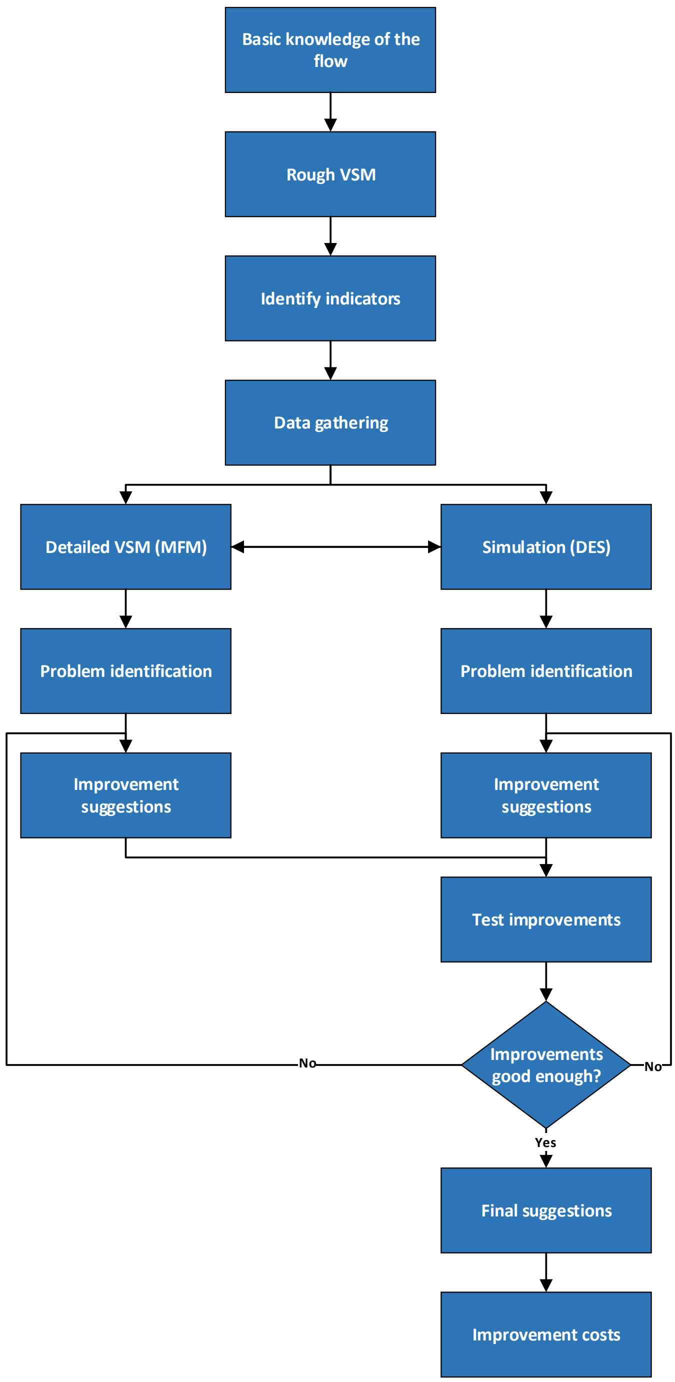

Figure 15: A flowchart over the working method of the thesis work.

3.1 Basic Knowledge of the material flow

To start the work a basic knowledge of the material flow was needed to be able to get an understanding of the important nodes in the flow. This was obtained both by interviews, general information and to actually go through the flow and observe it. This was a very good basis for the next step in the workflow flowchart.

3.1.1 Rough VSM

As described in chapter 2.4.2 a strength of VSM is that it is easy and quick to perform and therefore a rough VSM was performed to get a deeper understanding of the actual flow. Since there were several flows only one was analyzed. To do a rough VSM a walk in the flow was needed and this was performed upstream of the actual material flow.

When walking through the flow it was important to gather data for the VSM by for example counting number of products, asking workers for cycle times and getting to understand the information flow behind the physical material flow. When all data had been gathered the actual final rough VSM was drawn and problem areas that needed attention could be identified.

3.2 Identifying Indicators

Indicators were used to know what specifics were important to improve and they were also used to compare how much improvement was reached compared to the current state of the material flow. If these were not decided before the improvement suggestion was started the possible improvements might have been infinite and some limitations had to be in place.

3.3 Data gathering

Identifying and gathering the data needed was a crucial step in the project and was performed according to the steps in the flowchart by Johansson and Skoogh (2009) in Figure 16. The steps were the same for data gathering both for the VSM, MFM and the simulation.

In the first step the relevant parameters was identified and defined for this project. The most relevant data was the data that allowed for a detailed mapping of the transportation as most of the tasks performed found in the rough VSM were transportations. Focus was on identifying transport times, loading times, buffers and distances. Other data was also needed to give a complete picture of the flow.

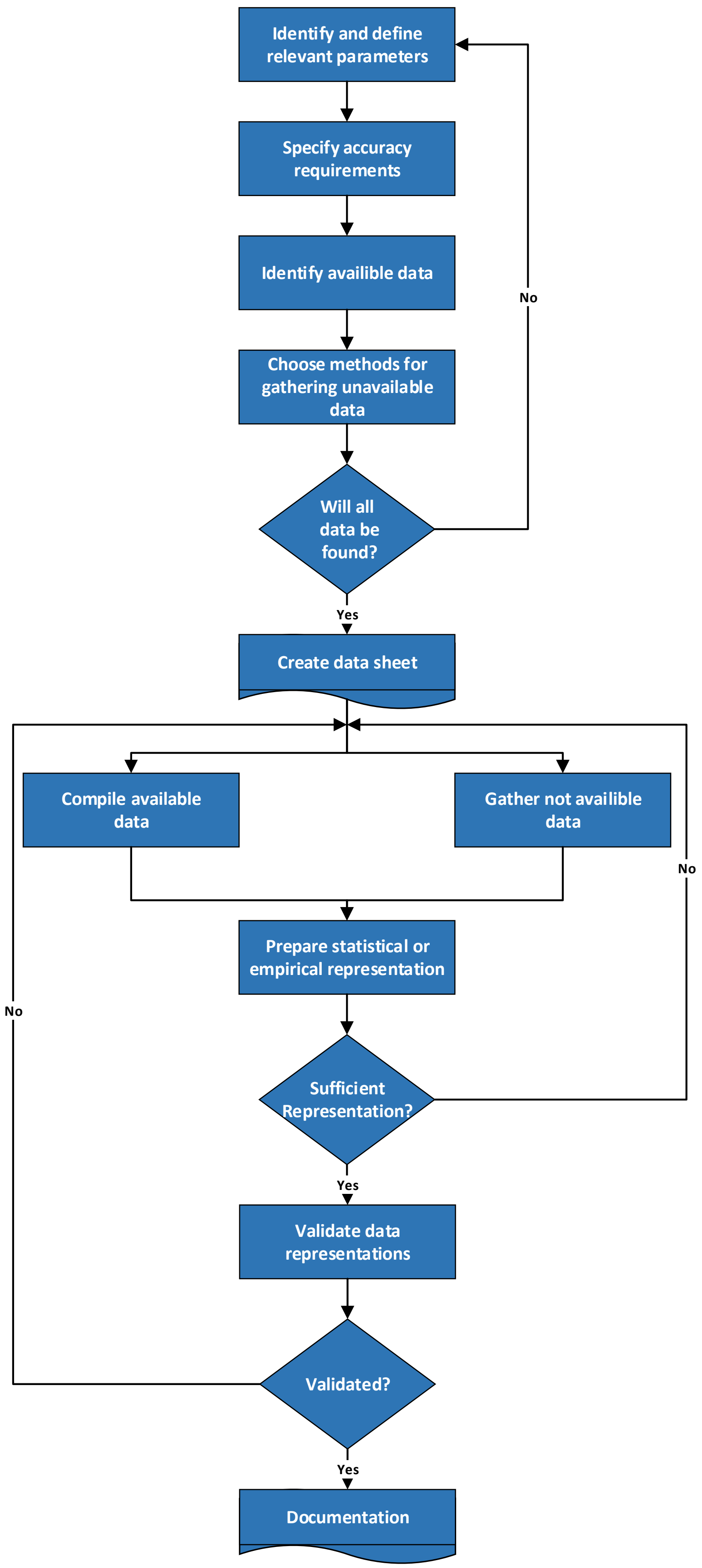

Figure 16: Flowchart of workflow for data gathering (Johansson & Skoogh, 2009)

The data needed for the analysis were:

- Transport times and distances, the times it takes for the each different transport and the distance the goods travels.
- Ordering times, the time it takes to order material or transportation.
- Ordering procedures, how the ordering of material or transportation is performed.
- Amount of material in both transports and in the production lines.
- How the flow of information for both ordering and transports are used.
- The mean time of the heat treatment.
- Time for administrative procedures.
- Time for handling procedures.
- Number of goods in buffers.

(Skoogh, 2013-11-14), (Medbo, 2015).

In the next step the accuracy of the data was determined. As the material logistics flow that was analyzed in this project was rather short and did not include many steps, the data needed to be detailed to be able to identify areas with potential for improvement.

SKF had a lot of data with regards to delivery times and ordering times. The already collected data at SKF has been used as the core of the data. The data not available directly from the company was gathered using different methods, including time studies and interviews.

Asking if all data was found was an important step as this dictated how to proceed with the analysis of the material flow and if the focus and parameters had to be changed. When this step was passed a data sheet was created and the gathering of data began. The data that was not available was collected with the methods mentioned above. When enough data was gathered the data was validated with SKF employees to make sure that the gathered data was representative of the actual material flow.

3.4 Time Studies

The purpose of time studies are to measure the time it takes for a qualified operator to perform a work task performed at normal performance level and also according to a specified method. The study also usually looks at the method and tries to improve it to reduce the time the task takes. (Zandin, 2001)

Performing a proper time study requires the right tools. According to Zandin (2001) this should include these seven items:

- A time study watch
- A clipboard with bracket
- A time study form
- A pencil
- A measurement tool
- A stroboscope
- A calculation tool.

However today other tools are available such as tablets and video cameras which can also be used for the same purpose. Performing a time study also requires experience and training especially if performed with the basic tools listed. (Zandin, 2001) (Olhager, 2000)

The development of technology have made it possible to perform time studies in other ways for example using video cameras to record the work task and then use a computer program to analyze the task. This requires less experience of the person performing the study as the recording can be reviewed as many times as needed to determine the time the work task takes (Almström, 2014).

Getting the right time when measuring is always a problem as the person who is studied might work faster or slower than normal because of being observed. Choosing the right operator to study is also important. (Zandin, 2001) In this thesis an audio recording was used to describe what was happening and this gave both the order of activities as well as how long time it took to perform.

3.5 Value Stream Mapping and Material Flow Mapping.

According to Finnsgård, Medbo and Johansson (2011) the VSM is not a tool adapted to analyze material flows within supply chains so a more detailed MFM was created, going more into detail of how the material flow was constructed focusing on the activities Transport, Administration, Handling and Storage of material. For these four different categories some different data was important, for the first three, time was an important factor to record, however for Administrative actions for example the distance traveled was of no importance. The detailed MFM had the purpose to identify unnecessary steps in the material flow as well as areas of improvement.

As the overall flow was followed when performing the VSM the first step in doing the MFM was to find the different HATS activities in the flow. To make sure that no steps were missed while observing the work activities and measuring the time of the different steps the workers were interviewed about what activities the work was made up of before performing the time studies.

Following the materials through the flow in one go was deemed hard as the flow consisted of several different locations at SKF and thus each location was analyzed at different times while doing time studies. As explained in chapter 2.5 following the flow upstream might be complicated and hence the flow was followed downstream at each of the locations.

To confirm that the HATS activities identified in the interviews were correct the work was observed while at the same time performing time studies of the work. The time studies were performed by voice recording stating when each activity started and what activity was performed. To get data about the distances the components were transported, a digital map was used.

After the time studies and identification of HATS activities the number of components in the buffers was counted to be able to calculate the lead time of the different components. This was performed during the same day in all locations. All the data collected was gathered in a flow map as described in the theory chapter and the finished current MFM maps can be found in Appendix A .

3.6 Indicators

The indicators found through interviews with the people working in the factory were lead time, delivery precision, discarded pallets of goods and repair costs. As the three latter are related to the forklift drivers performance the main indicator that was interesting to look at was lead time. Other indicators were also the number of HATS-activities from the MFM. Another identified indicator was WIP.

3.7 Problem identification

Using the identified indicators as a reference, areas which could affect them in a negative way or have potential for improvement was identified by using the detailed MFM and the simulation. The Material Flow Map was analyzed and the seven questions answered and a future state map was created.

3.8 Comparing MFM and DES

This chapter covers the comparison of the two analysis methods MFM and DES with consideration to the material flow in the D-factory at SKF. The comparison is based on the MFM performed as well as the gathered data and theory of the DES.

3.8.1 Needed data

To compare the data needed by each of the methods a list was created of data that might be used when performing either a MFM or a DES, this list of data is a mix between data suggestions from literature and the authors' previous experience from courses in VSM and DES. (Medbo, 2015) (Skoogh, 2013-11-14) The lists were then compared with the data used in the final MFM and data that would have been used in a DES.

This comparison looks at the amount of data and what kind of data is needed to make a full analysis with the two methods. This analysis will take into consideration what data was available and what had to be gathered as well as the amount of data needed for each method.

3.8.2 Time and effort

This comparison looks at the different parts of the two methods with regards to how easy or hard they are to perform and how much time it takes to perform the task. The attributes that was compared are:

- Collecting data
- Managing data
- Creating a model
- Validation

The comparison of the first two attributes, Collecting Data and Managing Data, is based on the experience from the case study. While the attributes Creating a Model and Validation is based on the case regarding the MFM and the theoretical creation of a DES.

3.8.3 Possible Level of detail

By changing the level of detail the effort of creating an MFM or DES could change. If some actions could be generalized and simplified the analyze method is easier to perform and also takes less time however if the method has a low level of detail so will the results. Choosing the right level of detail before performing the method is important. The methods will be compared based on their possible level of detail theoretically achievable within the method.

3.8.4 Theoretical results

Both methods had the possibility to improve material flow but they had different ways to do it. To know if improvements were beneficial, some kind of theoretical result was the outcome of the analysis methods. The quality and how likely the results are to match the real world if implemented was compared as well as what type of result that the methods produce.

4 Results

The result of the thesis work is presented below.

4.1 The material flow in the D-factory

The material flow in the D-factory was extensive and the deliveries of materials were widely spread throughout the whole production area in Gothenburg. The rings were delivered directly from the external supplier to the D-factory where they were unloaded from the trucks, delivered to the hardening department and then further delivered to the channel after the hardening process was complete. The rest of the components had a very similar flow when they arrived at the D-factory, however before they arrived there were big differences.

The rollers were produced in the RK-factory that was located on the other end of the factory area and were then transported to the storage at HF200. After this a call of components was performed from the forklift operators at the D-factory to HF200 and the rollers were transported from one end of the production area to the other and arrived at the D-factory by truck.

The guide rings were produced in Katrineholm and were delivered to the Central Warehouse (CW) every other day. In the CW the guide rings were transported from floor one to floor four by a vertical pallet elevator and after that put in storage to await a call of components from the supply chain. When a call of components came the pallet was taken to the vertical elevator and transported to floor two where it was processed, weighted and labeled for a transport to the D-factory.

The cages were produced by an external supplier located at SKF's production area in Gothenburg and were delivered to the HF200 terminal when completed. From there they were directly transported to the D-factory by internal truck transport.

When the remaining component types, rollers, guide rings and cages, arrived at the D-factory they were unloaded from the truck and added to an unloading buffer. They were then moved to the 24h supply buffer which was then slowly emptied by the forklift operators when there was a need for components in the channels.

4.2 Value Stream Mapping

A value stream map was created for one of the producing channels material flow, each type of component was analyzed separately. Due to the limitations set earlier in the project almost no processes in the analyzed flow gave any value to the product since most activities were transports of production material.

Since one of the key factors in Value Stream Mapping is to look at lead time and the comparison between lead time and value adding time this analysis method was not really suited for the flow in this project. This lead to research for a more appropriate analysis method and the method found was a method that is similar to Value Stream Mapping but focuses on the material flow, Material Flow Mapping.

4.3 Material Flow Mapping

Here the results of the Material Flow Mapping method are presented. First a presentation of general findings followed by some suggested improvements. This is followed by a detailed analysis of the different components. All MFM future maps can be found in Appendix B .

4.3.1 General analysis

A problem in all flows was the number of computer systems used, this resulted in a lot of extra work time spent with administrative work which could be considered a loss and most importantly it was confusing and hard to work with. In the current state SKF used six different systems as well as e-mail and physical papers called splits and transport lists.

Another issue found was that the existing standards were usually not followed, each forklift driver did the job in a way that suited the worker. This resulted in a flow that was hard to analyze since there was little regularity in the execution of work tasks.

There was no pull system at all in any of the flows, all of the material planning and ordering of raw material was handled centrally by the supply chain department. The lack of a pull system also resulted in more work for the forklift drivers since they had to keep track of how many pallets of each component currently was present in the producing channel and this could only be performed by driving to the channel buffer and look if there was room for more pallets. There were a lot of inventory in buffers causing long lead times for the components and this was the major part of the total lead times.

4.3.2 General improvement suggestions

A big improvement for all of the flows should be to remove all old computer system except the internal hardening system and replacing them with a single user-friendly new computer system that could perform all needed operations for the supply chain and workers. This new computer system should also communicate with the internal hardening computer system so that information about the hardening process can be available to people working in the supply chain through the new computer system.

All standards should be reviewed and all staff should be trained in why there are standards, how they should be used and what they actually contain and mean. When this is done the process of continued improvements of the standards can start, however if the standards are not followed by all it will be very difficult to improve and evolve the standards.

To start the process of using pull systems in the D-factory the channels should call components from the forklift operators. When there is room for more pallets in the channel buffer the channel should call for more components so that the forklift operators does not have to keep track of each buffer status. This calling of components and the following order of material should be performed in the new single computer system.

To reduce the amount of goods in the buffers an already existing idea should be more enforced, a 24h buffer where the components in the channel and the 24h buffer is not allowed to contain more than a stock for 24 hours of production. Also a leveling of the production in the hardening department should be able reduce the inventory in the hardening buffers.

4.3.3 Cages

This section will cover the analysis and improvement suggestions of the cage flow.

4.3.3.1 *Analysis*

The analysis of the flow for the cages started from the time when they arrived in the storage facility HF200 and continued until it reached the production line in the D-factory. When analyzing the material flow for the cages it was found that three Handling, ten Administrative, six Transportation and six Storage activities existed within the flow. The total lead time was found to be 48,9 hours where 99.5 percent of the lead time was time spent in storage. The material flow along with the collected data and times for each activity can be found in Appendix A.2. Using the seven questions, further analysis was performed.

1. What is the real customer demand?
   a. The demand from the channel is 25,8pcs/h.
2. To what degree can we achieve a continuous material flow?
   a. Remove many Administrative activities with a better computer system.
   b. Removal of the control buffer.
3. How can we achieve a pull controlled material flow?
   a. The channel will use a call of components to the forklift drivers who will supply the channel from the 24-h buffer.
4. How can a levelled material flow be achieved?
   a. Not of interest at this point since it is a production to storage system.
5. How can the material flow be synchronized with the takt of customer production flow?
   a. Channels produce by prognoses planned 24 hours ahead.
6. Which process improvements are needed?
   a. Standardization and training in the standard.
   b. Deliveries must be on time to be able to plan the needed workforce.
7. How can the material flow be further improved?
   a. -

4.3.3.2 *Improvement suggestions*

At the HF 200 terminal there were a lot of unnecessary steps performed in the material flow. The improvement suggestions here are to use the new computer system to only scan the pallet once and then immediately put the pallet in the outgoing truck buffer. The transport list should be replaced with a digital list.

When the goods arrive at the D-factory the pallets are scanned and gods receipt by the forklift operators. After that it is sorted and then added to the 24h buffer from where components should be called by the channel. The improvement results can be seen in Table 1.

Table 1: The HATS and lead time of the cage flow

	Current	Future	Difference
H	3	3	0
A	10	3	-7
T	6	5	-1
S	6	5	-1
Lead time	48,9 h	24,2 h	-24,7 h

4.3.4 Guide rings

This section will cover the analysis and improvement suggestions of the guide ring flow.

4.3.4.1 Analysis

The analyzed flow for the guide rings started when they were received at the Central Warehouse (CW) and ended at the production line in the D-factory. The analysis found that there were three Handling, three Administrative, ten Transports and five Storage activities in the flow. The lead time for the guide ring analyzed was 40.2 hours where 99.2 percent of the time was spent in storage. The material flow and collected data can be seen in Appendix A.4. Using the seven questions further analysis was performed.

1. What is the real customer demand?
   a. The demand from the channel is 12,9pcs/h.
2. To what degree can we achieve a continuous material flow?
   a. Remove many Administrative activities with a better computer system.
   b. Remove all of the involvement of the Central Warehouse.
   c. Store the components in the basement of the D-factory and don't use the 24h buffer OR use daily deliveries directly to the D-factory and use the 24h buffer but no other storage
3. How can we achieve a pull controlled material flow?
   a. The channel will use a call of components to the forklift drivers who will supply the channel from the 24-h buffer or basement.
4. How can a levelled material flow be achieved?
   a. Not of interest at this point since it is a production to storage system.
5. How can the material flow be synchronized with the takt of customer production flow?
   a. Channels produce by prognoses planned 24 hours ahead.
6. Which process improvements are needed?
   a. Standardization and training in the standard.
   b. Deliveries must be on time to be able to plan the needed workforce.
7. How can the material flow be further improved?
   a. -

4.3.4.2 Improvement suggestions

For the guide ring flow there are two improvement suggestions. In both suggestions the central warehouse is removed from the flow completely and the unloading of goods from the supplier will be performed at the D-factory or possibly at CW and transported in the underground tunnel to the D-factory.

In suggestion one there will still be some storing of components however this will be stored in the basement of the D-factory and will be administered by the forklift operators in the D-factory. When a pallet of guide rings is called from the channel the pallet will be moved directly from the basement to the channel.

In suggestion two the delivery of gods have to be on a daily basis and the components will be unloaded by the forklift drivers in the D-factory, goods receipt and then added directly to the 24 h buffer and from there transported to the channel when there is a call for components. These suggestions can either be viewed as two separate suggestions or as two different steps in one improvement. The result of the improvements can be viewed in Table 2 and Table 3.

Table 2: Results from suggestion one of the guide ring flow.

	Current	Future	Difference
H	3	3	0
A	3	2	-1
T	10	3	-7
S	5	3	-2
Lead time	40,2 h	40,0 h	-0,2 h

Table 3: Results from suggestion two of the guide ring flow.

	Current	Future	Difference
H	3	1	-2
A	3	2	-1
T	10	2	-8
S	5	3	-2
Lead time	40,2 h	23,9 h	-16,3 h

4.3.5 Rollers

This section will cover the analysis and improvement suggestions of the roller flow.

4.3.5.1 Analysis

The analysis of the rollers started from the storage in HF200 until it reached the production line in the D-factory. It was found that two Handling, eight Administrative, six Transports and five Storage activities existed within the flow. The lead time for the rollers were 108 hours and 99.6 percent of the time is storage activities. The material flow and data is depicted in Appendix A.1.

Using the seven questions further analysis was performed.

