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Physical Internet – readiness of Material Handling Technology

MASTER'S THESIS

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Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources. The text document uploaded to TUGRAZonline is identical to the present master‘s thesis.

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Abstract

The way in which current logistics operates worldwide is not economic, social and environmental sustainable. To address these issues a new term "Physical Internet" was developed by Benoit Montreuil, Eric Ballot and Russell D. Meller.

This master thesis evaluates the readiness of present material handling technology in the Physical Internet systems. For this purpose, first, a literature research about Physical Internet and material handling equipment used in the Physical Internet intralogistics was conducted. Afterwards, an analysis of current situation of logistics was done and an investigation about the material handling equipment used in the present intralogistics was accomplished. To gather first-hand information for the investigation, a survey strategy was selected. The findings were used to evaluate and compare the readiness of present material handling equipment into Physical Internet systems. Finally, KPIs were used to analyze the technological gaps between present equipment and Physical Internet systems.

Kurzfassung

Die Art und Weise, wie die heutige Logistik weltweit funktioniert, ist unwirtschaftlich sowie sozial und ökologisch nicht nachhaltig. Um diese Probleme zu überwinden, wurde von Benoit Montreuil, Eric Ballot und Russell D. Meller ein neuer Begriff "Physical Internet" entwickelt.

Diese Masterarbeit bewertet die Einsatzbereitschaft der aktuellen Fördertechnik hinsichtlich deren Verwendung im System des Physical Internets. Zu diesem Zweck wird zunächst eine Literaturrecherche über das Physical Internet, dessen Prozessen in der Intralogistik und der dabei verwendeten Flurfördertechnologien durchgeführt. Anschließend folgen eine Analyse zum Stand der Technik der Logistik und eine Untersuchung hinsichtlich der aktuellen Abläufe sowie der zum Einsatz kommenden Logistiksystemen. Um Informationen aus erster Hand für die Untersuchung zu sammeln, wird eine Umfrage mit Hilfe eines Fragenbogens umgesetzt. Die Ergebnisse werden genutzt, um die Einsatzbereitschaft der vorhandenen Flurfördertechnik in Physical Internet Systemen zu bewerten und zu vergleichen. Abschließend werden an Hand von bestimmten KPIs die technologischen Unterschiede zwischen vorhandener Ausrüstung und Physical Internet-Systemen analysiert.

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1 Introduction

Today's world can be represented as an extensive hyper connected logistics network. Countless products and packages are moved around the globe, reaching their destinations within days. The raising of services like E-commerce and the growing demands of customers for a faster delivery are two of the main characteristics thriving the domain of logistics. Keeping the principles that founded it (movement of objects) but developing very complex infrastructures and equipment capable of covering great distances in very short periods of time, which has led to a scenario, where economic, environmental and social aspects are unsustainable. This means, the way logistics handles, stores, transport and supplies need a major transformation to make it sustainable. [BMM14]

To overcome this situation, a new concept "Physical Internet (PI)", was first introduced by Benoit Montreuil, Georgia Institute of Technology, USA and then developed together with Russell D. Meller, University of Arkansas, USA and Eric Ballot, Mines Paris Tech, France.

Physical Internet (PI) is a global logistics system based on the interconnection of logistics networks by a standardized set of collaboration protocols, modular containers and smart interfaces for increased efficiency and sustainability. The network of networks. [BMM14]

PI is a wide topic with numerous research fields, the scope of this master thesis is the identification of PI Material handling equipment and the identification and readiness of present material handling technologies in PI Systems.

1.1 Motivation

The rapid technological development of the world is changing the way logistics operates, and therefore, significant opportunities of growth and innovation are emerging. As mentioned before, new business lines like E-commerce are bringing new challenges that logistics companies need to be overcome to be successful.

Logistics sector is facing higher customer expectations because of Digitalization and the rise of quicker delivery services. All these factors have put the spotlight on the necessity for changing not only economic but social and environmental aspects.

PI appears as a great solution to meet the new challenges. It has brought a new insight into sustainable logistics, aiming for reasonable transporting of goods, in which the environment, the society and the economy are in balance with each other.

Brand new technologies will be presented and developed in order to meet the PI sustainability principles. And this leads to the main focus of the present thesis: does the current equipment for material handling have a place in the future PI Systems?

This question summarizes the author's main interest for writing the present master thesis, the readiness of material handling systems in PI.

1.2 Objectives

The goal of this master thesis is to analyze and evaluate present equipment for material handling and its readiness in the PI. This comparison and evaluation open new possibilities of integrating current material handling systems in the PI technologies.

The focus is on identification of material handling systems used inside of the hubs within the supply chain network, identification of main attributes of key elements of PI and finding technological gaps between present equipment for material handling and PI Systems.

In order to support and achieve the goals described above, three research questions have been developed:

RQ1: What are the material handling processes and the corresponding material handling systems within the present hubs?

RQ2: What are the PI Hub main elements and their characteristics regarding material handling processes?

RQ3: What are the technological gaps between the current material handling systems and the potential systems for PI?

1.3 Structure of the thesis

This master thesis is structured as it is shown in Figure 1-1.

Chapter 1 introduces the topic and the motivation, presents the goals to achieve regarding the research questions and provides an overview of the master thesis structure.