1. What is the real customer demand?
    a. The demand from the channel is 567,6 pcs/h.
2. To what degree can we achieve a continuous material flow?
    a. Remove many Administrative activities with a better computer system.
    b. Many manual steps at HF200 that can be improved with digitalization.
    c. Remove the control buffer.
    d. Remove the first handling action since the new computer system will take care of that problem.
3. How can we achieve a pull controlled material flow?
    a. The channel will use a call of components to the forklift drivers who will supply the channel from the 24-h buffer or basement.
4. How can a levelled material flow be achieved?
    a. Not of interest at this point since it is a production to storage system.
5. How can the material flow be synchronized with the takt of customer production flow?
    a. Channels produce by prognoses planned 24 hours ahead.
6. Which process improvements are needed?
    a. Standardization and training in the standard.
    b. Deliveries must be on time to be able to plan the needed workforce.
7. How can the material flow be further improved?
    a. A consumption step will be added to the flow when the rollers are delivered to the channel. (Consumption is a way to show in what department the pallet is located)

4.3.5.2 Improvement suggestions

The counting of components performed by the forklift operators could be removed since all of the planning of components will be performed by Supply Chain. At HF200 the order list with components to ship will be in digital form on the computer screens in the forklifts. The pallets will be scanned, automatically counted and then placed at the right outgoing buffer. No physical transport list will be used since this will be performed digitally.

When arriving at the D-factory the components will be unloaded and goods receipt. After this they will be sorted and added to the correct buffer. When there is a need for components in the channel a call of components could be performed through the new computer system and the forklift operators will deliver the pallets. The result of the improvements can be seen in Table 4.

Table 4 : Results of the roller flow.

	Current	Future	Difference
H	4	3	-1
A	8	4	-4
T	6	5	-1
S	5	4	-1
Lead time	108,1 h	89,2 h	-18,9 h

4.3.6 Rings

This section will cover the analysis and improvement suggestions of the ring flow.

4.3.6.1 <u>Analysis</u>

The analysis of the rings started when they arrived with truck to D1, it continued through the hardening process and then until it reached the production line in the D-factory. It was found that four Handling, twelve Administrative, five Transports and six Storage activities existed within the flow. The lead time for the rings were 22.3 hours and 65 percent of the time was storage activities. The material flow and data is depicted in Appendix A.3.

Using the seven questions further analysis was performed.

1. What is the real customer demand?
    a. The demand from the channel is 25,8 pcs/h.
2. To what degree can we achieve a continuous material flow?
    a. Remove many Administrative activities with a better computer system.
    b. Remove the unpacking buffer for the hardening, this can be performed at the loading buffer.
3. How can we achieve a pull controlled material flow?
    a. The channel will use a call of components to the forklift drivers who will supply the channel from the 24-h buffer
4. How can a levelled material flow be achieved?
    a. The hardening department should use a levelled production to reduce the stock of rings.
5. How can the material flow be synchronized with the takt of customer production flow?
    a. Channels produce by prognoses planned 24 hours ahead.
6. Which process improvements are needed?
    a. Standardization and training in the standard.
    b. Deliveries must be on time to be able to plan the needed workforce.
7. How can the material flow be further improved?
    a. Add a consumption when the rings are delivered to the channel.

4.3.6.2 <u>Improvement suggestions</u>

In the flow for the rings many Administrative steps could be removed with the new computer system. Here the forklift operator will unload and goods receipt and then sort and add it to the hardening buffer white.

In the hardening department the unpacking could be performed at the loading buffer. A consumption step should be added when rings are delivered to the channel. The result of the improvements can be seen in Table 5.

Table 5: Results from the ring flow.

	Current	Future	Difference
H	4	4	0
A	12	9	-3
T	5	4	-1
S	6	5	-1
Lead time	22,3 h	22,2 h	-0,1 h

4.4 Comparing the methods

This chapter covers the results of the comparisons between the MFM and DES as methods of analyzing material flows. All results are based on the case study performed at SKF as well as theory of the two methods.

4.4.1 Needed data

The main difference in the data needed to perform the analysis was that DES required data over time whereas the MFM only needed data for one specific moment. This made the amount of data needed for the DES by default larger than for the MFM.

Below in Table 6 the data that might be needed is listed and the data that was not needed for making an analysis in the case study is crossed over. As can be seen the lists are similar with the difference of a few areas. Noticeable was that Value Creating Time was not needed for either as the material flow only had one process which could be deemed value adding. Table 6 also shows that the DES would require more types of data and as stated earlier also need data over time making the MFM the preferable tool when it comes to being able to collect data quickly.

Table 6: Comparison of the needed data between MFM and DES methods

MFM	**DES**
Data in one moment	Data over time
Type of process and description of process	Type of process and description of process
Demand (takt)	Demand (takt)
No. of operators needed to perform the task	No. of operators needed to perform the task
Cycle time	Cycle time
~~Value creating time~~	~~Value creating time~~
~~Change over time~~	Change over time
~~Uptime~~	Uptime
~~Scrap rework~~	Scrap rework
~~Shifts~~	Shifts
~~Working hours, breaks~~	Working hours, breaks
Batch sizes	Batch sizes
Storage space	Storage space
Package/item type and size	Package/item type and size
Part/ item characteristics	Part/ item characteristics
Distance	Distance
Frequency of process or transport	Frequency of process or transport

Quantity of parts	Quantity of parts
Control of process (information flow)	Control of process (information flow)
Activity times	Activity times
Time to order parts	Time to order parts
Ordering procedures	Ordering procedures
Information flow	Information flow

Based on the case study performed at SKF and the data that was gathered the conclusion was made that the MFM needs less types of data than the DES as well as a lesser amount of each data. For the case study the data acquired for the MFM was sufficient to reach the desired result of the study and hence the MFM was a better choice with regards to needed data.

4.4.2 Time and effort

This chapter will cover the results from the comparison regarding time and effort.

4.4.2.1 Collecting data

The collection of data when performing the MFM was mainly performed on the floor while interviewing the personnel, observing how the work was performed, counting parts in storage and measuring times. With the exception of measuring times the other steps were quickly performed and did not require much time or effort.

Based on the authors' previous experience from courses in DES the data from the MFM can be useful when creating the DES base model as a DES often can be based on a VSM map for structure and basic data. Aside from the data used for the MFM a DES would also need existing data from the company to get the dynamic perspective. In the case study this data was easy to find and get a hold of due to the fact that SKF had already gathered all needed data.

The time and effort needed for collecting the data for a DES depends highly on the data available at the company. For the case study the data collection for the MFM was more extensive than for the DES since almost all data for the DES had already been collected by SKF making the collection of data for the DES slightly easier than for the MFM.

4.4.2.2 Managing Data

Most of the data used in the MFM was easy to use directly in the current state map the exception being the time studies which needed to be reviewed and calculated to mean times which took a lot of time. For the DES this step was one of the major ones as data often do not come in exactly the needed form and needed to be sorted and reworked. Most of the data needed conversion to mathematical functions so that the simulation could be as realistic as possible. For this case study the data management was clearly less for the MFM since the main work was managing the measured times, the data for the DES however had to be extensively managed.

4.4.2.3 *Creating a model*

Creating a MFM can be performed with nothing more than a paper and a pen if needed. When all the data was collected creating a current state map was both easily and quickly created. For the case study a rough MFM was drawn when walking through the flow and then it was transferred to a digital model, this part took some extra time.

Creating a DES takes time and effort as it requires the experience with a simulation program and doing the actual coding (Gullander & Solding, 2009). For the case study the MFM was the better method with regard to the time and effort it takes to create the model.

4.4.2.4 *Validation*

Validating the MFM required confirming the map with people knowledgeable about the material flow as well as comparing calculations of lead-time with the lead times previously gathered by SKF. This was easily and quickly performed.

For a DES the validation would need the model to be close enough to the real world to be of use. To validate a DES model a different number of conditions needs to be validated against the real world and it is time consuming and never perfected since the model can never be coded exactly as the real world (Dahl & Eliasson, 2011). For this case study the time and effort of validation is less extensive for the MFM than for a DES, had a model been performed.

4.4.3 *Possible Level of detail*

The MFM analysis method has the possibility to go to the detail level of each action that is performed in a material flow and that can be measured in some way and this gives it a high possible level of detail. (Finnsgård, Medbo, & Johansson, 2011)

Based on the authors' previous experience from courses in DES, DES can be used to get a high level of detail of an analysis and the only limit is the level of detail of the input data to the model as well as the available time to code the model. Since both methods have the same possible level of detail either method can be chosen.

4.4.4 *Theoretical results*

The theoretical results of the MFM analysis is an un-validated approximation of the future based on an analysis of the current state of a material flow. Since the future state is just a guessed result and there is no way of verifying the results with the real world.

The DES analysis creates a model of the current state that is validate against the real world and can be programed to be an approximate model of the real world. (Dahl & Eliasson, 2011) Based on the authors' previous experience from courses in DES, improvement suggestions can be tested in an almost identical model of the real world which makes the theoretical results reliable and validated. For this case study a validated result would have been preferable so with regards to Theoretical results the DES is the better method.

4.4.5 Comparison

When summarizing the comparison the MFM is considered the best method in four of the attributes and the DES in two attributes and for the attribute Possible level of detail both methods are equally good, this can be seen in Table 7.

Table 7: Summation of comparison between the methods

Attribute	Best choice
Needed data	MFM
Collecting data	DES
Managing data	MFM
Creating a model	MFM
Validation	MFM
Possible level of detail	Draw
Theoretical results	DES

4.5 Improving the MFM method

In the MFM method described by Finnsgård, Medbo and Johansson (2011) and Medbo (2015) there is no good way to see what activities were performed in what department of a factory, to solve this each activity was given a color that represented in what department the action was performed. To easily know what color represents what department colored boxes with the department names was also added to the MFM. The colored boxes and activities can be seen in Figure 17.

To see how the information flows in the material flow, computer system labels were created in the MFM that data arrows could be drawn to from different actions to the correct computer system. In this part the colored department boxes was used to represent how data traveled from each department to the different computer systems or activities, this can be seen in Figure 17.

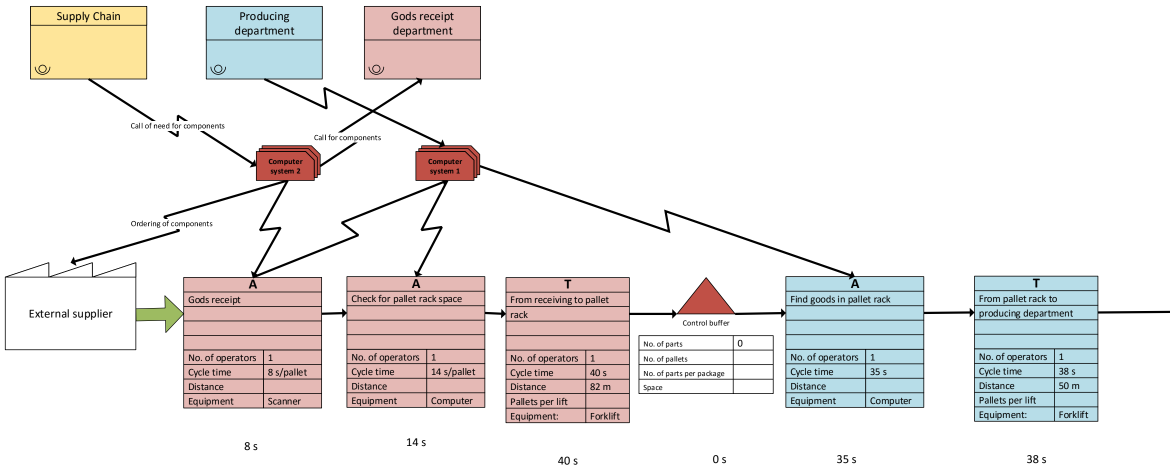

Figure 17: An example of a part of an MFM, showing the information flow arrows and colored department boxes

5 Discussion

In this chapter a discussion about this thesis work will follow. It will be divided in the sub-chapters, SKF where the findings at the factory will be discussed, Scientific, where the theories and methods will be discussed and Comparison, where the comparison will be discussed.

5.1 SKF

To use a DES in a material flow can be hard since a material flow usually contains much human work and little machine work. If standards exist and are followed in the material flow then the simulation will be easier to perform since all workers will perform the same activity in the same way. Simulation was a to detailed analysis tool to analyze the rough material flow in the D-factory at SKF, the simpler and in this case more rewarding tool, MFM was a more appropriate method. However if standards are prepared and followed a future simulation will be possible.

The shifting between computer systems is a waste of time and it is also a factor for confusion for the personnel that are using them. Another finding regarding the computer systems was that the newest system that was being implemented in the factory when this thesis was conducted did not have the ability to scan multiple pallets since the operator had to press two buttons on the computer in the forklift between each pallet scan. This created a dependence of the forklift when pallets were scanned and the cordless scanners were almost worthless.

The pallets had both a physical location and a tracked location in the computer system; the tracked location and physical location should be equal since this was the way to follow the pallets through the flow. The tracked location of the pallets was by far not good enough to actually follow the pallets and keep track of them.

A problem was that the movements of the pallets in the system were not updated at all stages of the physical pallets moving through different departments, for example the only move of the tracked location is when the pallets of rings leaves the transportation department and was moved to the hardening department. When the pallet was moved back to the care of the transportation department or when it was moved to the producing channel the pallet was not moved in the computer system. With the suggested system where a consumption of goods receipt is performed when a pallet is moved the problem with lost pallets should be solved.

When the rings arrived at the D-factory the pallets on the truck might be turned the wrong way so that the truck driver had to use a hand drawn pallet truck to rotate the pallets into the right position, this resulted in waiting time for the forklift drivers.

There was also a problem with high inventory both before and after the hardening process. This is mainly due to the fact that the hardening process did not have a leveling of production and hence the hardening would run all rings for each channel all at once, this resulted in a lot of inventory so that the channels were supplied at all times. A leveled production could be implemented however if and how this should be executed could be researched by another thesis work.

At SKF there were a lot of spare components in the basement of the D-factory, this was due to the fact that the grinding processes at SKF were not reliable and this resulted in an over ordering of components so that the correct amount of bearings could be produced, all spare components after production were stored in the basement. The analysis and improvement of the grinding process could be performed in another thesis work.

5.2 Scientific

The method to use a voice recording to do the time measurements was decided on because it would be easier to follow the forklift operators when they traveled long distances rather than doing it with a video camera. It would also require less experience than doing it by pen and paper as the measurements could be reviewed. The result was not as detailed as it could have been with a video camera where software can be used to do an analysis. Another aspect to the time studies was that the person studied for the time studies was not always the most experienced with the best work speed but rather the person available at the time of the studies.

Since the material flow involved many humans and not so many automated machines it is important that the humans are working according to standards so the flow can be approximated in a good enough way. If each employee performs the work in its own way it is difficult to create a valid DES model. In this way the usage of DES in material flows is limited and can be difficult and/or time consuming to implement, however if a successful base model can be created it will yield useful results that the MFM does not yield. The DES is also a good way to test improvement suggestions.

The large degree of humans involved in this material flow increases the variations in the system. This might be one of the reasons why the MFM was determined as the superior method when analyzing this system. If the system had less variation by for example being fully automated, DES might be able to become a more competitive method.

Another aspect when choosing a method to analyze a material flow is what kind of results the method should yield. In this case the main focus have been on lead times which for the MFM meant focus on decreasing activities as well as parts in storage. If the main focus of the study instead had been to try and find bottlenecks or buffer utilization DES might have been a better method. This is also relevant when considering the first research question as the performance of a material flow can mean different things depending on the focus of the study.

In a material flow a big part of the actual flow are transports and these transports are analyzed differently in the two methods. In the MFM a measurement of the actual time it takes an operator to move a pallet between point a and point b is performed, this gives an exact measurement with different speeds during the whole transport, however this only analyses one transport in one flow. In the DES an approximate continuous speed is used for the forklifts and this can be inaccurate since different goods on the forks can result in different speeds depending on how sensitive the cargo is. This can be a problem if the flow have different distances with deliveries since the starting and stopping speed are different from the actual transport time. However many different transports with different goods and to different locations can be analyzed.

The information arrows added to the MFM in this thesis have been very useful since the information flow is an important part of the result in the case at SKF. The arrows gives a fast and good view of how complex or simple an information flow is. Perhaps another symbol for computer system than the VSM-Kanban symbol should be used.

A possible way to analyze a material flow could be to do a high level of detail MFM to see the workflow and analyze it with focus on work methods and workflow. A DES could then be performed with a lower level of detail to analyze transport routes and the dynamic aspects of the material flow such as bottlenecks, buffer and transportation utilization. If mean data over time is used in an MFM it would give a better perspective over the material as such, however this would require much data to be gathered over a long period of time, a correct and validated base model in DES is a better alternative. An interesting new research question could be how a material flow can be analyzed so that the right method, DES or MFM, is chosen from the beginning or possibly rather if the flow is worth doing a DES model.

5.3 Comparison

Since the comparison was performed based mostly on empirical studies but with some theoretical base the results of the comparison could be questioned however since the theoretical research was fair and the authors' previous experience from courses in the field of DES was used that should not be the case.

5.3.1 Needed data

The major difference in needed data is that the DES needs data over time whilst the MFM only needs data in a static point in time. The number of different types of data does not differ that much however the amount of data for each data type differs greatly since the DES needed the dynamic data.

Of interest is also that value adding time was not seen as important for either analysis as only one process was value adding in the material flow and the only way to increase the relative amount of value adding time is to decrease the non-value adding time. Whereas focusing on the non-value adding time was the important part.

Most of the data for a VSM and a DES is usually already gathered by producing companies since much of that data is connected to performance indicators. The data usually have to be processed somewhat to be useful for the methods but very little data usually have to be gathered. However for the MFM a larger amount of data had to be gathered since transportation times for each operation was not recorded by the companies and gathering this data took time.

5.3.2 Time and effort

The measuring of times in the factory is a big time consumer for both methods. The DES however also have time consuming steps both for managing data as well as actually building the model. This is one of the biggest difference in the two models.

5.3.3 Level of detail

The possible level of detail is equal for both methods since both can be analyzed in the highest level of detail however the DES requires much more work and time to perform in a high level of detail whereas the MFM can more easily be changed in the level of detail.

5.3.4 Theoretical results

This is one comparison attribute where the DES was better in the case study, since the MFM only gives a qualified guess as a result that cannot be tested without implementation this is the big downside of the MFM. In a DES model the improvement suggestions can be tested in a model that is similar to the real material flow and hence gives a more validated result.

5.3.5 Summary

The MFM is an easy to perform, fast method that gives a good overview of the current state of the material flow with medium data, however the future state map is only a qualified guess that cannot be verified except for testing which is outside of the method. The DES requires a lot of time, data and an experienced person to perform the model but gives a reliable and detailed result.

6 Conclusion

The research questions stated in chapter 1.4 are:

How can the performance of a logistic material flow without value adding activities be analyzed?

How can data from static analysis and dynamic simulation be used together to enhance analytics?

For question one two methods was found, the static tool MFM and the dynamic tool DES. Both of these methods can analyze material flows that has none or few value adding activities since none of them focuses on the adding of value.

For question two the MFM and DES methods are good complements of each other since the results between the two are different kind of factors. Where the MFM gives a good analysis of what activities are unnecessary and in what order they should be performed the DES gives results about buffer sizes and utilization of personnel and machines over time as well as data for bottleneck analysis.

When standards are not followed in material flows there can be difficulties to perform a DES since different workers performs the same task in different ways. Since a lot of the material flows usually are performed by humans this becomes a problem. Standards that are followed will ease these problems so that all personnel performs the same action in the same way. If this is executed it will also become easier to improve the existing standards for continuous improvements.

The information flow added to the MFM analysis is a useful tool since it will show how the information flows executes and how each department and action communicates. This has been a large part of the results in this thesis and would have been hard to conclude without the adding of information flow to the MFM.

The comparison of the two methods showed that the MFM was the more preferable method for this case mostly because of the differences in effort to manage data and to create the model.

Based on this result MFM should be used to answer where the problem areas in the material flow are located and where there are wasteful activities being performed. The MFM is also a good tool for mapping how a material flow is built up and how information flows between the different departments. However to analyze buffer capacity, bottlenecks and the right route to choose the DES method is a better tool.

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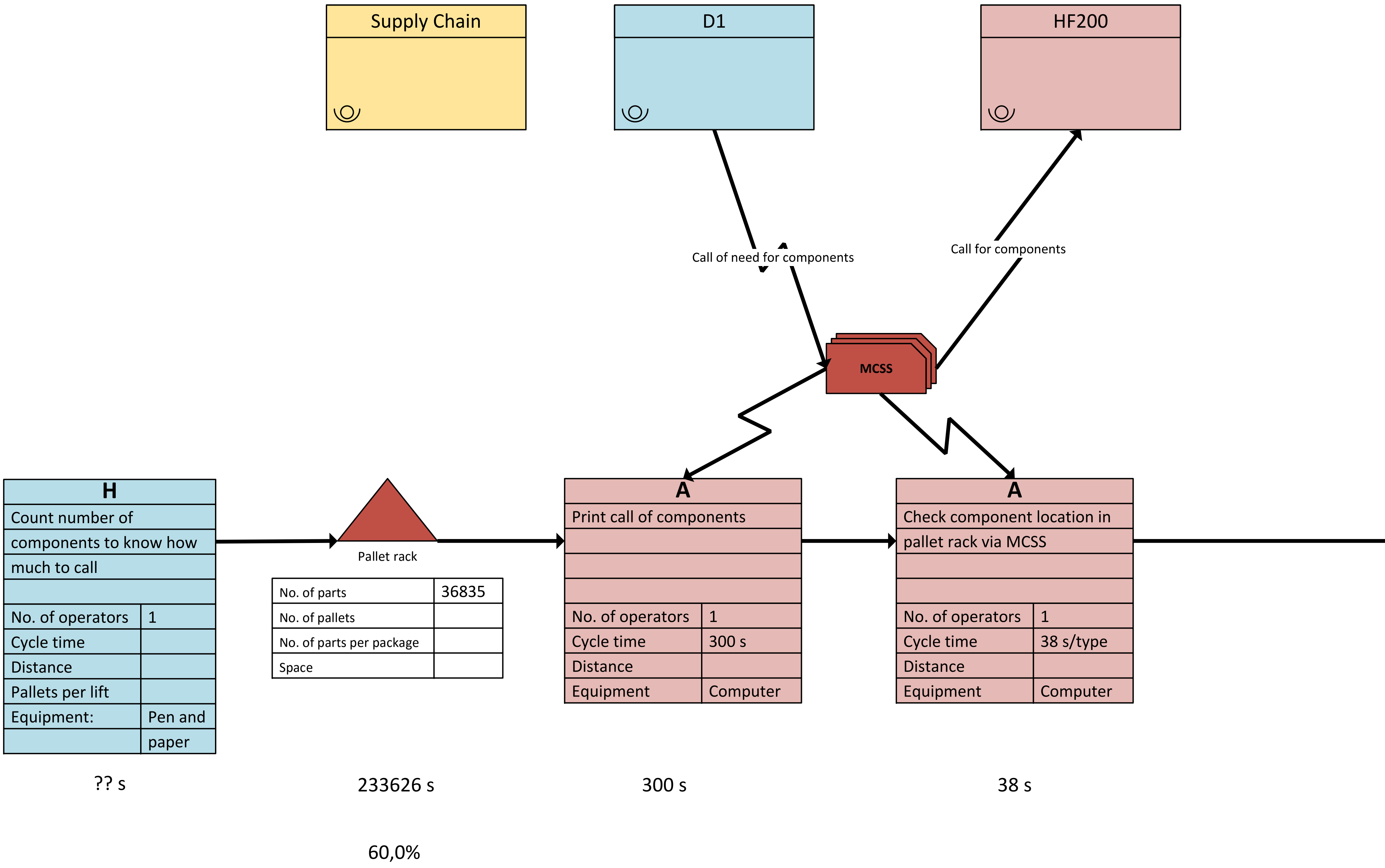
Appendix A Current Material Mapping

Appendix A.1 Rollers



Supply Chain
D1
HF200
Call of need for components
Call for components
MCSS
H
Count number of components to know how much to call
No. of operators 1
Cycle time
Distance
Pallets per lift
Equipment: Pen and paper
Pallet rack
No. of parts 36835
No. of pallets
No. of parts per package
Space
A
Print call of components
No. of operators 1
Cycle time 300 s
Distance
Equipment Computer
A
Check component location in pallet rack via MCSS
No. of operators 1
Cycle time 38 s/type
Distance
Equipment Computer
?? s
233626 s
300 s
38 s
60,0%

Rollers Current map

H=2 A=8 T=6 S=5

T	
From forklift location to the right section of pallet rack	
No. of operators	1
Cycle time	34 s
Distance	~50 m
Pallets per lift	0
Equipment:	Forklift

34 s

A	
Find the right pallet in pallet rack and check number of components	
No. of operators	1
Cycle time	39 s
Distance	
Equipment	Forklift

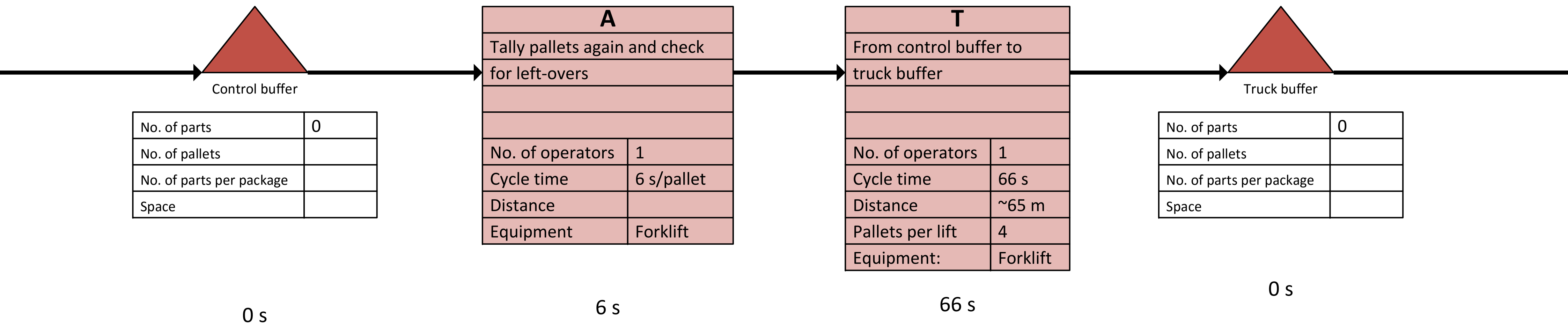
39 s

A	
Count number of pallets needed and check left-overs	
No. of operators	1
Cycle time	47 s
Distance	
Equipment	Forklift

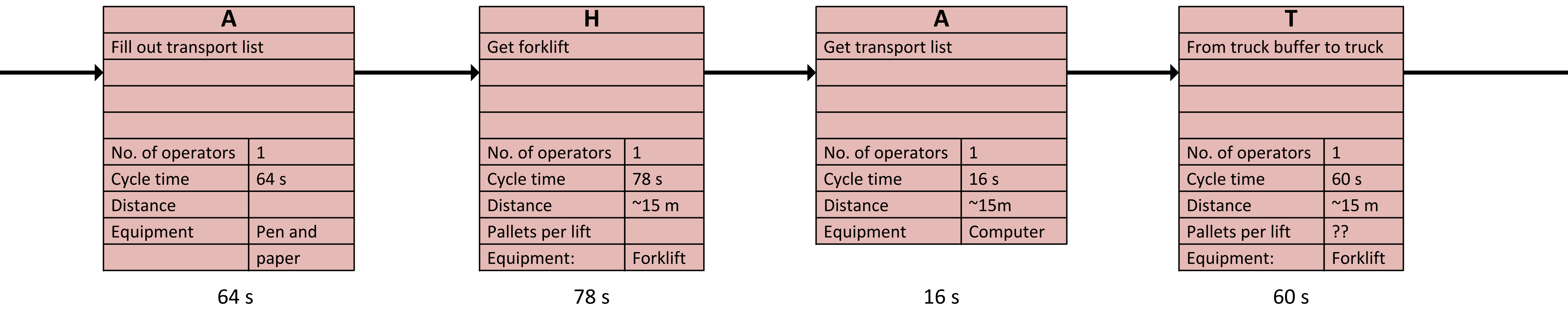
47 s

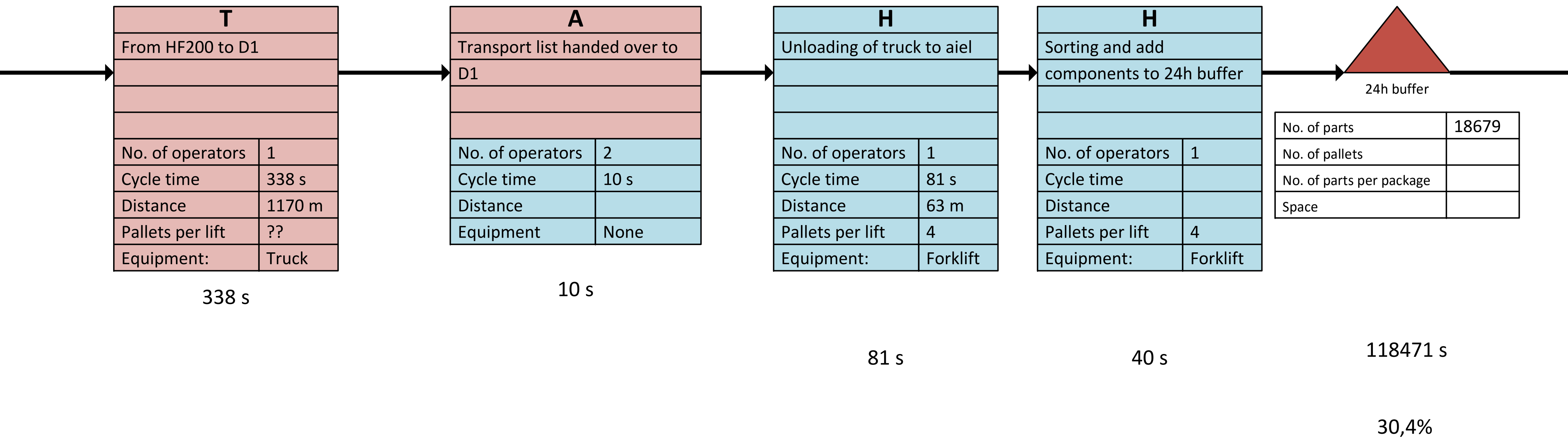
T	
From pallet rack to control buffer	
No. of operators	1
Cycle time	39 s
Distance	~10 m
Pallets per lift	1
Equipment:	Forklift

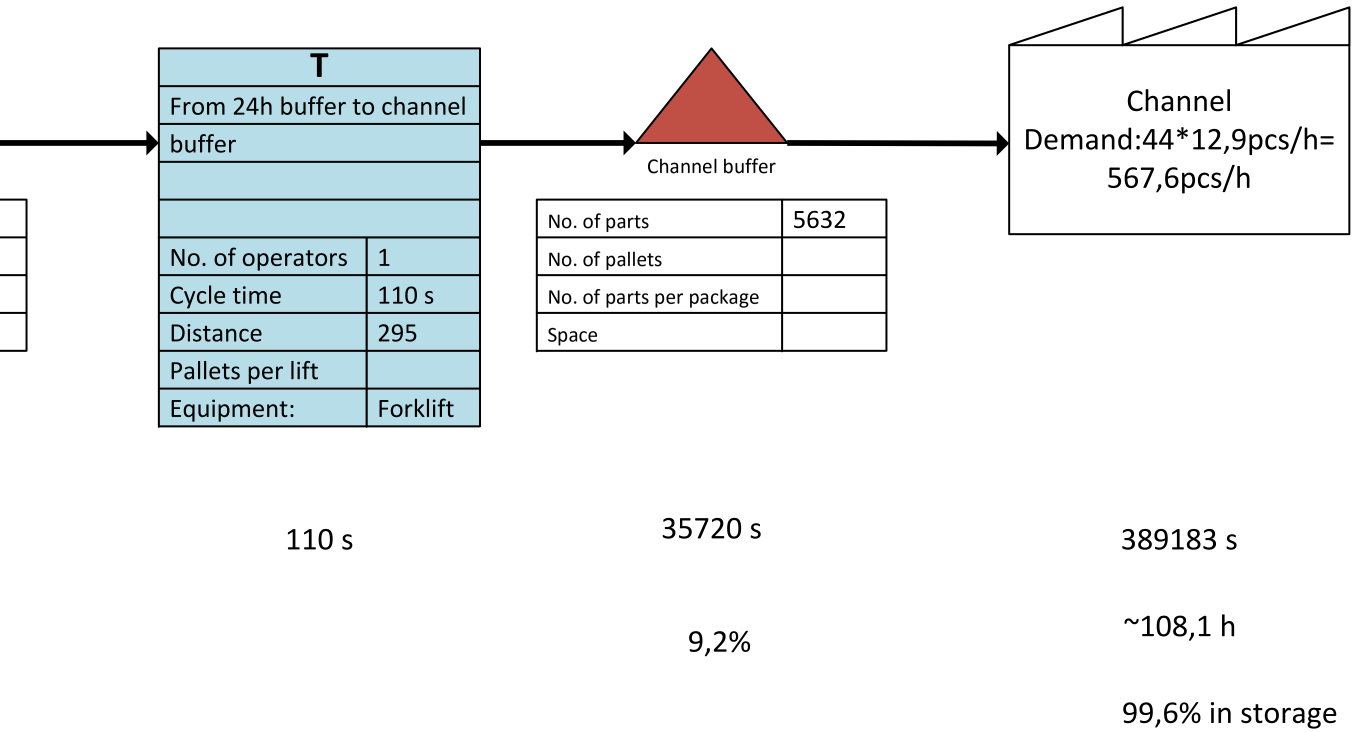
39 s



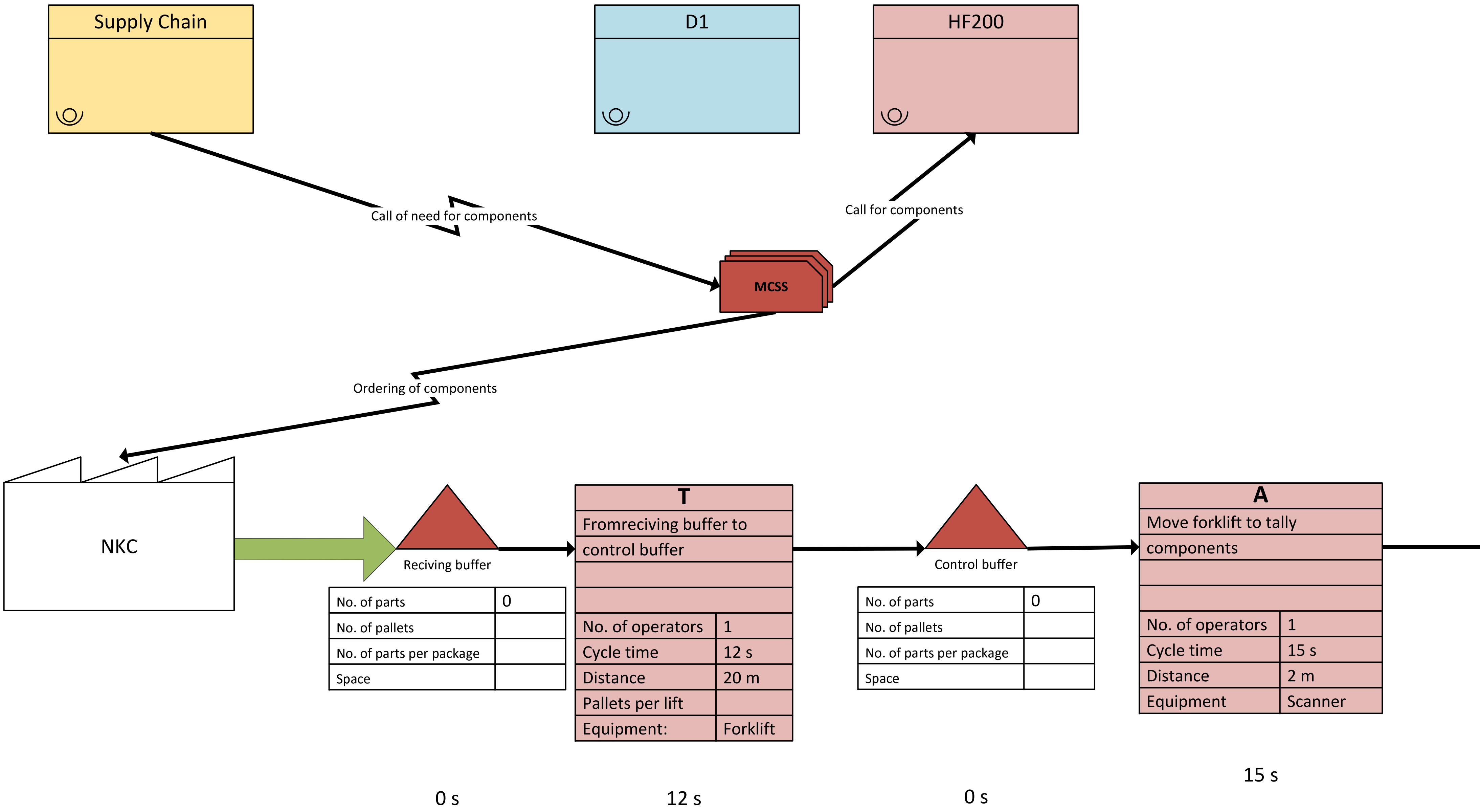
Control buffer
No. of parts
0
No. of pallets
No. of parts per package
Space
0 s
A
Tally pallets again and check for left-overs
No. of operators
1
Cycle time
6 s/pallet
Distance
Equipment
Forklift
6 s
T
From control buffer to truck buffer
No. of operators
1
Cycle time
66 s
Distance
~65 m
Pallets per lift
4
Equipment:
Forklift
66 s
Truck buffer
No. of parts
0
No. of pallets
No. of parts per package
Space
0 s


A
Fill out transport list
No. of operators 1
Cycle time 64 s
Distance
Equipment Pen and paper
64 s
H
Get forklift
No. of operators 1
Cycle time 78 s
Distance ~15 m
Pallets per lift
Equipment: Forklift
78 s
A
Get transport list
No. of operators 1
Cycle time 16 s
Distance ~15m
Equipment Computer
16 s
T
From truck buffer to truck
No. of operators 1
Cycle time 60 s
Distance ~15 m
Pallets per lift ??
Equipment: Forklift
60 s


T
From HF200 to D1
No. of operators 1
Cycle time 338 s
Distance 1170 m
Pallets per lift ??
Equipment: Truck
338 s
A
Transport list handed over to
D1
No. of operators 2
Cycle time 10 s
Distance
Equipment None
10 s
H
Unloading of truck to aiel
No. of operators 1
Cycle time 81 s
Distance 63 m
Pallets per lift 4
Equipment: Forklift
81 s
H
Sorting and add
components to 24h buffer
No. of operators 1
Cycle time
Distance
Pallets per lift 4
Equipment: Forklift
40 s
24h buffer
No. of parts 18679
No. of pallets
No. of parts per package
Space
118471 s
30,4%

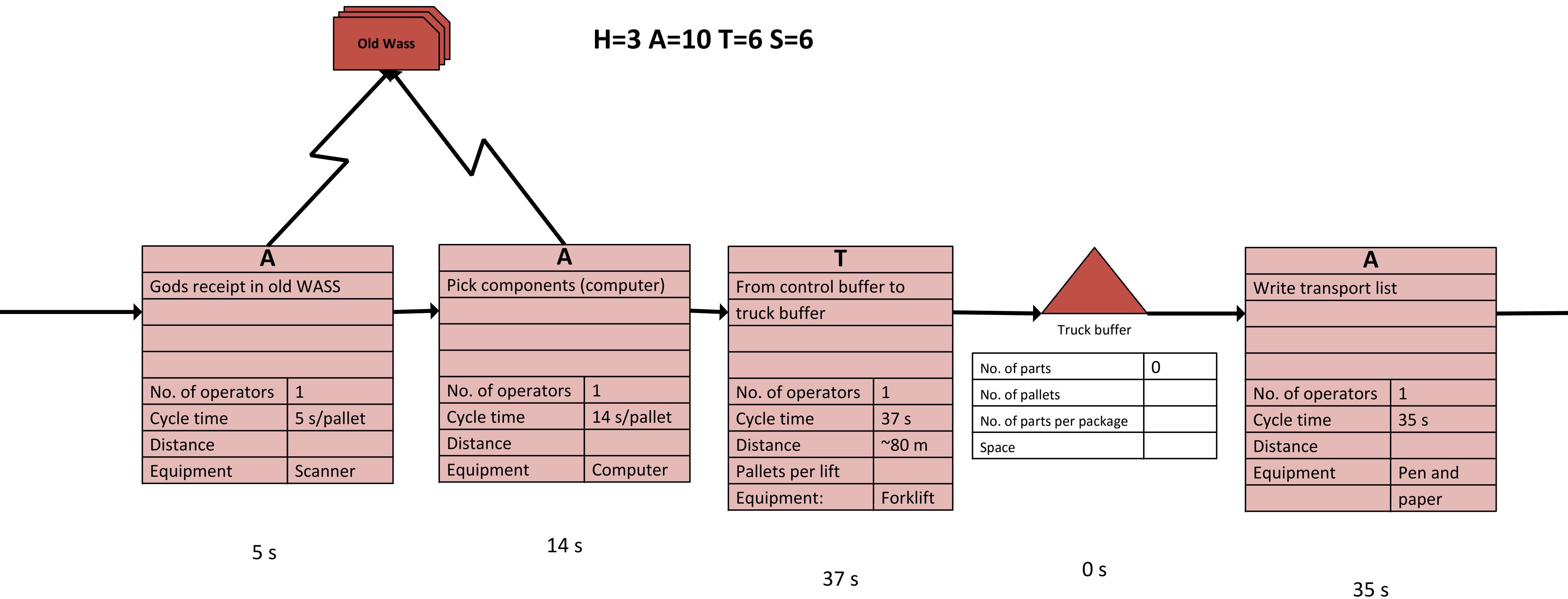

T
From 24h buffer to channel buffer
No. of operators
1
Cycle time
110 s
Distance
295
Pallets per lift
Equipment:
Forklift
Channel buffer
No. of parts
5632
No. of pallets
No. of parts per package
Space
Channel
Demand:44*12,9pcs/h=
567,6pcs/h
110 s
35720 s
9,2%
389183 s
~108,1 h
99,6% in storage

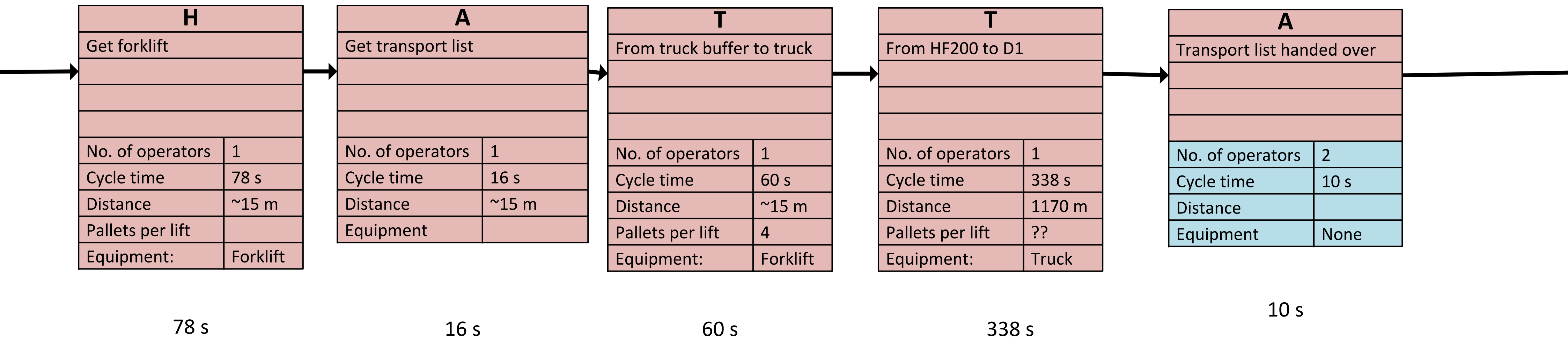
Appendix A.2 Cages

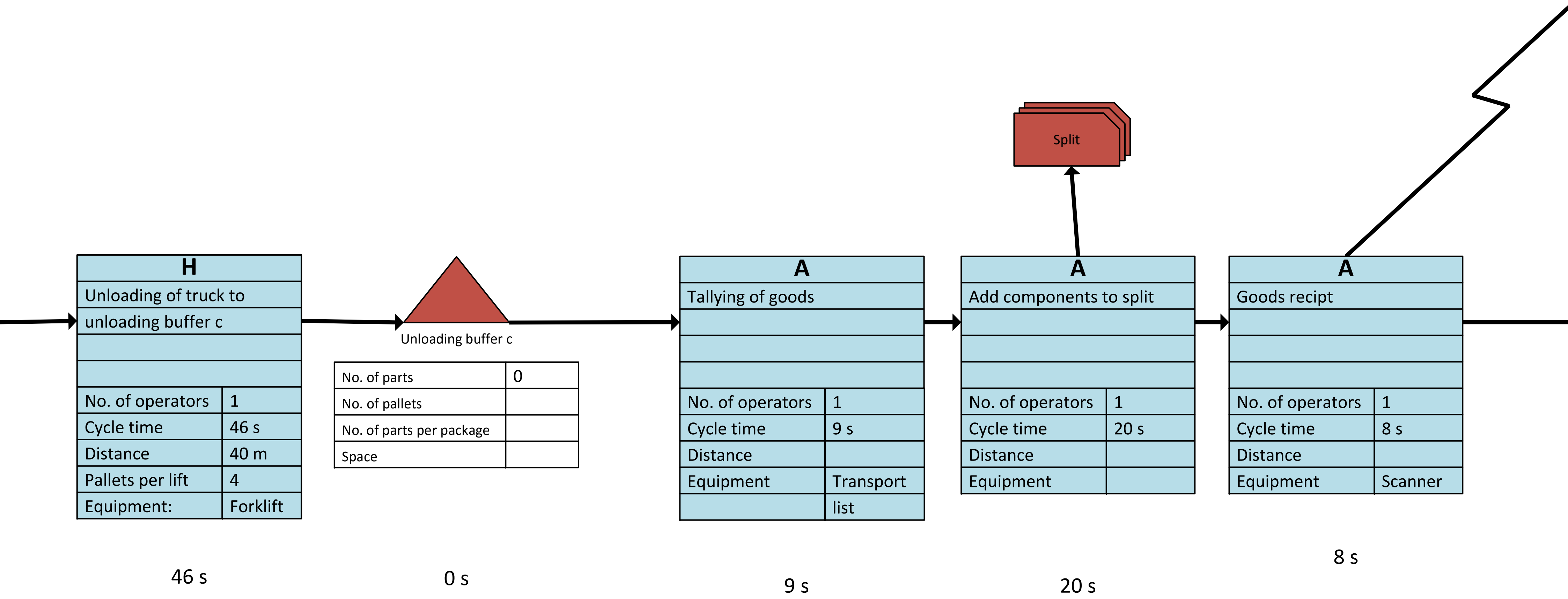


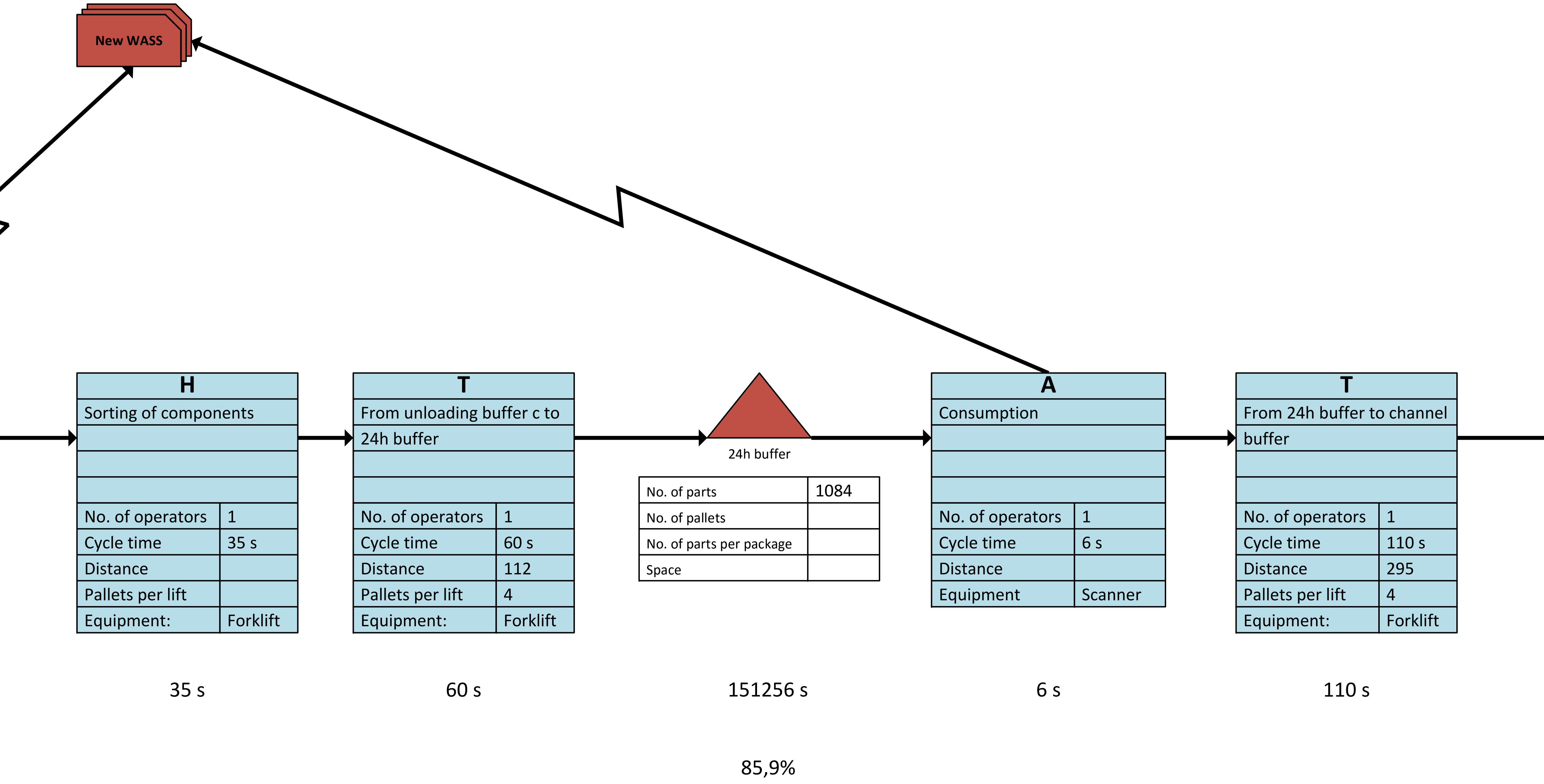
Supply Chain
D1
HF200
Call of need for components
Call for components
MCSS
Ordering of components
NKC
Reciving buffer
No. of parts 0
No. of pallets
No. of parts per package
Space
T
Fromreciving buffer to
control buffer
No. of operators 1
Cycle time 12 s
Distance 20 m
Pallets per lift
Equipment: Forklift
Control buffer
No. of parts 0
No. of pallets
No. of parts per package
Space
A
Move forklift to tally
components
No. of operators 1
Cycle time 15 s
Distance 2 m
Equipment Scanner
0 s
12 s
0 s
15 s

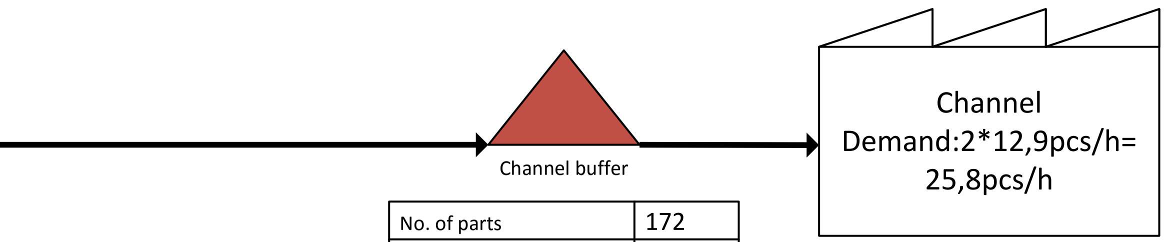
Cages Current map




H
Get forklift
No. of operators
1
Cycle time
78 s
Distance
~15 m
Pallets per lift
Equipment:
Forklift
78 s
A
Get transport list
No. of operators
1
Cycle time
16 s
Distance
~15 m
Equipment
16 s
T
From truck buffer to truck
No. of operators
1
Cycle time
60 s
Distance
~15 m
Pallets per lift
4
Equipment:
Forklift
60 s
T
From HF200 to D1
No. of operators
1
Cycle time
338 s
Distance
1170 m
Pallets per lift
??
Equipment:
Truck
338 s
A
Transport list handed over
No. of operators
2
Cycle time
10 s
Distance
Equipment
None
10 s


H
Unloading of truck to
unloading buffer c
No. of operators
1
Cycle time
46 s
Distance
40 m
Pallets per lift
4
Equipment:
Forklift
46 s
Unloading buffer c
No. of parts
0
No. of pallets
No. of parts per package
Space
0 s
A
Tallying of goods
No. of operators
1
Cycle time
9 s
Distance
Equipment
Transport
list
9 s
Split
A
Add components to split
No. of operators
1
Cycle time
20 s
Distance
Equipment
20 s
A
Goods recipt
No. of operators
1
Cycle time
8 s
Distance
Equipment
Scanner
8 s


New WASS
H
Sorting of components
No. of operators 1
Cycle time 35 s
Distance
Pallets per lift
Equipment: Forklift
T
From unloading buffer c to 24h buffer
No. of operators 1
Cycle time 60 s
Distance 112
Pallets per lift 4
Equipment: Forklift
24h buffer
No. of parts 1084
No. of pallets
No. of parts per package
Space
A
Consumption
No. of operators 1
Cycle time 6 s
Distance
Equipment Scanner
T
From 24h buffer to channel buffer
No. of operators 1
Cycle time 110 s
Distance 295
Pallets per lift 4
Equipment: Forklift
35 s
60 s
151256 s
6 s
110 s
85,9%



No. of parts	172
No. of pallets	
No. of parts per package	
Space	

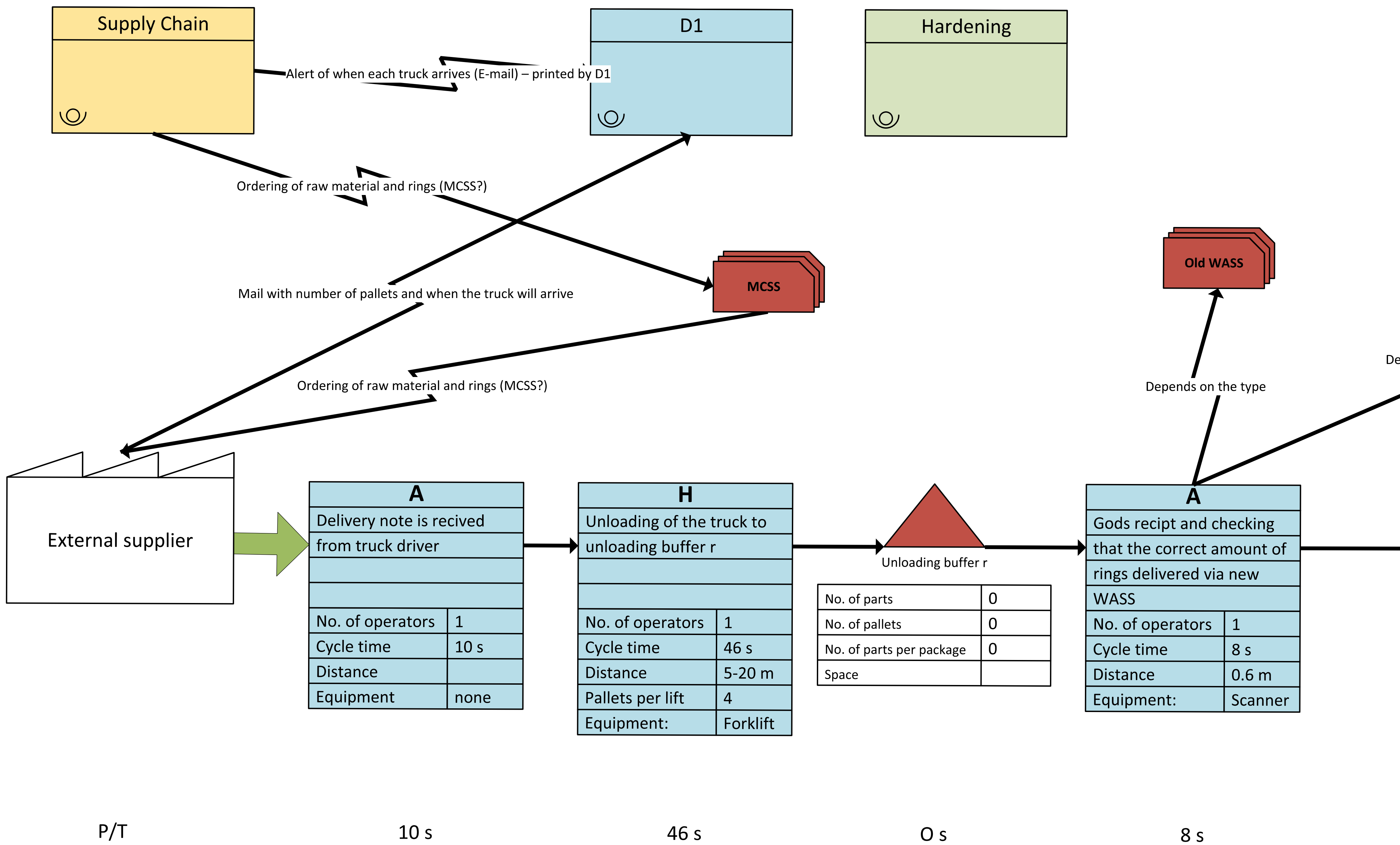
24000 s

176170 s

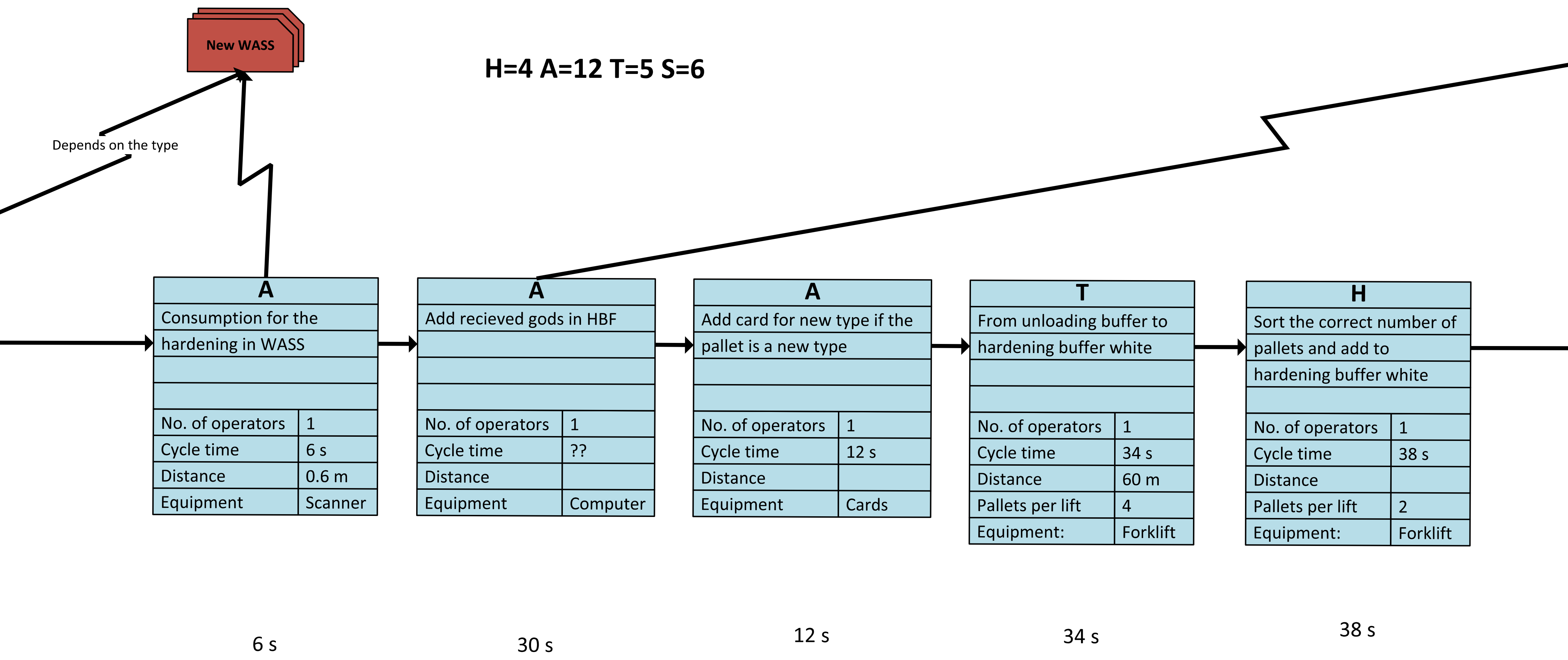
48,9 h

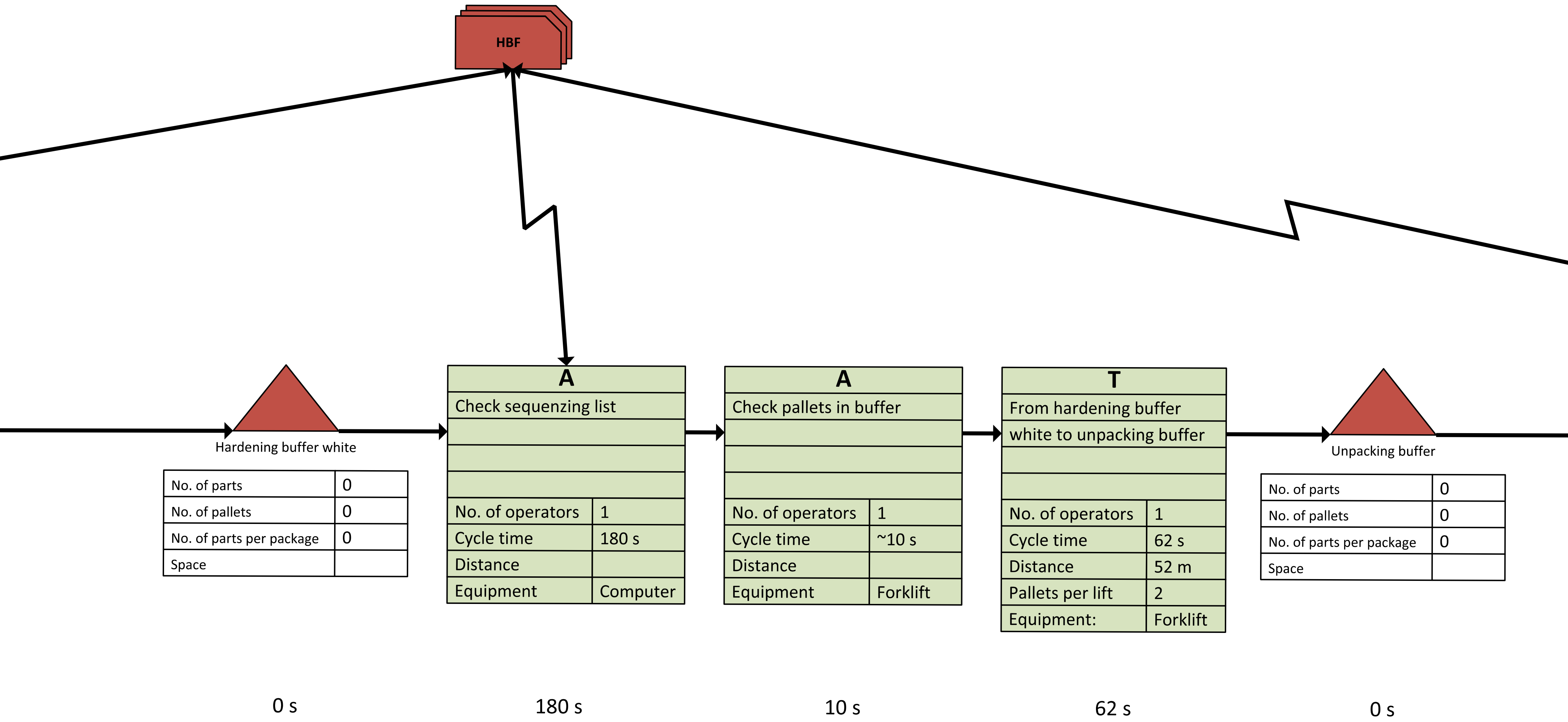
13,6%

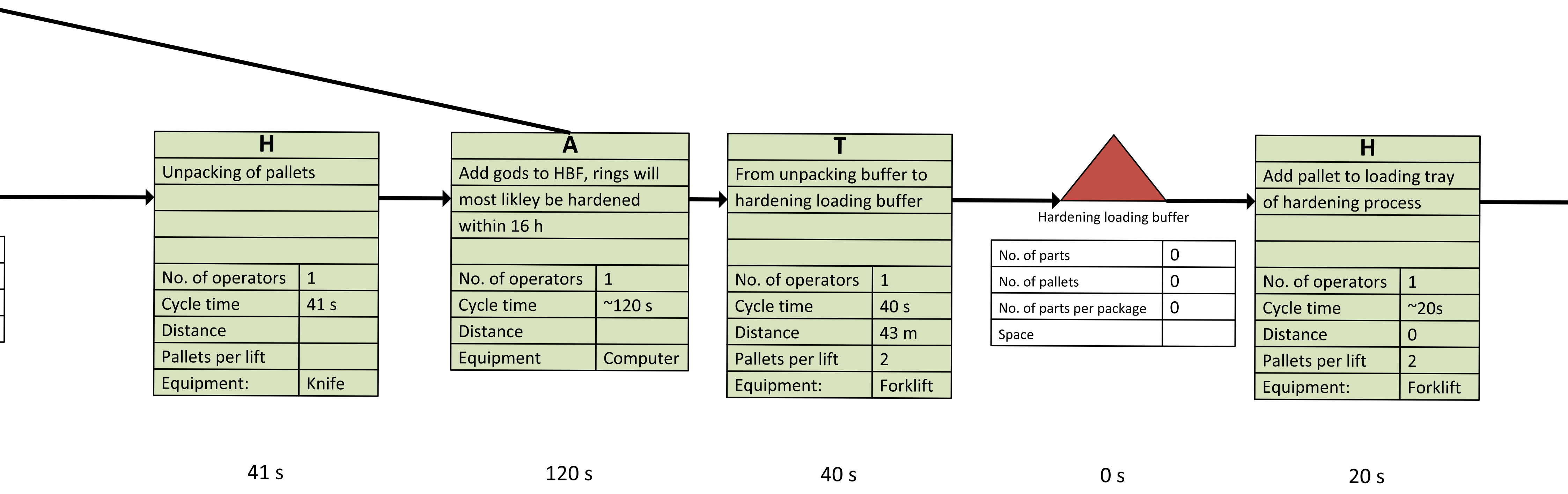
Appendix A.3 Rings


Supply Chain
D1
Hardening
Alert of when each truck arrives (E-mail) – printed by D1
Ordering of raw material and rings (MCSS?)
MCSS
Mail with number of pallets and when the truck will arrive
Ordering of raw material and rings (MCSS?)
Old WASS
Depends on the type
De
External supplier
A
Delivery note is recived
from truck driver
No. of operators
1
Cycle time
10 s
Distance
Equipment
none
H
Unloading of the truck to
unloading buffer r
No. of operators
1
Cycle time
46 s
Distance
5-20 m
Pallets per lift
4
Equipment:
Forklift
Unloading buffer r
No. of parts
0
No. of pallets
0
No. of parts per package
0
Space
A
Gods recipt and checking
that the correct amount of
rings delivered via new
WASS
No. of operators
1
Cycle time
8 s
Distance
0.6 m
Equipment:
Scanner
P/T
10 s
46 s
0 s
8 s

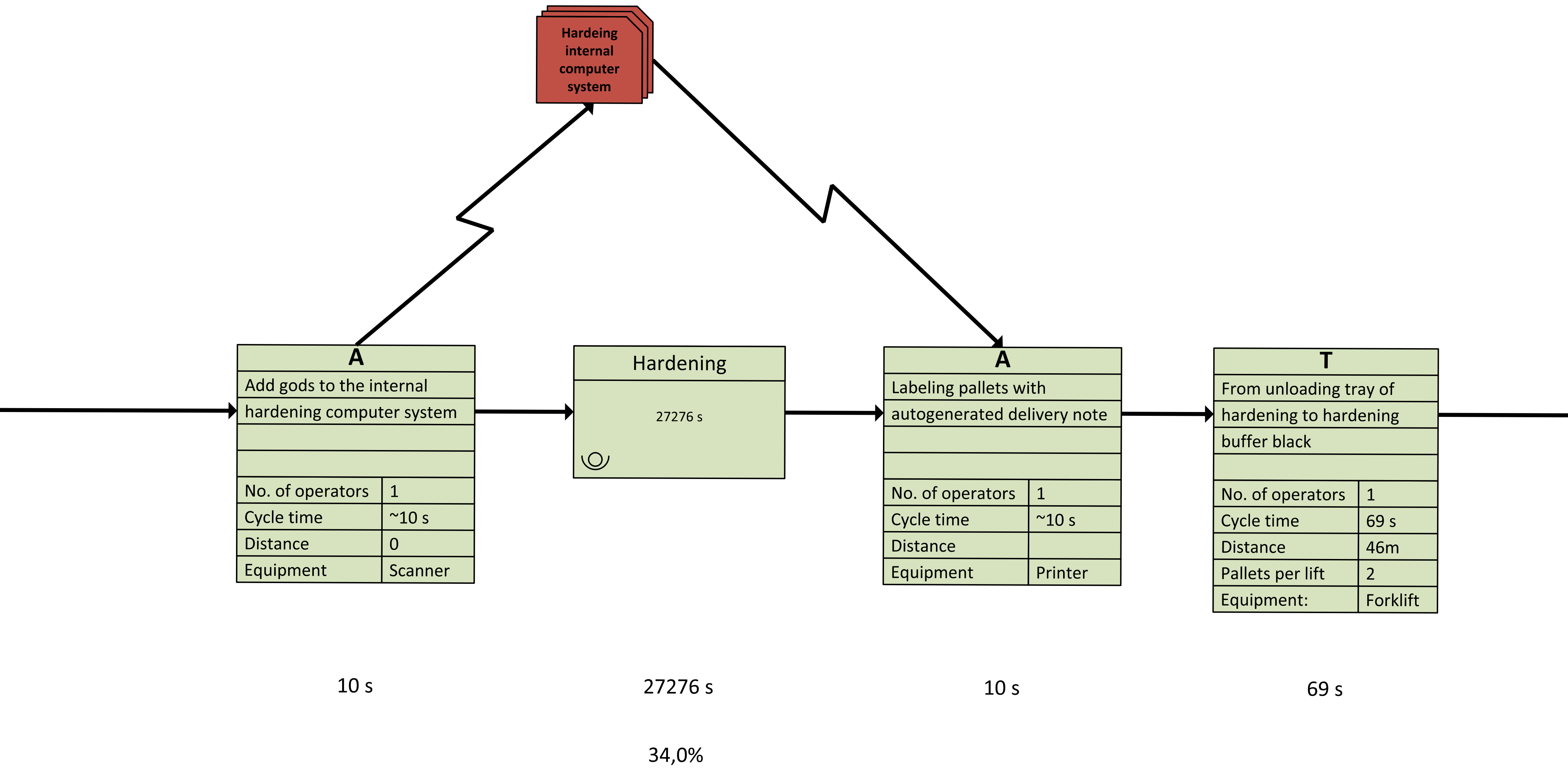
Rings Current map

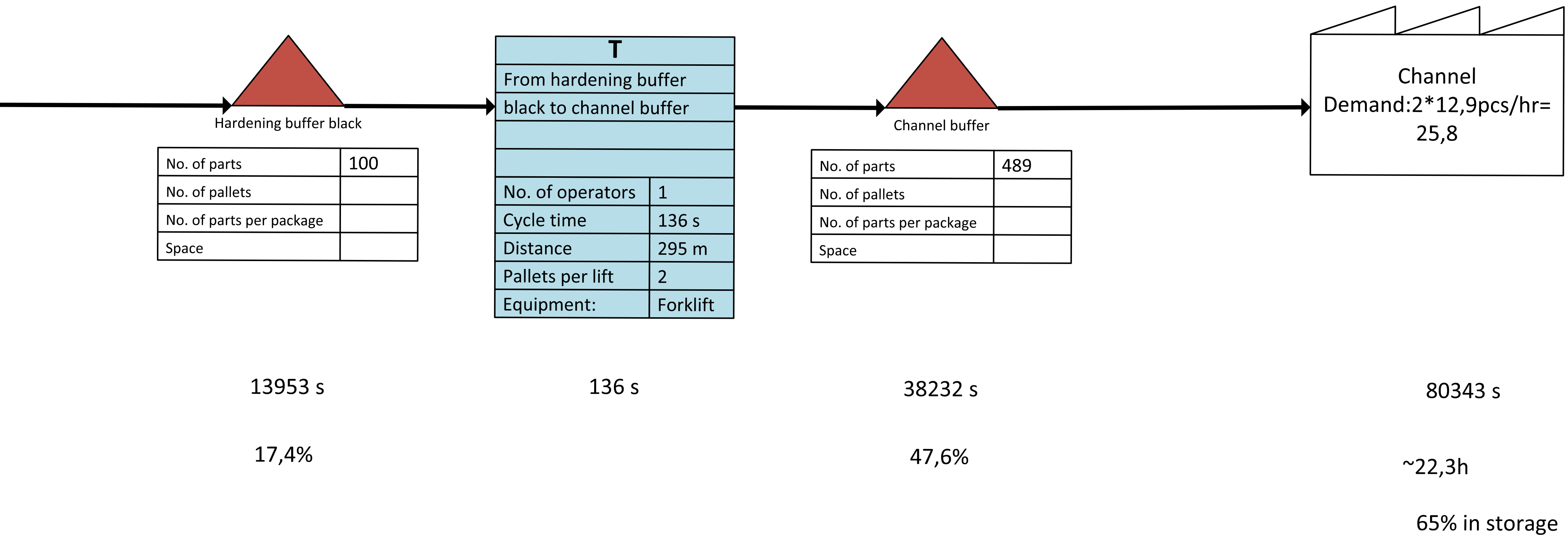



HBF
Hardening buffer white
No. of parts 0
No. of pallets 0
No. of parts per package 0
Space
A
Check sequenzing list
No. of operators 1
Cycle time 180 s
Distance
Equipment Computer
A
Check pallets in buffer
No. of operators 1
Cycle time ~10 s
Distance
Equipment Forklift
T
From hardening buffer
white to unpacking buffer
No. of operators 1
Cycle time 62 s
Distance 52 m
Pallets per lift 2
Equipment: Forklift
Unpacking buffer
No. of parts 0
No. of pallets 0
No. of parts per package 0
Space
0 s
180 s
10 s
62 s
0 s

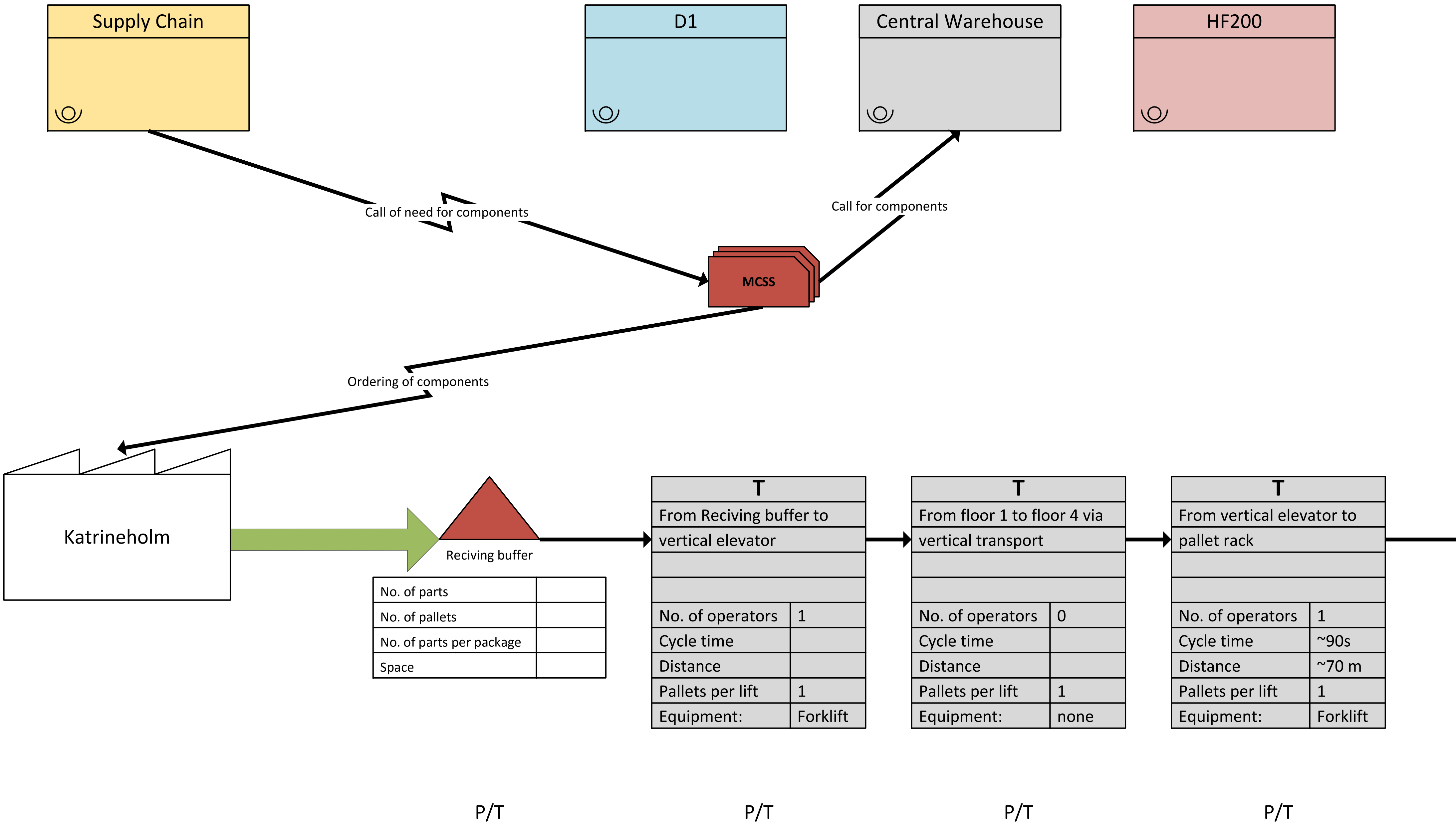


H
Unpacking of pallets
No. of operators 1
Cycle time 41 s
Distance
Pallets per lift
Equipment: Knife
41 s
A
Add gods to HBF, rings will most likley be hardened within 16 h
No. of operators 1
Cycle time ~120 s
Distance
Equipment Computer
120 s
T
From unpacking buffer to hardening loading buffer
No. of operators 1
Cycle time 40 s
Distance 43 m
Pallets per lift 2
Equipment: Forklift
40 s
Hardening loading buffer
No. of parts 0
No. of pallets 0
No. of parts per package 0
Space
0 s
H
Add pallet to loading tray of hardening process
No. of operators 1
Cycle time ~20s
Distance 0
Pallets per lift 2
Equipment: Forklift
20 s


Hardeing internal computer system
A
Add gods to the internal hardening computer system
No. of operators 1
Cycle time ~10 s
Distance 0
Equipment Scanner
Hardening
27276 s
A
Labeling pallets with autogenerated delivery note
No. of operators 1
Cycle time ~10 s
Distance
Equipment Printer
T
From unloading tray of hardening to hardening buffer black
No. of operators 1
Cycle time 69 s
Distance 46m
Pallets per lift 2
Equipment: Forklift
10 s
27276 s
10 s
69 s
34,0%

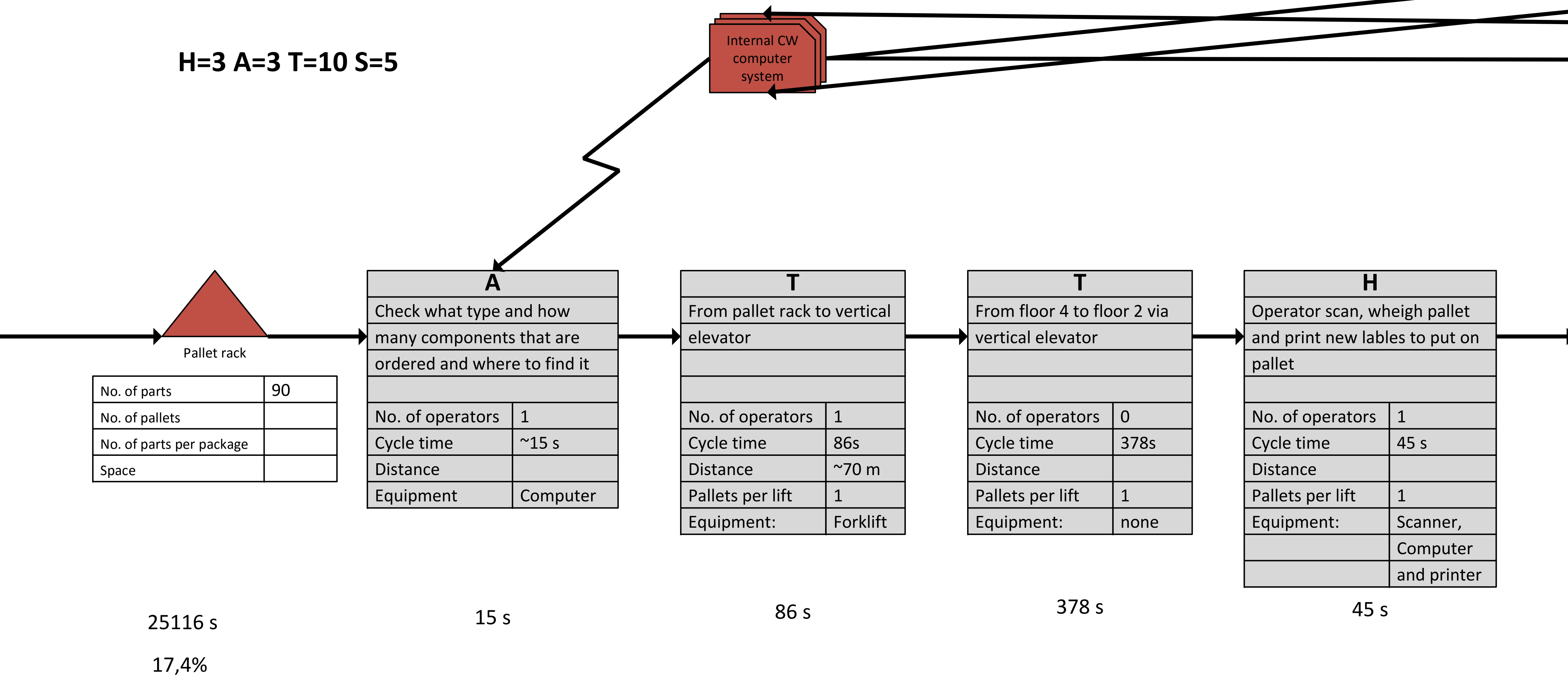

Hardening buffer black
No. of parts
100
No. of pallets
No. of parts per package
Space
T
From hardening buffer
black to channel buffer
No. of operators
1
Cycle time
136 s
Distance
295 m
Pallets per lift
2
Equipment:
Forklift
Channel buffer
No. of parts
489
No. of pallets
No. of parts per package
Space
Channel
Demand:2*12,9pcs/hr=
25,8
13953 s
136 s
38232 s
80343 s
17,4%
47,6%
~22,3h
65% in storage

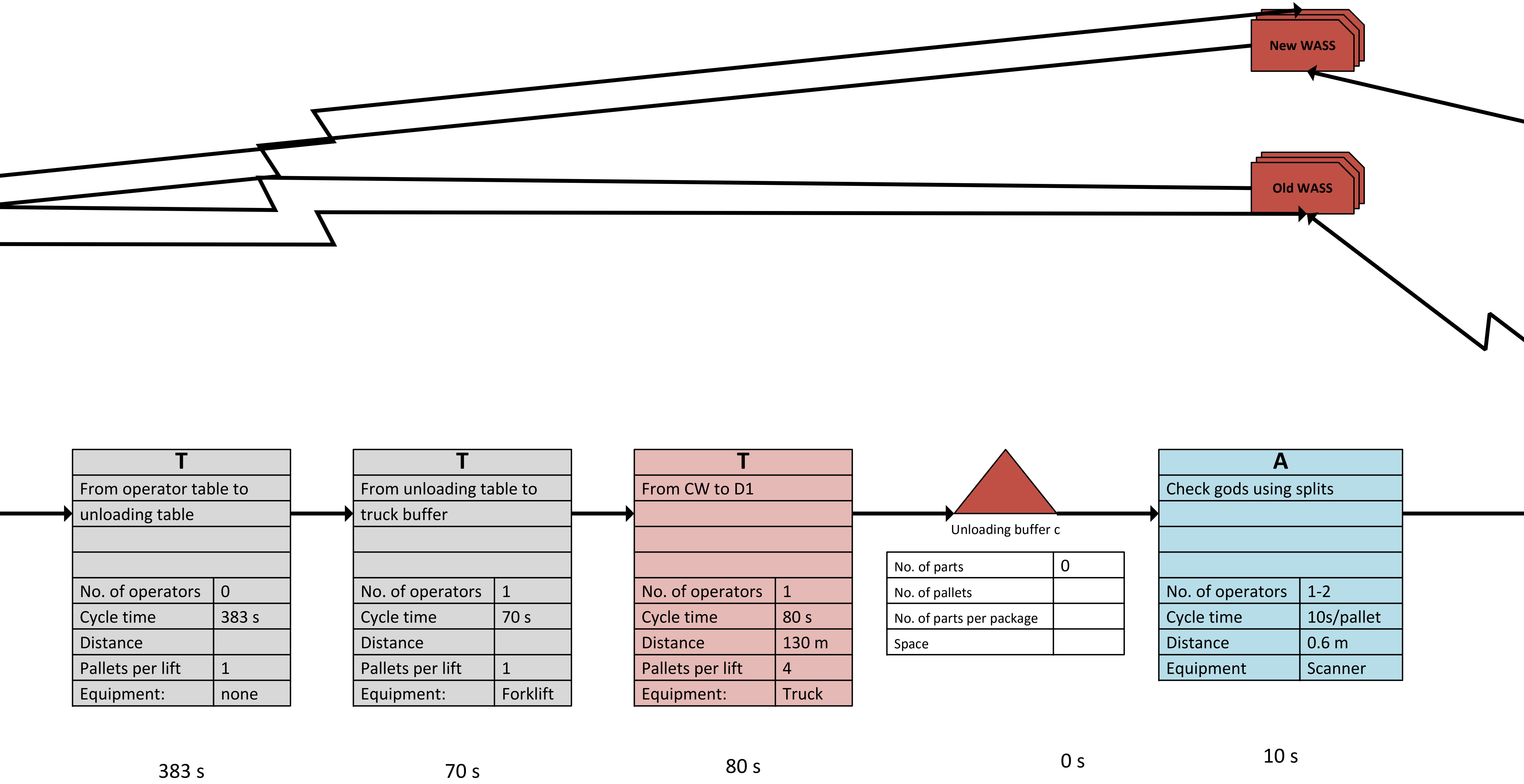
Appendix A.4 Guide rings

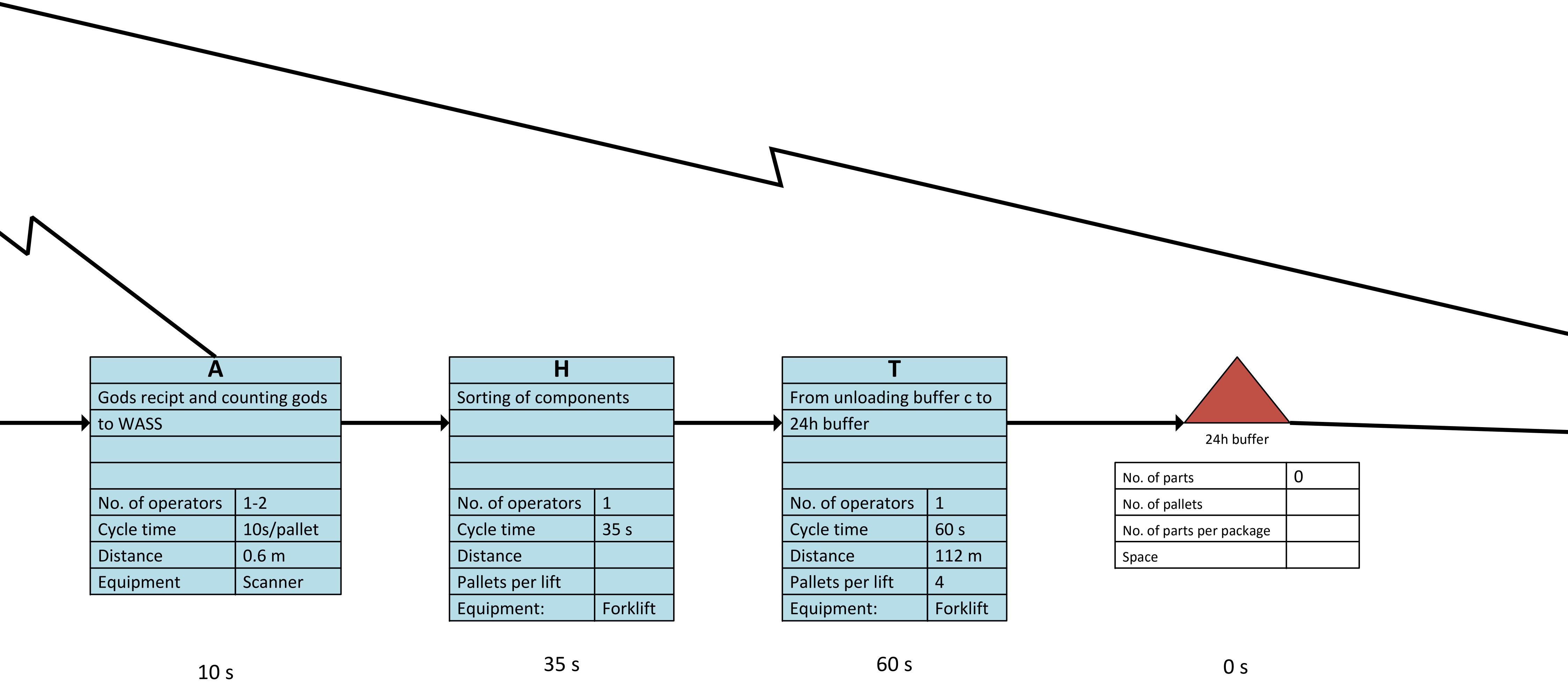

Supply Chain
D1
Central Warehouse
HF200
Call of need for components
Call for components
MCSS
Ordering of components
Katrineholm
Reciving buffer
No. of parts
No. of pallets
No. of parts per package
Space
T
From Reciving buffer to
vertical elevator
No. of operators 1
Cycle time
Distance
Pallets per lift 1
Equipment: Forklift
T
From floor 1 to floor 4 via
vertical transport
No. of operators 0
Cycle time
Distance
Pallets per lift 1
Equipment: none
T
From vertical elevator to
pallet rack
No. of operators 1
Cycle time ~90s
Distance ~70 m
Pallets per lift 1
Equipment: Forklift
P/T
P/T
P/T
P/T

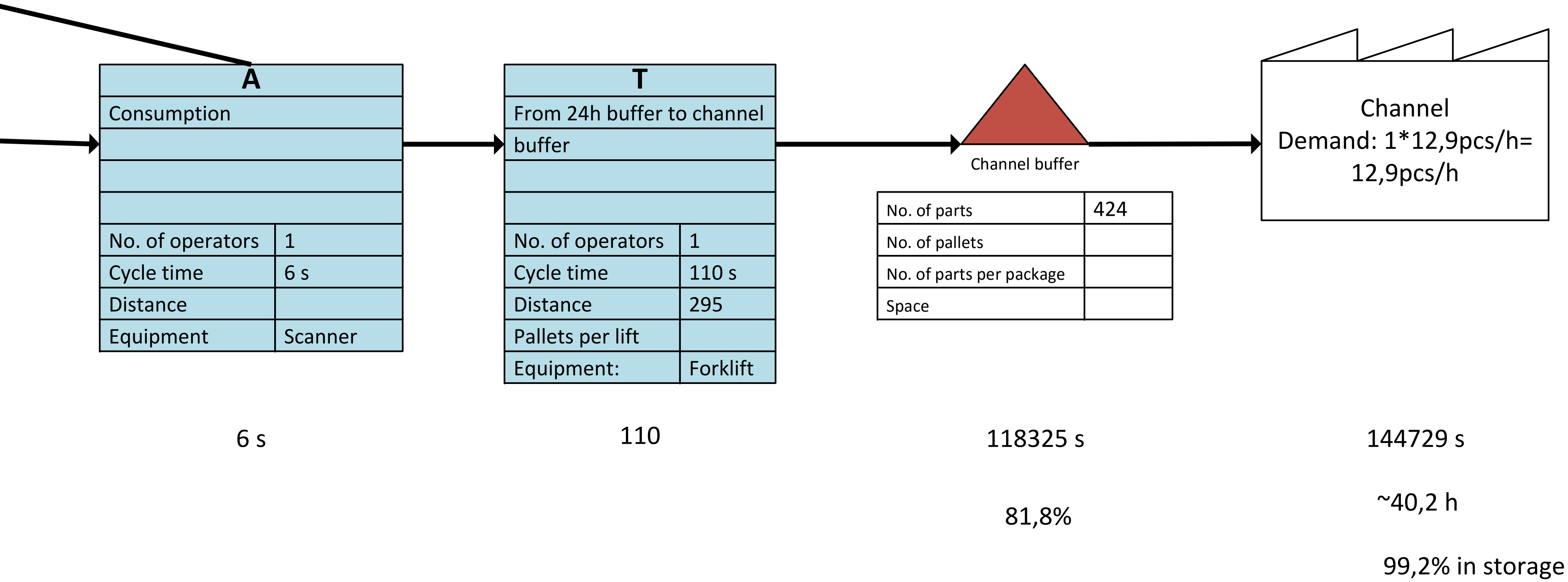
Guide rings Current map

H=3 A=3 T=10 S=5



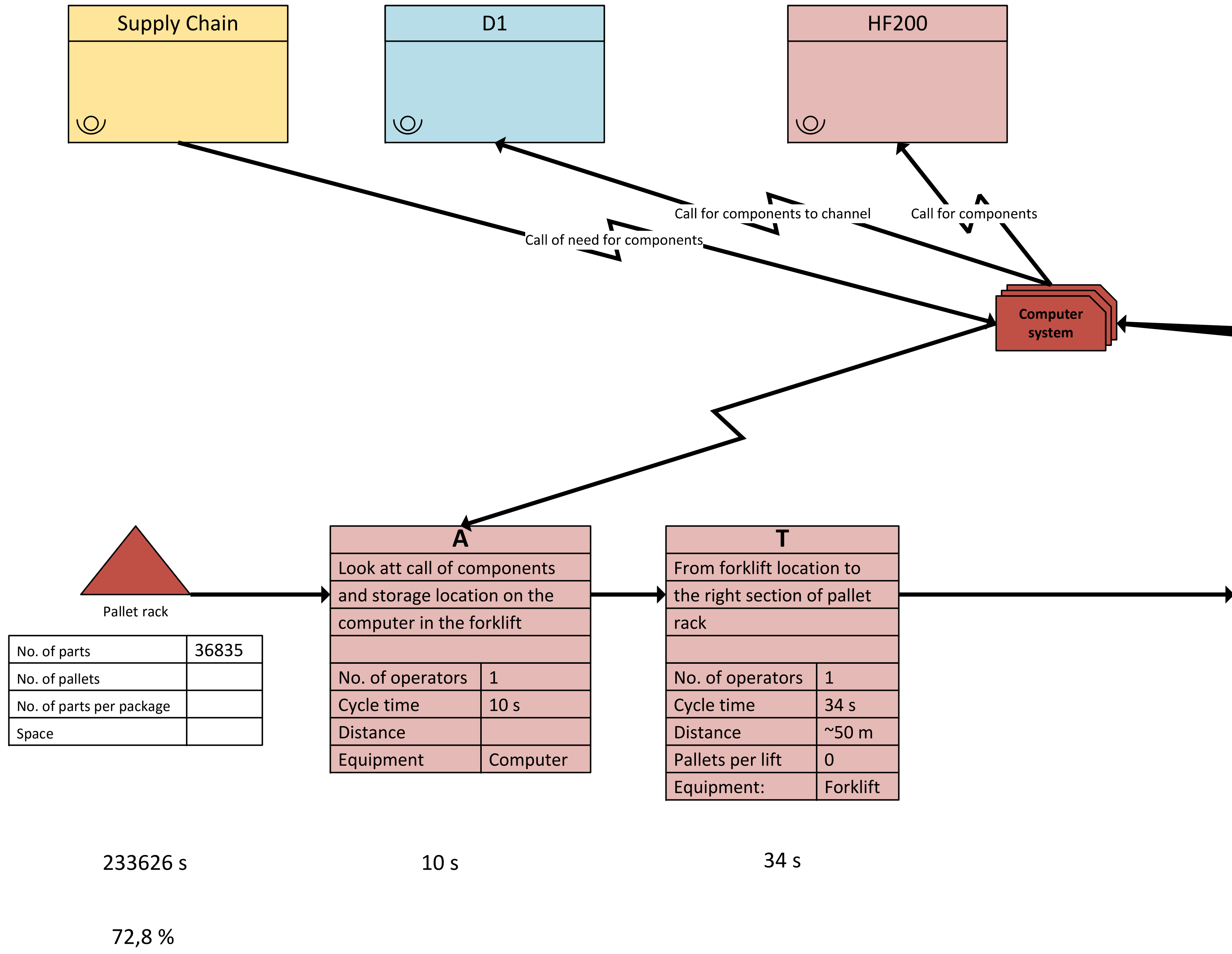

New WASS
Old WASS
T
From operator table to
unloading table
No. of operators 0
Cycle time 383 s
Distance
Pallets per lift 1
Equipment: none
T
From unloading table to
truck buffer
No. of operators 1
Cycle time 70 s
Distance
Pallets per lift 1
Equipment: Forklift
T
From CW to D1
No. of operators 1
Cycle time 80 s
Distance 130 m
Pallets per lift 4
Equipment: Truck
Unloading buffer c
No. of parts 0
No. of pallets
No. of parts per package
Space
A
Check gods using splits
No. of operators 1-2
Cycle time 10s/pallet
Distance 0.6 m
Equipment Scanner
383 s
70 s
80 s
0 s
10 s


A
Gods recipt and counting gods
to WASS
No. of operators
1-2
Cycle time
10s/pallet
Distance
0.6 m
Equipment
Scanner
H
Sorting of components
No. of operators
1
Cycle time
35 s
Distance
Pallets per lift
Equipment:
Forklift
T
From unloading buffer c to
24h buffer
No. of operators
1
Cycle time
60 s
Distance
112 m
Pallets per lift
4
Equipment:
Forklift
24h buffer
No. of parts
0
No. of pallets
No. of parts per package
Space
10 s
35 s
60 s
0 s


A
Consumption
No. of operators
1
Cycle time
6 s
Distance
Equipment
Scanner
T
From 24h buffer to channel buffer
No. of operators
1
Cycle time
110 s
Distance
295
Pallets per lift
Equipment:
Forklift
Channel buffer
No. of parts
424
No. of pallets
No. of parts per package
Space
Channel
Demand: 1*12,9pcs/h=
12,9pcs/h
6 s
110
118325 s
81,8%
144729 s
~40,2 h
99,2% in storage

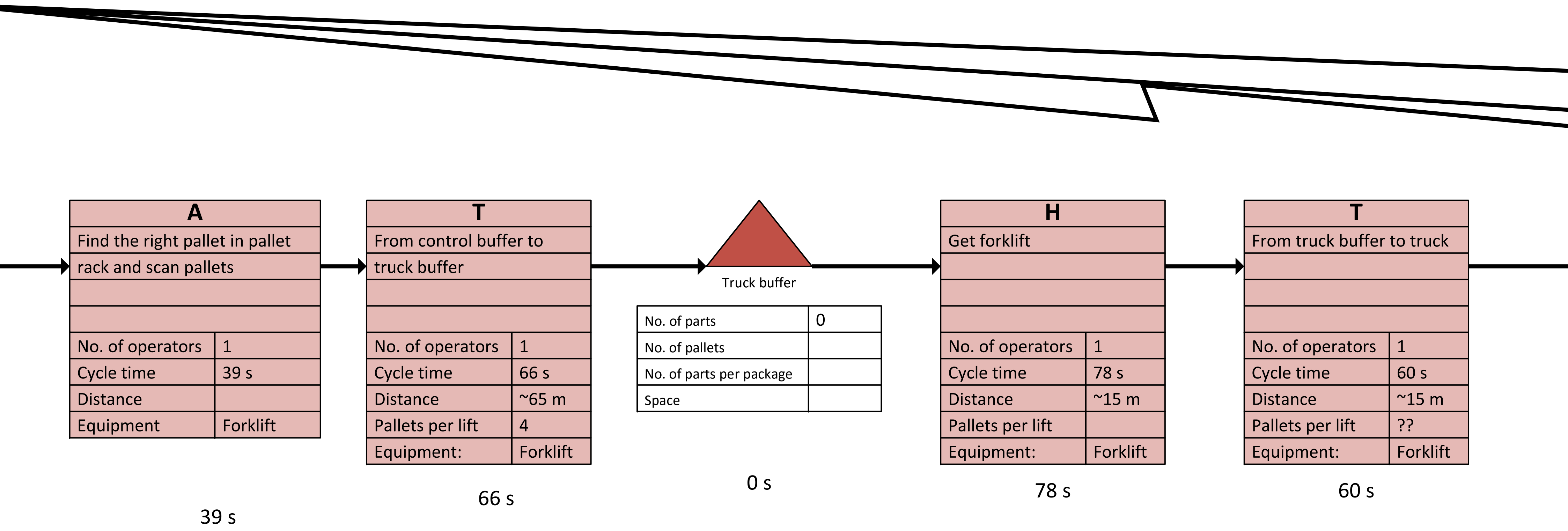
Appendix B Future Material Flow Mapping

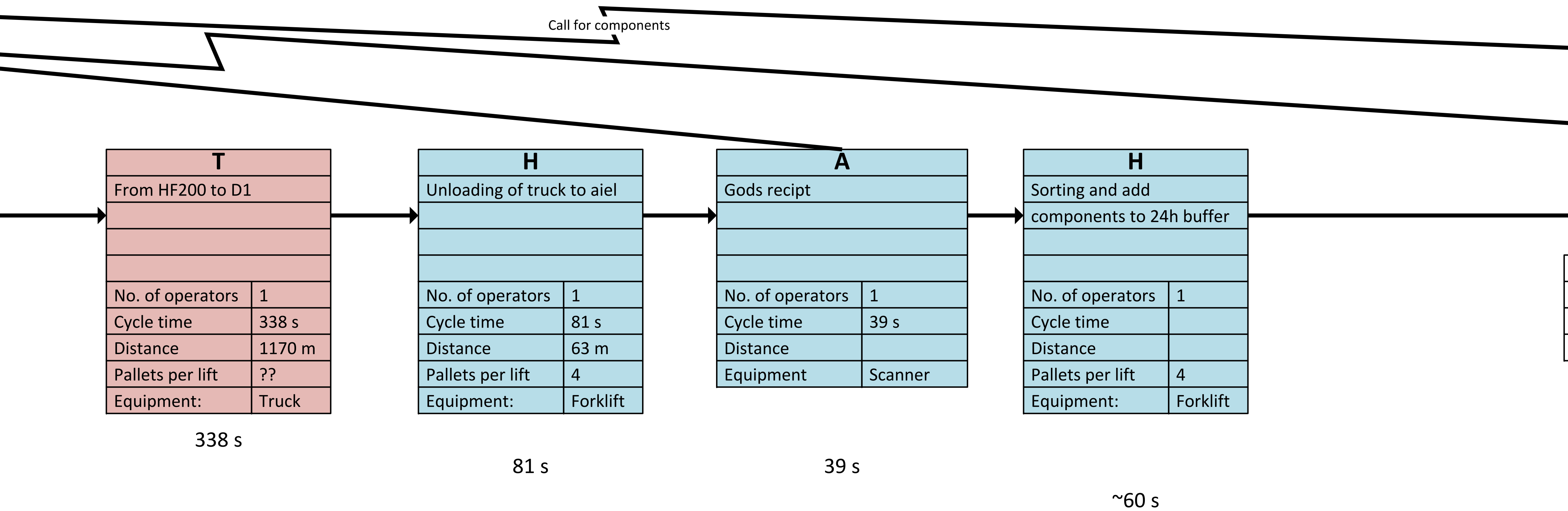
Appendix B.1 Rollers

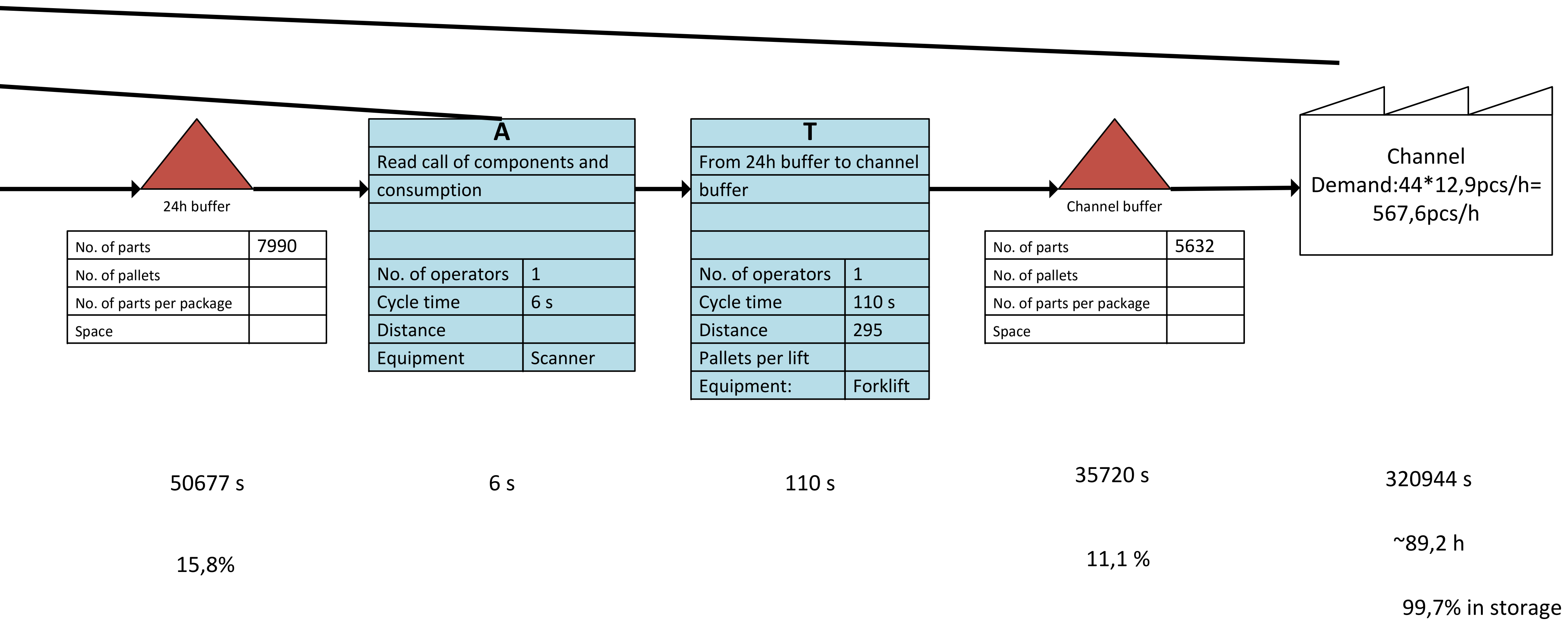

Supply Chain
D1
HF200
Call of need for components
Call for components to channel
Call for components
Computer system
A
Look att call of components
and storage location on the
computer in the forklift
No. of operators
1
Cycle time
10 s
Distance
Equipment
Computer
T
From forklift location to
the right section of pallet
rack
No. of operators
1
Cycle time
34 s
Distance
~50 m
Pallets per lift
0
Equipment:
Forklift
Pallet rack
No. of parts
36835
No. of pallets
No. of parts per package
Space
233626 s
10 s
34 s
72,8 %

Rollers Future map

H=4 A=4 T=5 S=4

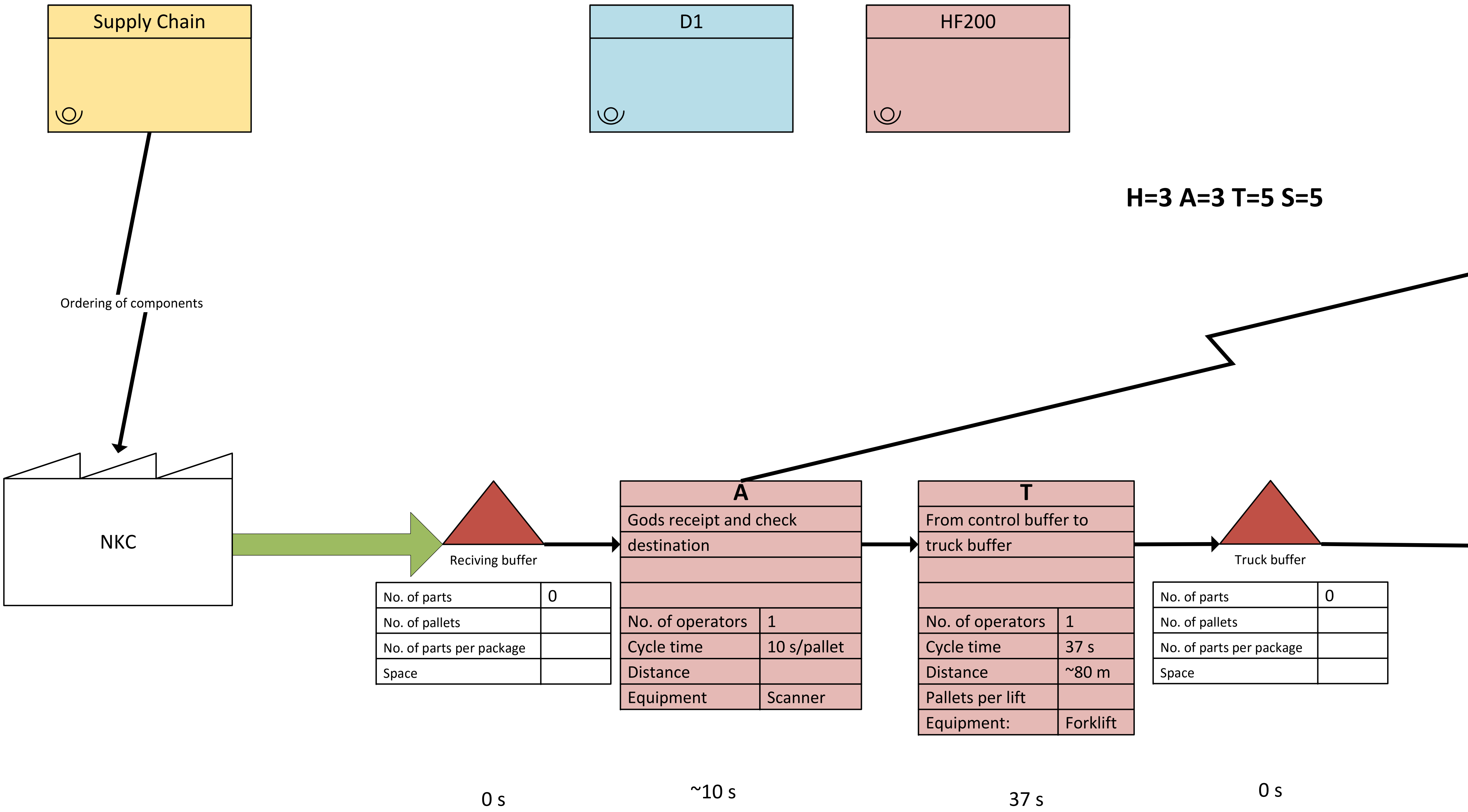



Call for components
T
From HF200 to D1
No. of operators 1
Cycle time 338 s
Distance 1170 m
Pallets per lift ??
Equipment: Truck
338 s
H
Unloading of truck to aiel
No. of operators 1
Cycle time 81 s
Distance 63 m
Pallets per lift 4
Equipment: Forklift
81 s
A
Gods recipt
No. of operators 1
Cycle time 39 s
Distance
Equipment Scanner
39 s
H
Sorting and add components to 24h buffer
No. of operators 1
Cycle time
Distance
Pallets per lift 4
Equipment: Forklift
~60 s

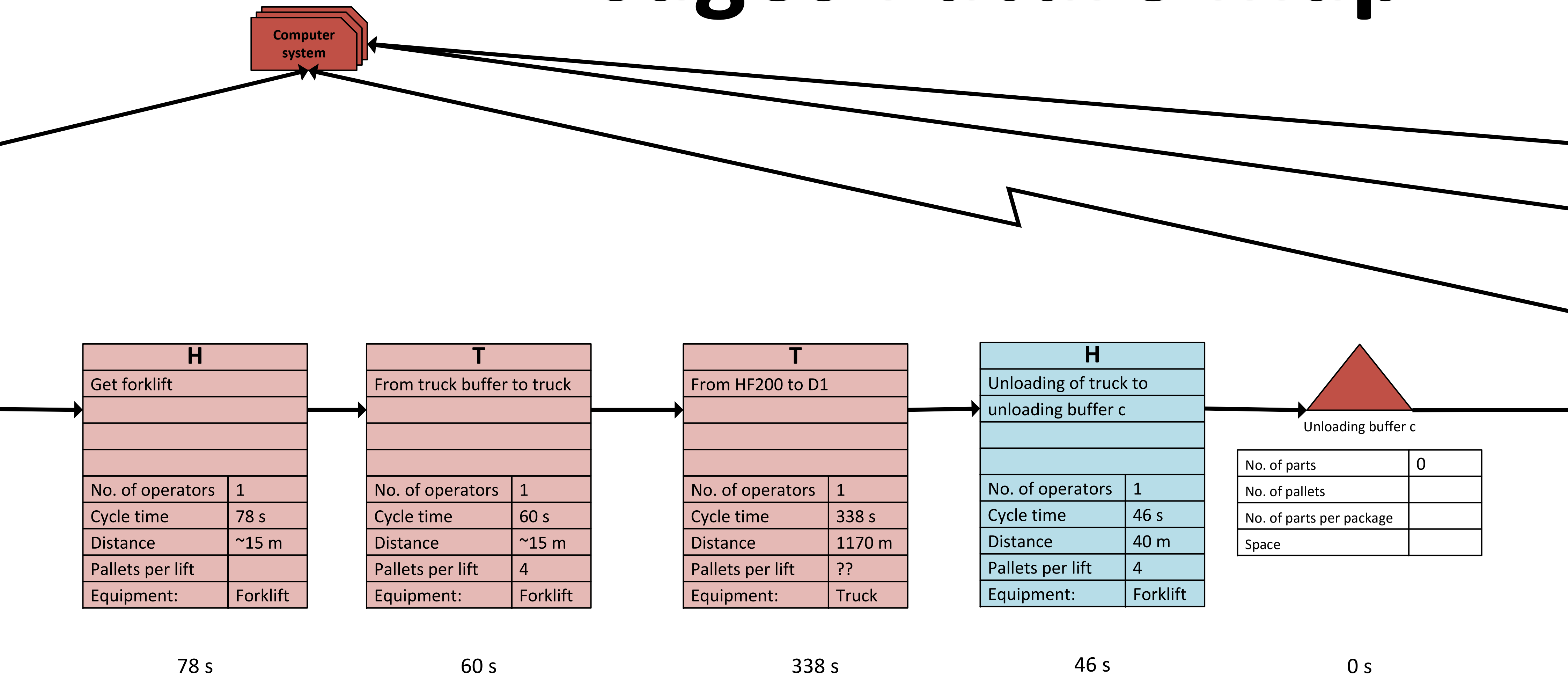


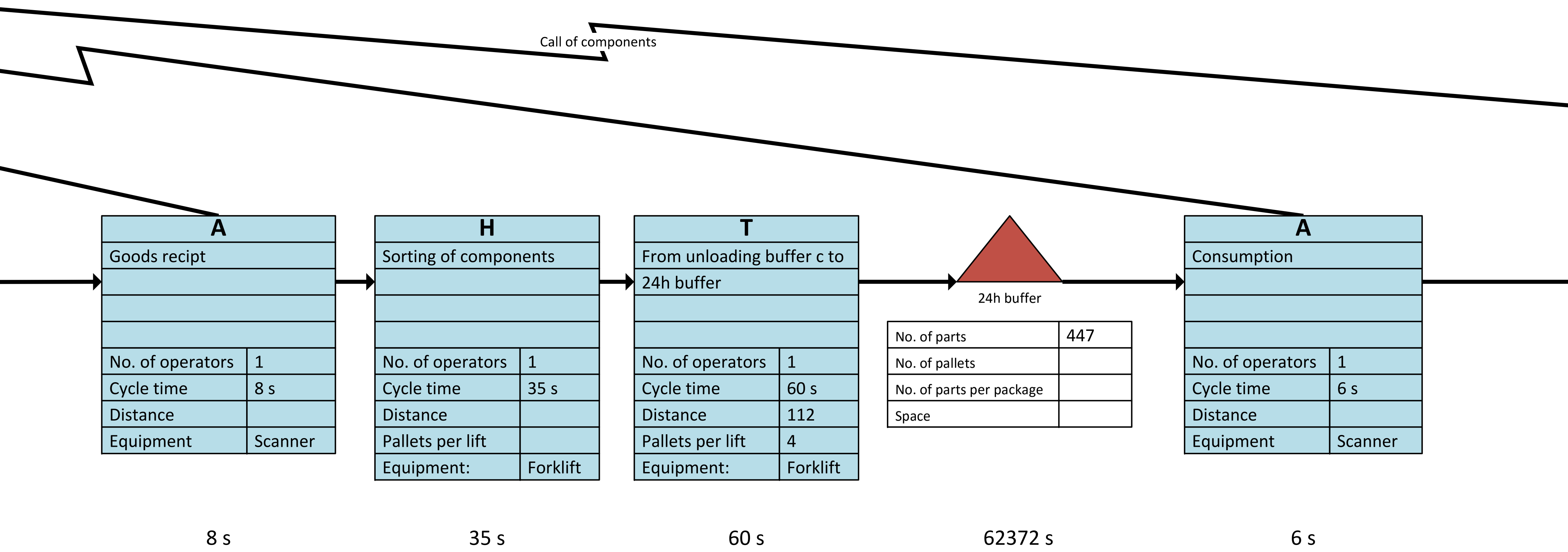
24h buffer
No. of parts 7990
No. of pallets
No. of parts per package
Space
A
Read call of components and consumption
No. of operators 1
Cycle time 6 s
Distance
Equipment Scanner
T
From 24h buffer to channel buffer
No. of operators 1
Cycle time 110 s
Distance 295
Pallets per lift
Equipment: Forklift
Channel buffer
No. of parts 5632
No. of pallets
No. of parts per package
Space
Channel
Demand:44*12,9pcs/h=
567,6pcs/h
50677 s
15,8%
6 s
110 s
35720 s
11,1 %
320944 s
~89,2 h
99,7% in storage

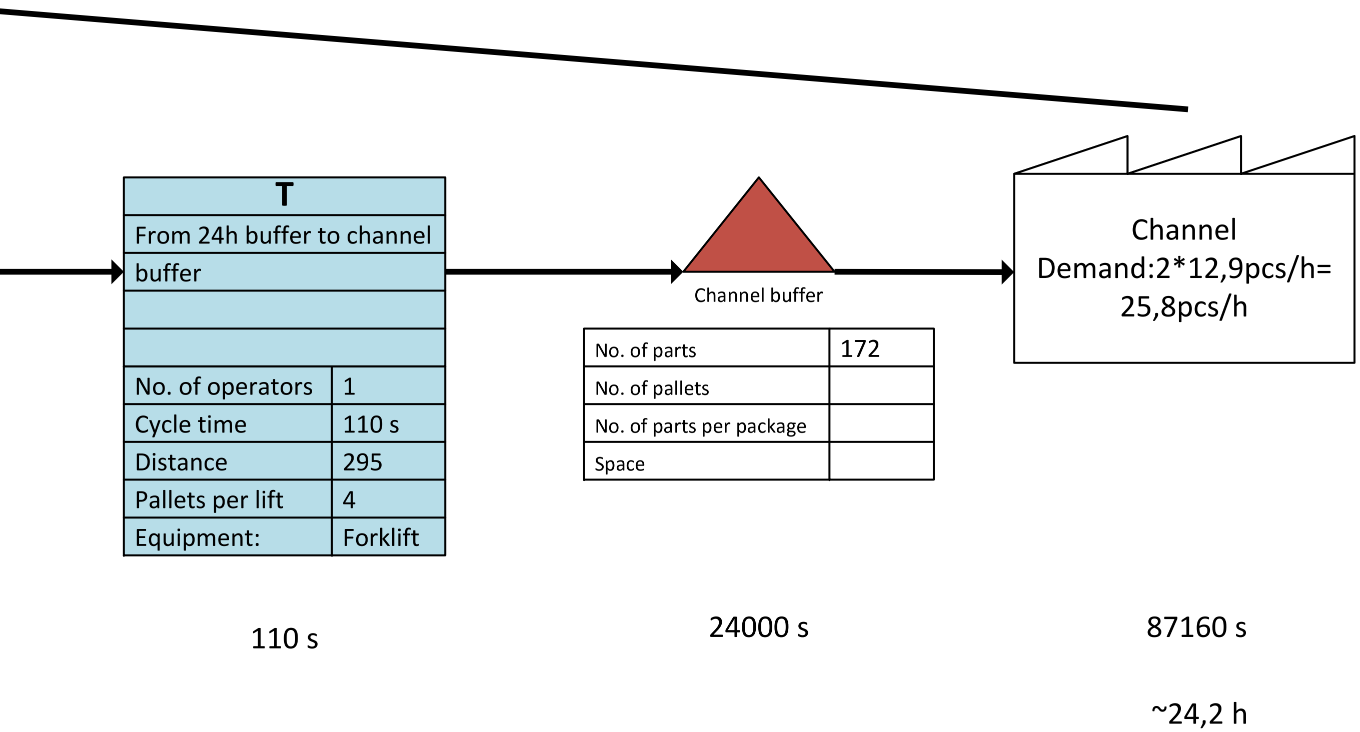
Appendix B.2 Cages


Supply Chain
D1
HF200
H=3 A=3 T=5 S=5
Ordering of components
NKC
Reciving buffer
No. of parts 0
No. of pallets
No. of parts per package
Space
A
Gods receipt and check destination
No. of operators 1
Cycle time 10 s/pallet
Distance
Equipment Scanner
T
From control buffer to truck buffer
No. of operators 1
Cycle time 37 s
Distance ~80 m
Pallets per lift
Equipment: Forklift
Truck buffer
No. of parts 0
No. of pallets
No. of parts per package
Space
0 s
~10 s
37 s
0 s

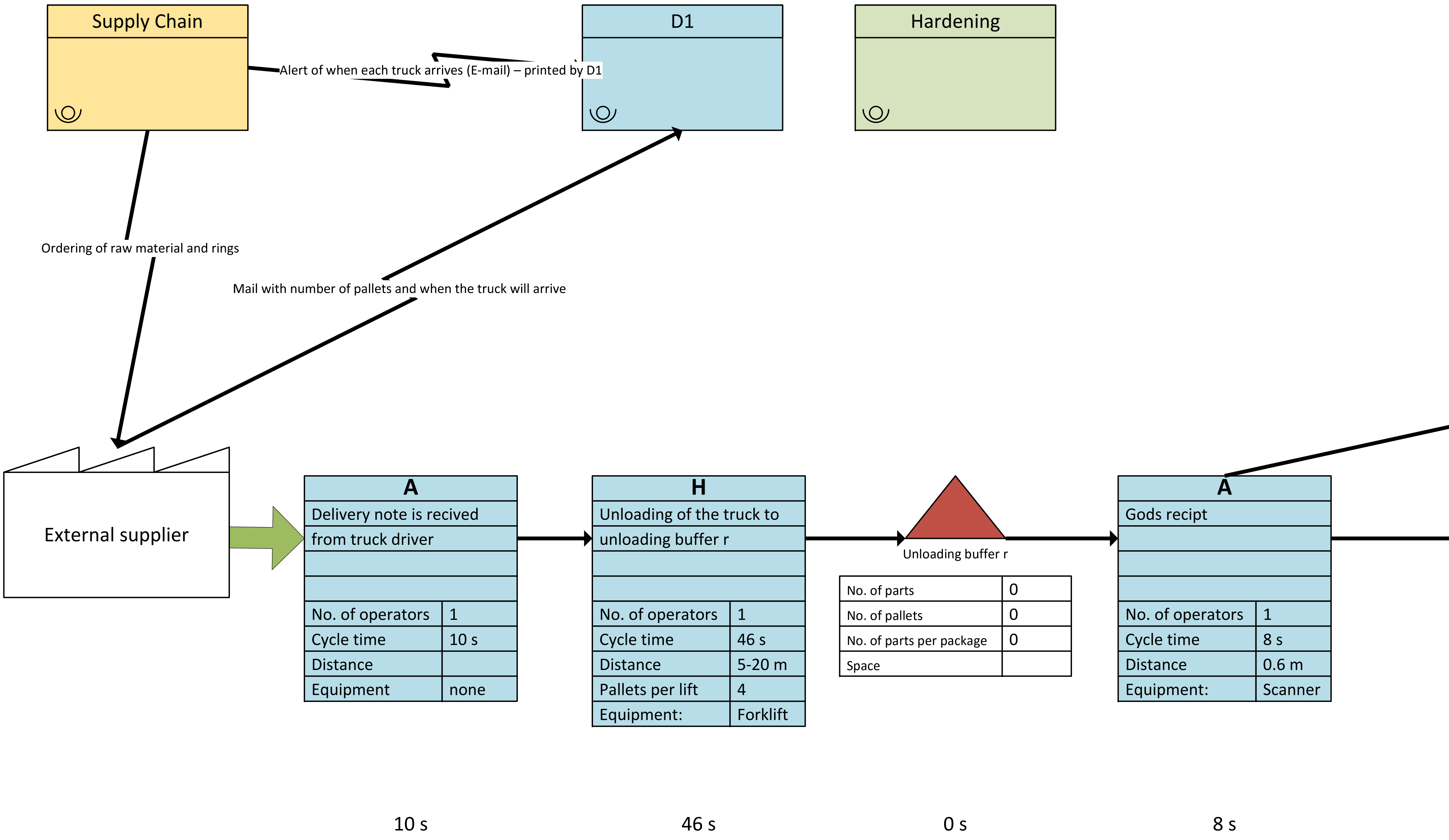
Cages Future map



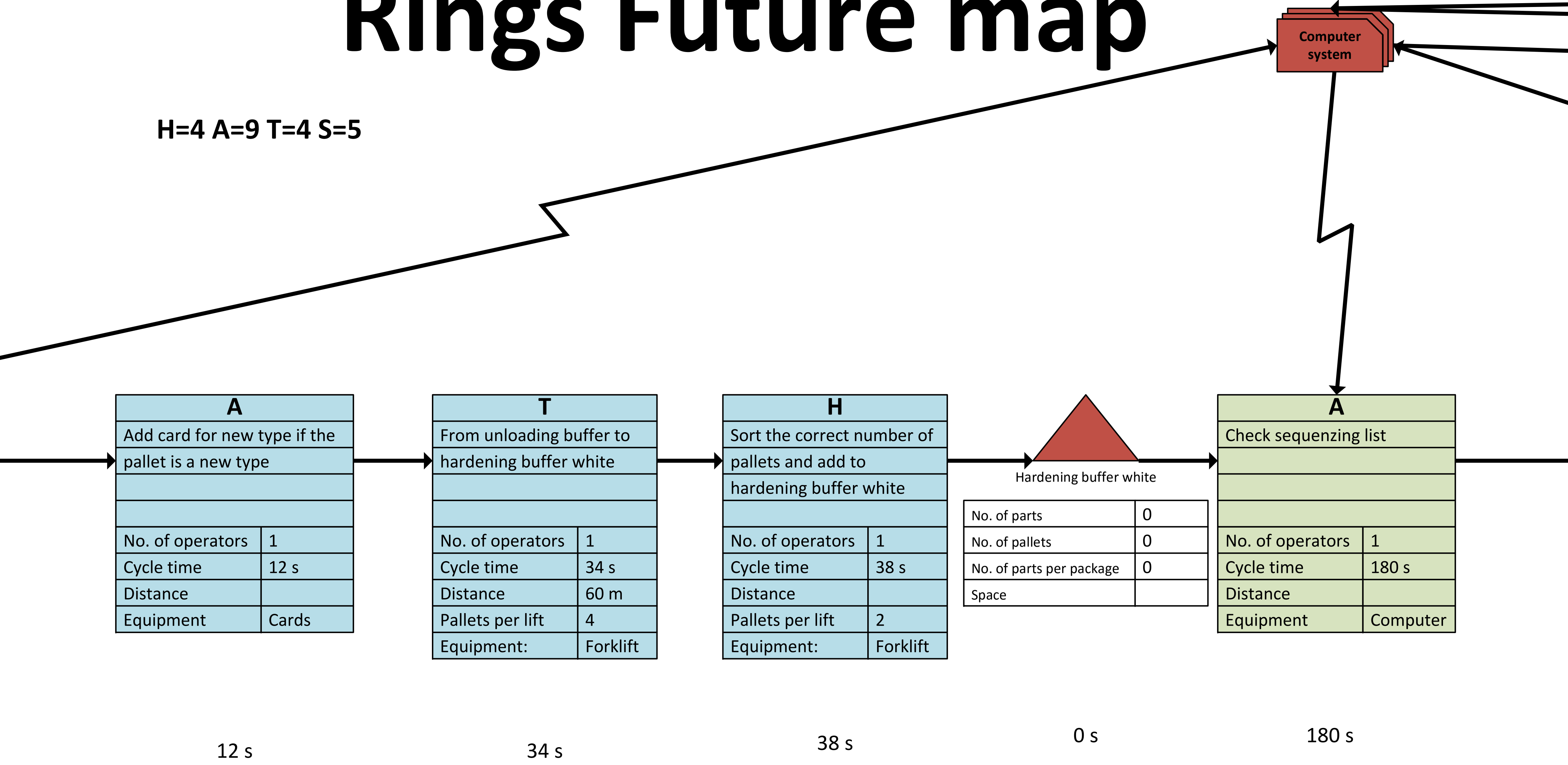

Call of components
A
Goods recipt
No. of operators 1
Cycle time 8 s
Distance
Equipment Scanner
H
Sorting of components
No. of operators 1
Cycle time 35 s
Distance
Pallets per lift
Equipment: Forklift
T
From unloading buffer c to
24h buffer
No. of operators 1
Cycle time 60 s
Distance 112
Pallets per lift 4
Equipment: Forklift
24h buffer
No. of parts 447
No. of pallets
No. of parts per package
Space
A
Consumption
No. of operators 1
Cycle time 6 s
Distance
Equipment Scanner
8 s
35 s
60 s
62372 s
6 s

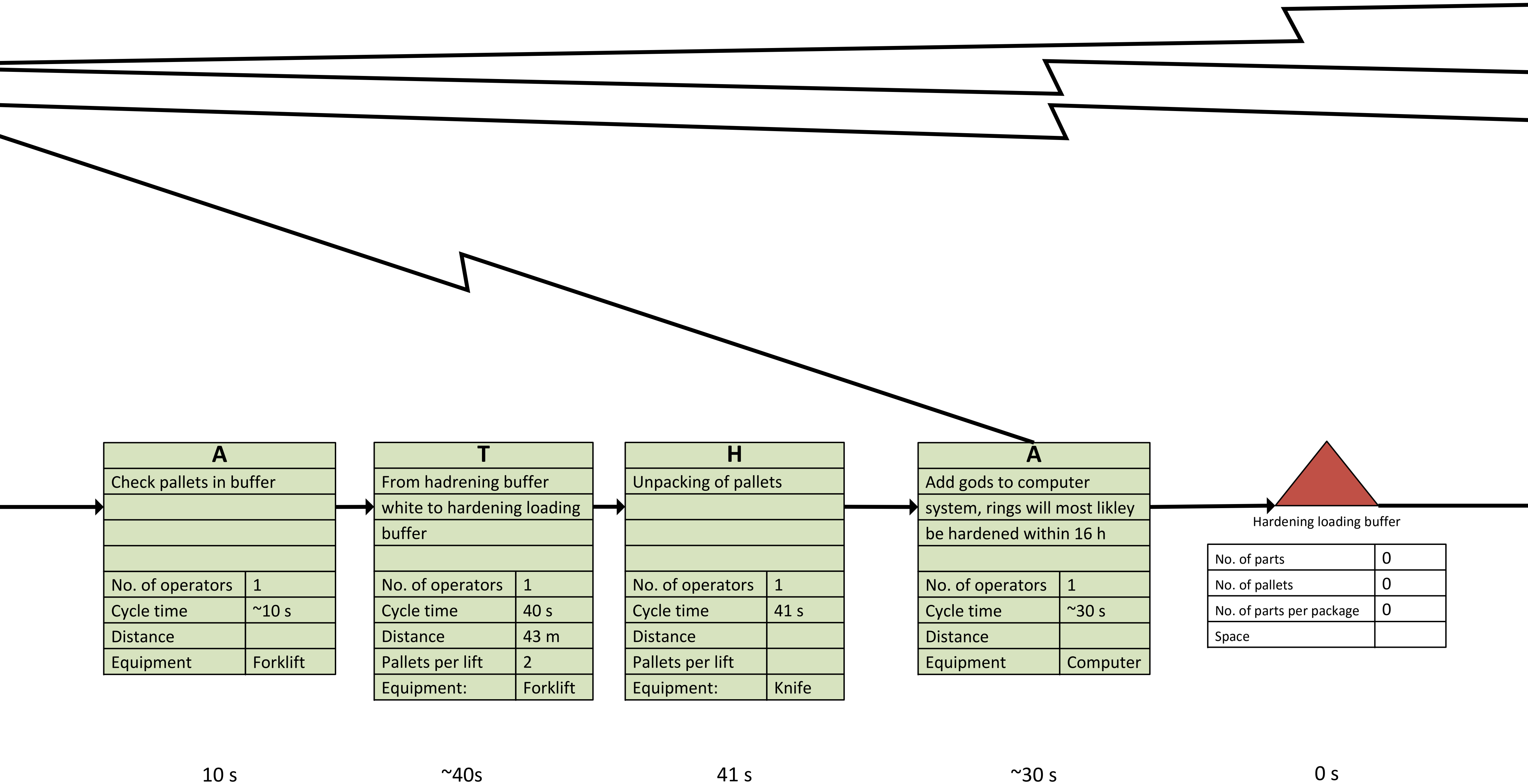

T
From 24h buffer to channel buffer
No. of operators 1
Cycle time 110 s
Distance 295
Pallets per lift 4
Equipment: Forklift
Channel buffer
No. of parts 172
No. of pallets
No. of parts per package
Space
Channel
Demand:2*12,9pcs/h=
25,8pcs/h
110 s
24000 s
87160 s
~24,2 h

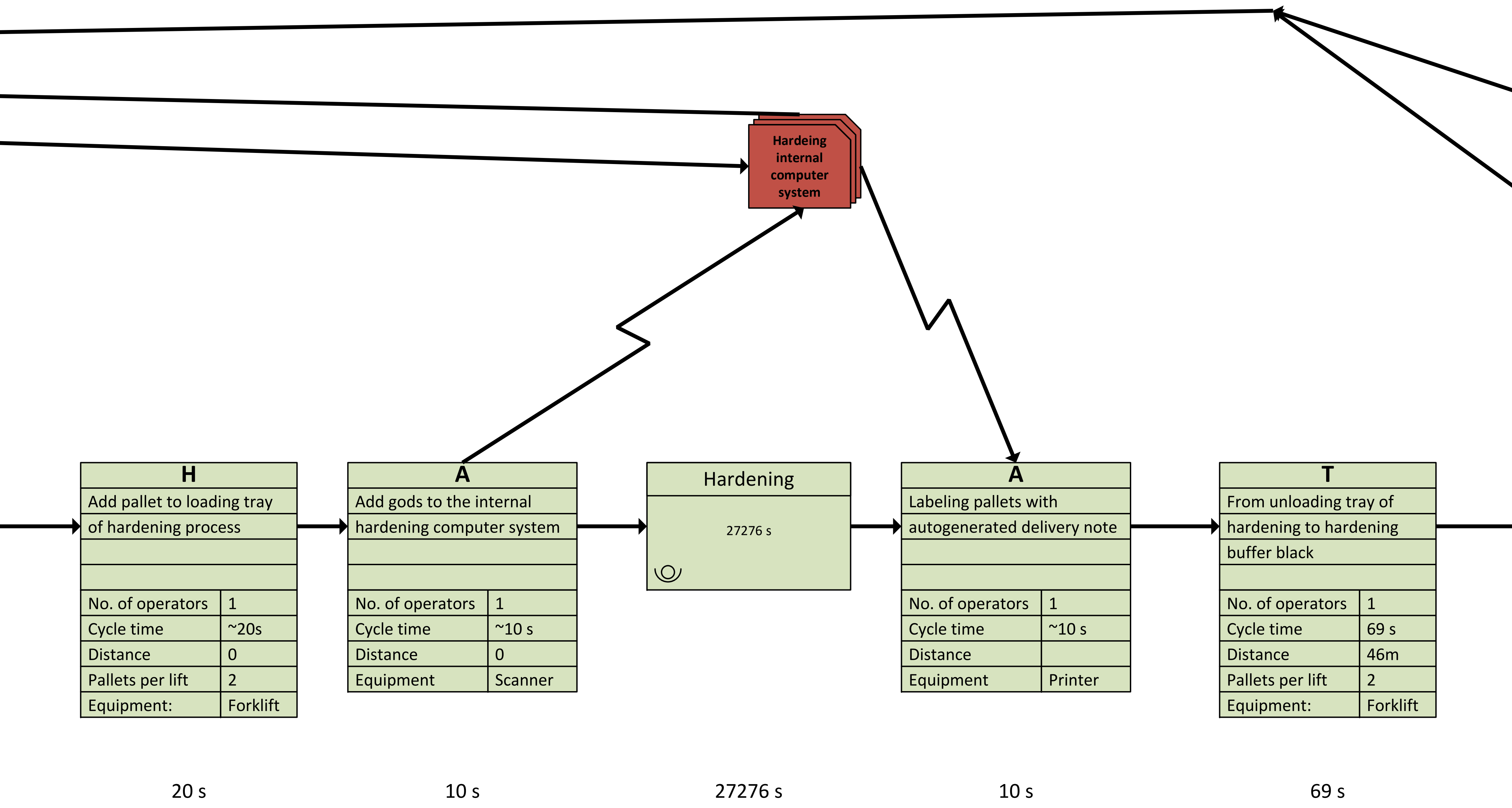
Appendix B.3 Rings


Supply Chain
D1
Hardening
Alert of when each truck arrives (E-mail) – printed by D1
Ordering of raw material and rings
Mail with number of pallets and when the truck will arrive
External supplier
A
Delivery note is recived
from truck driver
No. of operators 1
Cycle time 10 s
Distance
Equipment none
H
Unloading of the truck to
unloading buffer r
No. of operators 1
Cycle time 46 s
Distance 5-20 m
Pallets per lift 4
Equipment: Forklift
Unloading buffer r
No. of parts 0
No. of pallets 0
No. of parts per package 0
Space
A
Gods recipt
No. of operators 1
Cycle time 8 s
Distance 0.6 m
Equipment: Scanner
10 s
46 s
0 s
8 s

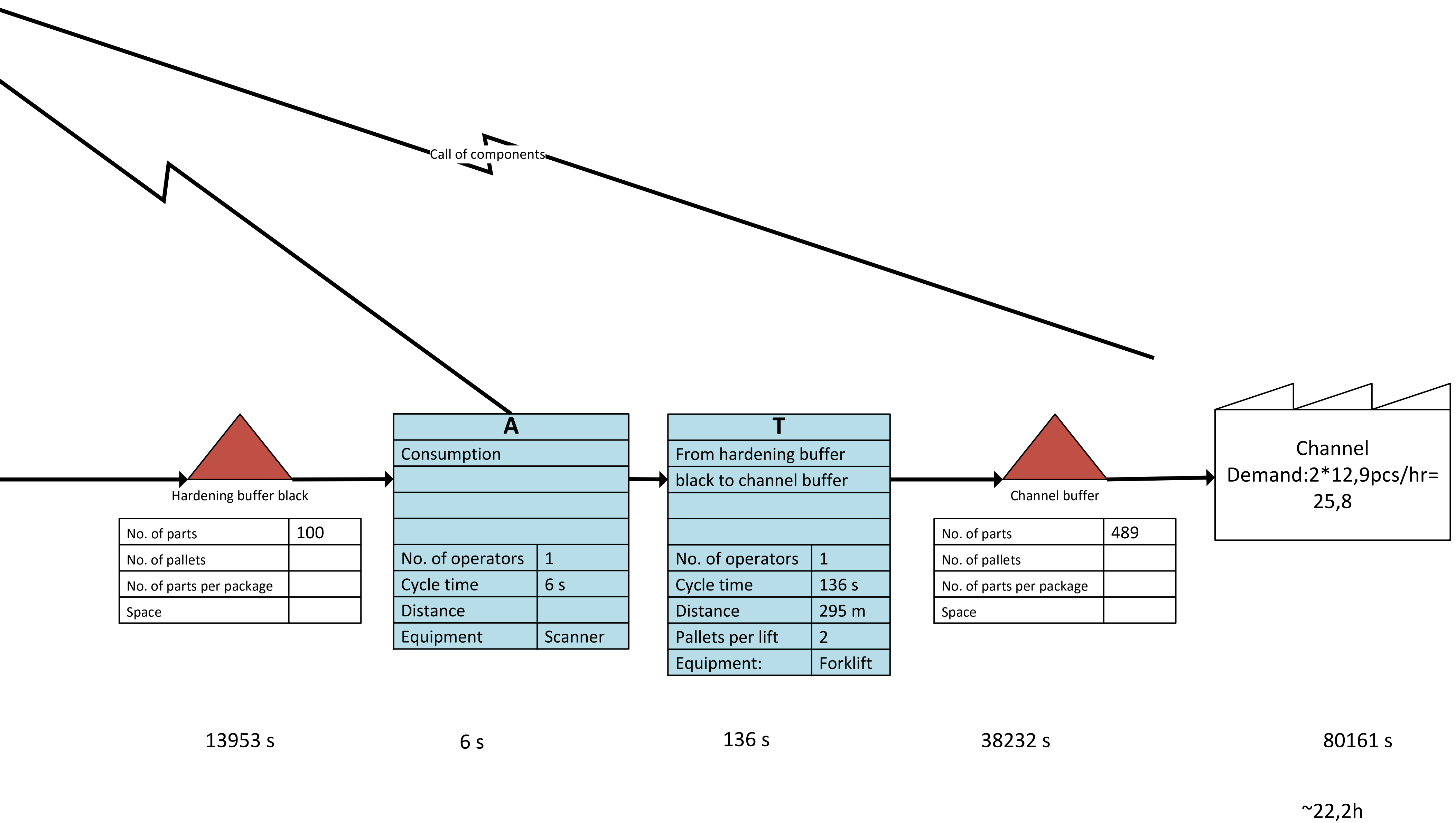
Rings Future map




A
Check pallets in buffer
No. of operators 1
Cycle time ~10 s
Distance
Equipment Forklift
T
From hadrening buffer
white to hardening loading
buffer
No. of operators 1
Cycle time 40 s
Distance 43 m
Pallets per lift 2
Equipment: Forklift
H
Unpacking of pallets
No. of operators 1
Cycle time 41 s
Distance
Pallets per lift
Equipment: Knife
A
Add gods to computer
system, rings will most likley
be hardened within 16 h
No. of operators 1
Cycle time ~30 s
Distance
Equipment Computer
Hardening loading buffer
No. of parts 0
No. of pallets 0
No. of parts per package 0
Space
10 s
~40s
41 s
~30 s
0 s

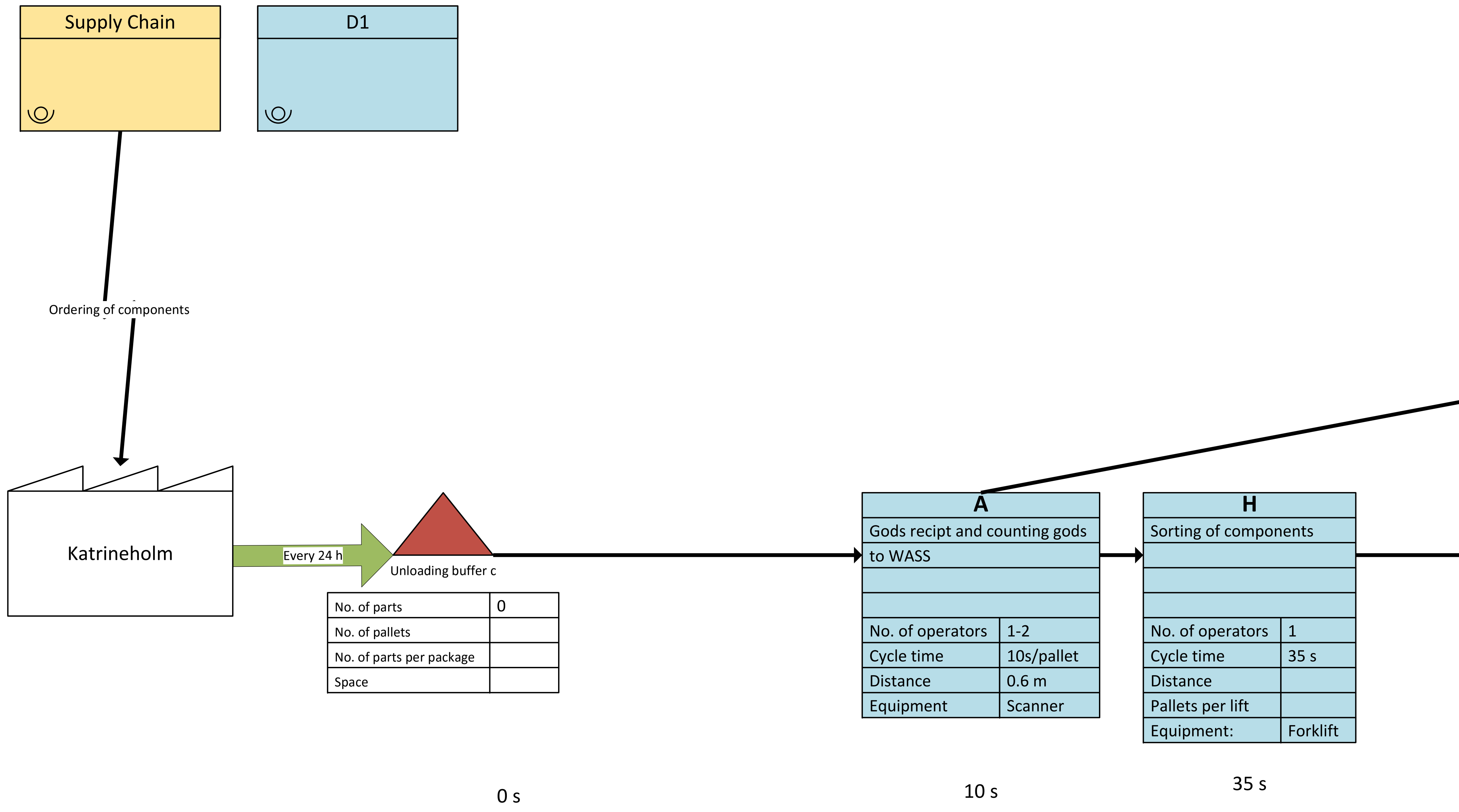


Hardeing internal computer system
H
Add pallet to loading tray of hardening process
No. of operators 1
Cycle time ~20s
Distance 0
Pallets per lift 2
Equipment: Forklift
A
Add gods to the internal hardening computer system
No. of operators 1
Cycle time ~10 s
Distance 0
Equipment Scanner
Hardening
27276 s
A
Labeling pallets with autogenerated delivery note
No. of operators 1
Cycle time ~10 s
Distance
Equipment Printer
T
From unloading tray of hardening to hardening buffer black
No. of operators 1
Cycle time 69 s
Distance 46m
Pallets per lift 2
Equipment: Forklift
20 s
10 s
27276 s
10 s
69 s

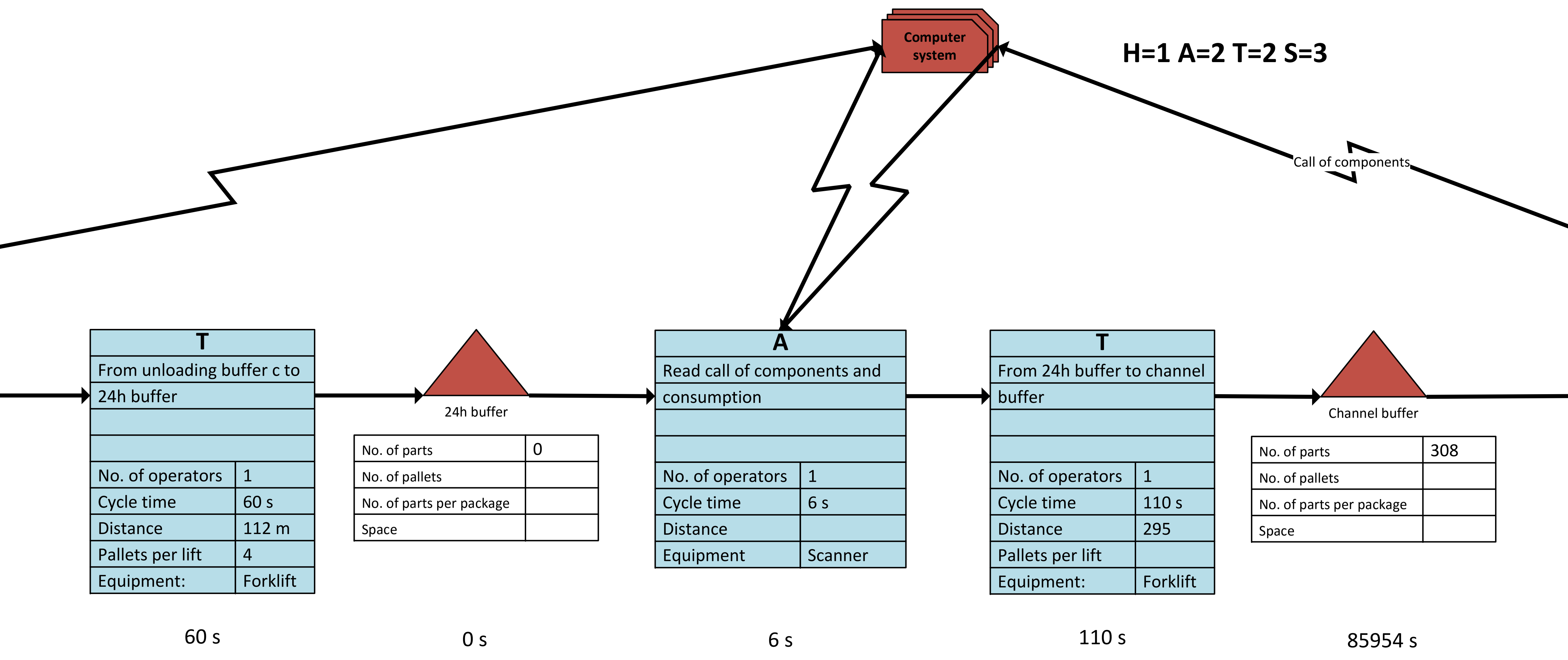


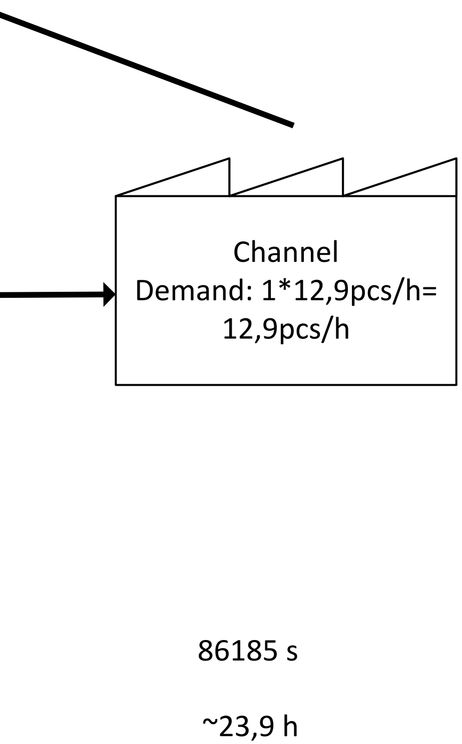
Call of components
Hardening buffer black
No. of parts 100
No. of pallets
No. of parts per package
Space
A
Consumption
No. of operators 1
Cycle time 6 s
Distance
Equipment Scanner
T
From hardening buffer
black to channel buffer
No. of operators 1
Cycle time 136 s
Distance 295 m
Pallets per lift 2
Equipment: Forklift
Channel buffer
No. of parts 489
No. of pallets
No. of parts per package
Space
Channel
Demand:2*12,9pcs/hr=
25,8
13953 s
6 s
136 s
38232 s
80161 s
~22,2h

Appendix B.4 Guide rings 1

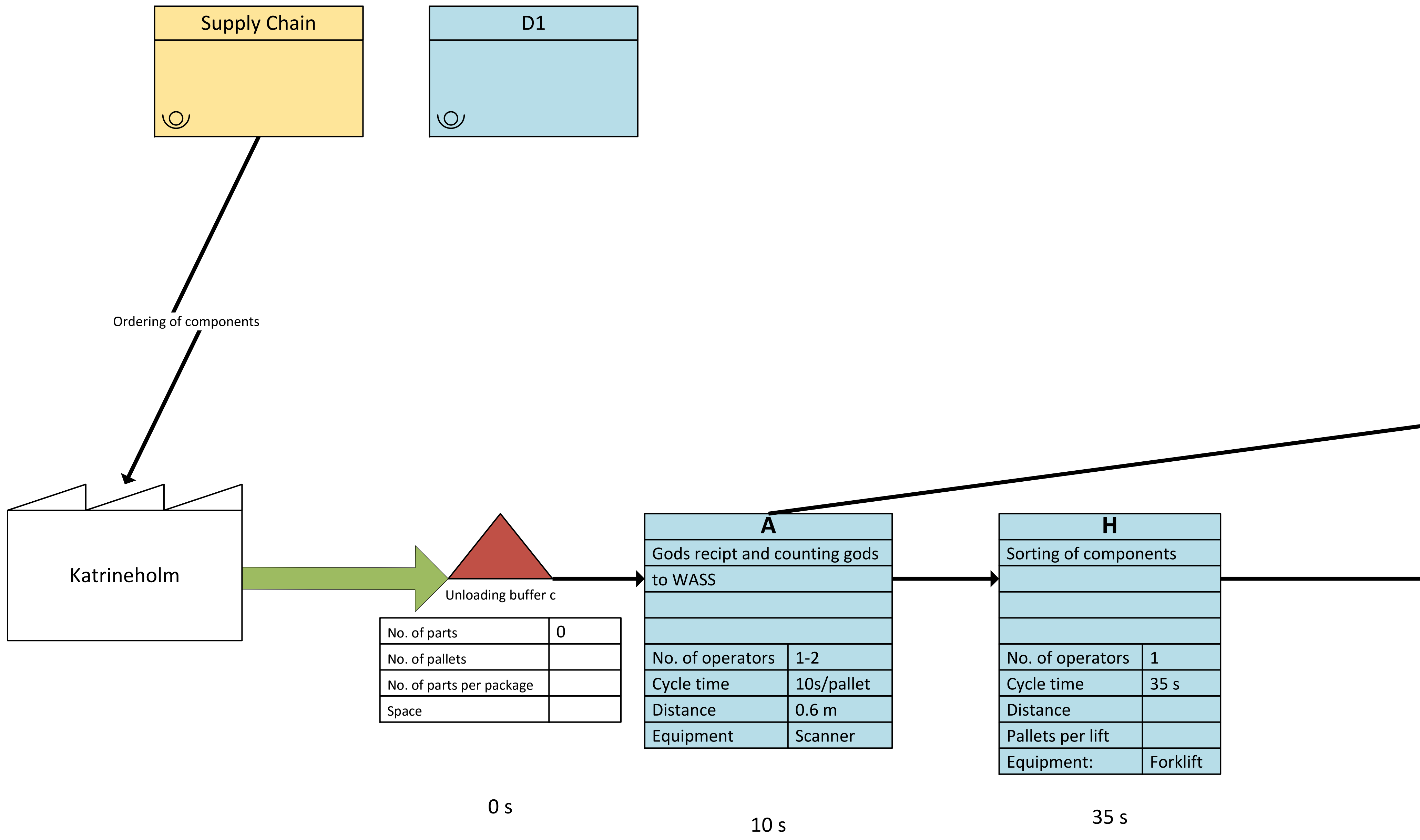

Supply Chain
D1
Ordering of components
Katrineholm
Every 24 h
Unloading buffer c
No. of parts 0
No. of pallets
No. of parts per package
Space
A
Gods recipt and counting gods
to WASS
No. of operators 1-2
Cycle time 10s/pallet
Distance 0.6 m
Equipment Scanner
H
Sorting of components
No. of operators 1
Cycle time 35 s
Distance
Pallets per lift
Equipment: Forklift
0 s
10 s
35 s

Guide rings Future map 1




Channel
Demand: 1*12,9pcs/h=
12,9pcs/h
86185 s
~23,9 h

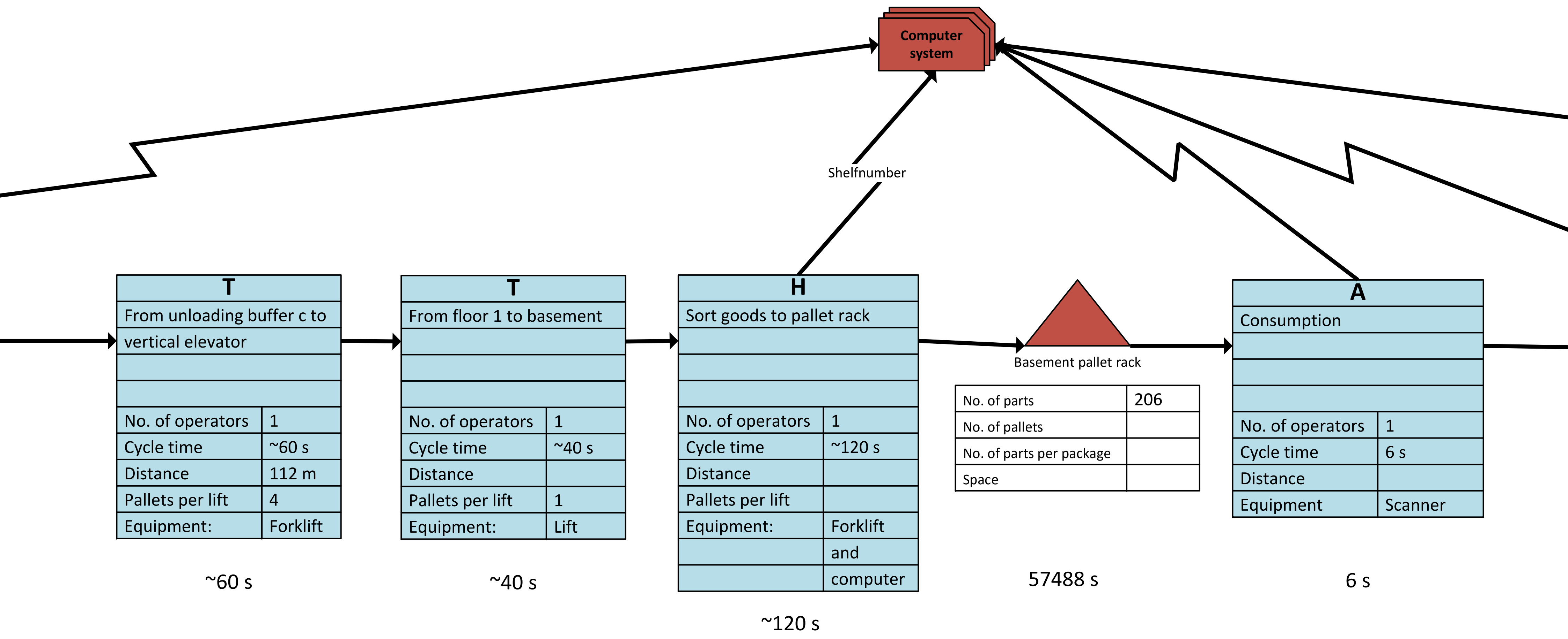
Appendix B.5 Guide rings 2

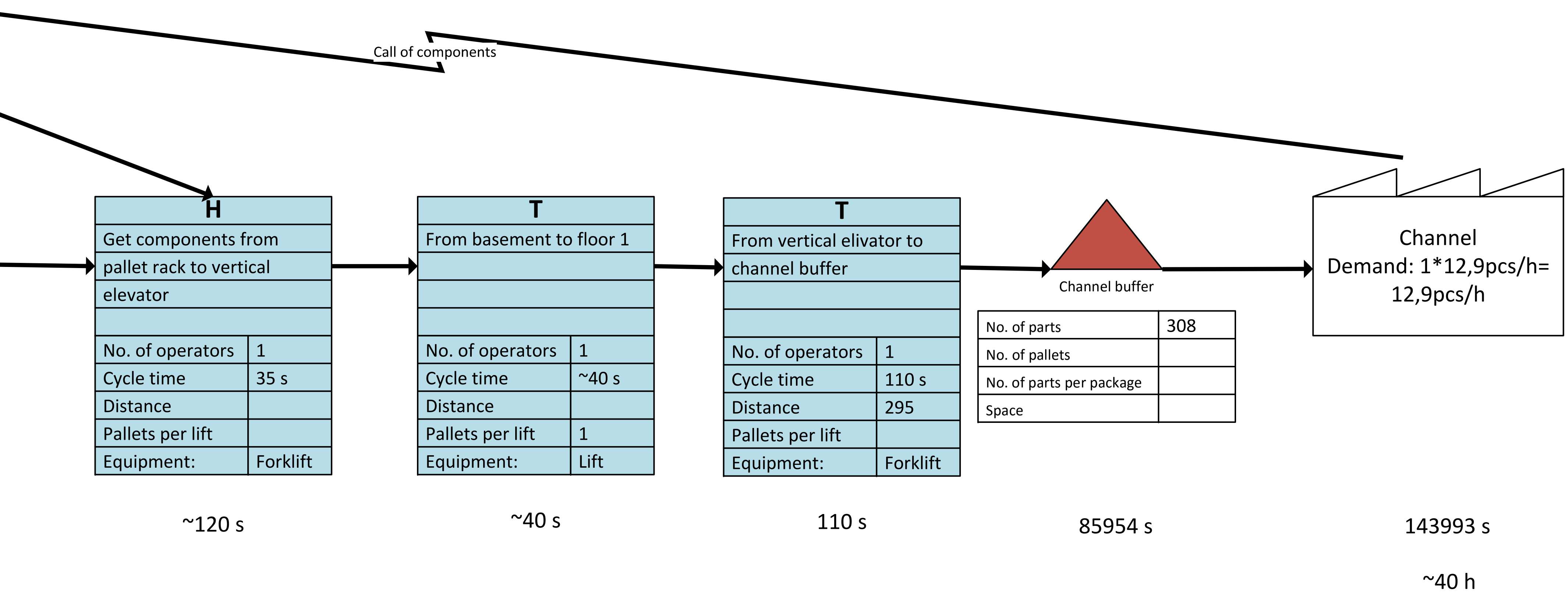


Supply Chain
D1
Ordering of components
Katrineholm
Unloading buffer c
No. of parts 0
No. of pallets
No. of parts per package
Space
A
Gods recipt and counting gods to WASS
No. of operators 1-2
Cycle time 10s/pallet
Distance 0.6 m
Equipment Scanner
H
Sorting of components
No. of operators 1
Cycle time 35 s
Distance
Pallets per lift
Equipment: Forklift
0 s
10 s
35 s

Guide rings Future map 2

H=3 A=2 T=3 S=3




Call of components
H
Get components from pallet rack to vertical elevator
No. of operators 1
Cycle time 35 s
Distance
Pallets per lift
Equipment: Forklift
T
From basement to floor 1
No. of operators 1
Cycle time ~40 s
Distance
Pallets per lift 1
Equipment: Lift
T
From vertical elivator to channel buffer
No. of operators 1
Cycle time 110 s
Distance 295
Pallets per lift
Equipment: Forklift
Channel buffer
No. of parts 308
No. of pallets
No. of parts per package
Space
Channel
Demand: 1*12,9pcs/h=
12,9pcs/h
~120 s
~40 s
110 s
85954 s
143993 s
~40 h