Chapter 2 exposes the problem analysis. The background section contains information about the status of current logistics regarding social, economic and environmental aspects and introduces the description of PI. It also includes the definition of terms, a PI Hub introduction, the system boundary definition essential to simplify the work and set up the boundary, the distribution reference center model and an overview of the PI Hub processes.

Chapter 3 contains the design and development of the research strategy and the methods used for collecting information from logistics companies. The KPIs and the modelling process is also presented.

Chapter 4 shows a PI literature study, the results obtained through the conducted research methods (questionnaires), and presents an investigation about current existing technologies for material handling that were not covered by the questionnaires.

Chapter 5 evaluates and compares the results obtained in the previous chapter and summarizes the outcome of the research.

Chapter 6 closes the thesis with conclusions and recommendations for future research.

Chapters 7 and 8 are for bibliography, listings of figures, tables and graphs respectively.

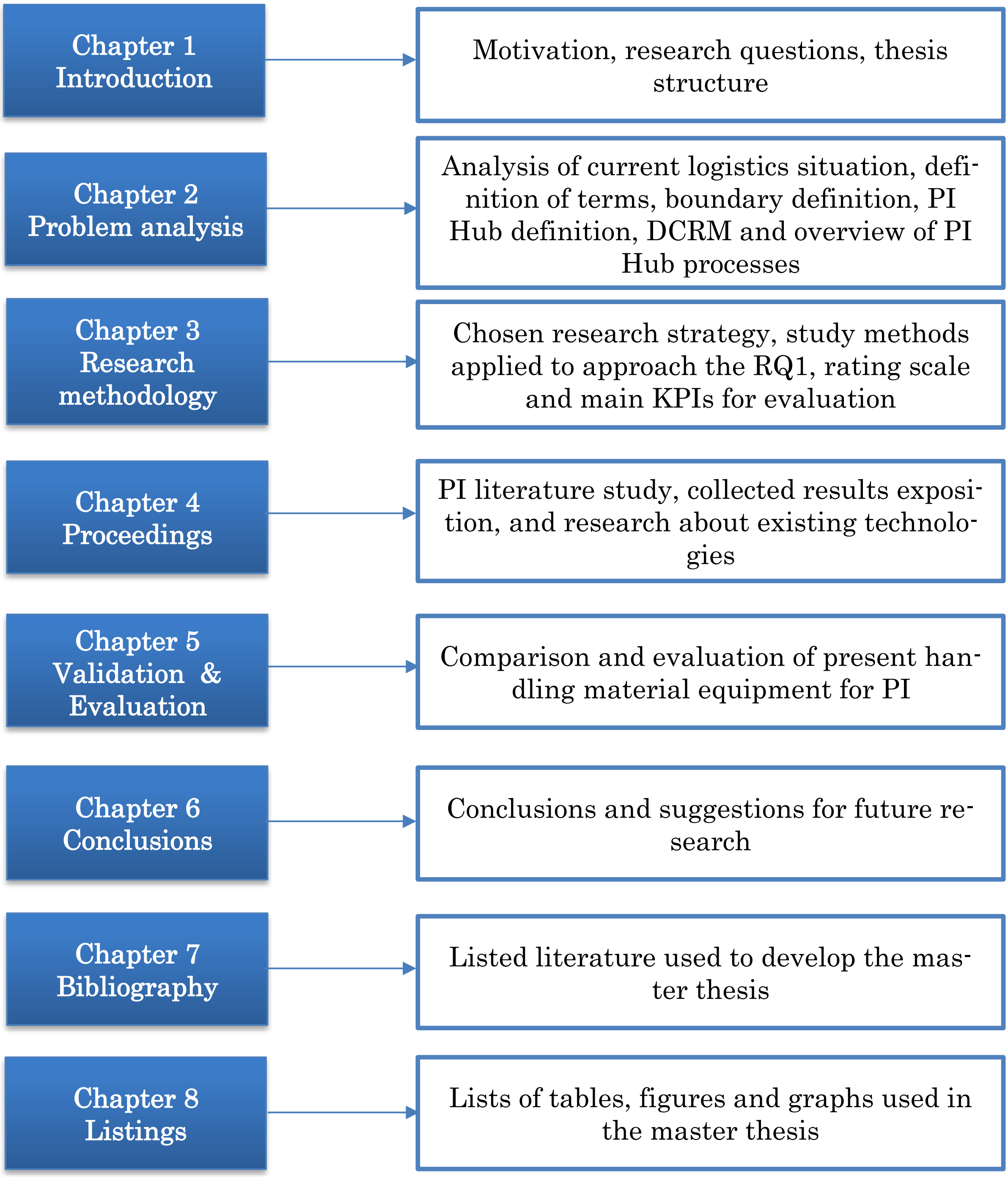


Figure 1-1: Structure of the thesis

2 Problem Analysis

This chapter introduces the background of the current logistics to support the idea behind the unsustainability of present logistics way of operating and thinking. Following what is presented, the definition of terms used in the thesis is given, and a PI Hub overview. The last part of this chapter, concludes with an overview of the boundary system, which serves for a better identification of the investigated problem.

2.1 Background

Before diving deeper in the topic, it's necessary to set up some preambles about the current logistics situation and its development in recent times. In this way, a general outline is provided to help to understand and clarify the problem this master thesis is covering.

Logistics industry has entered in a new expansion era, the raising of new manufacturing techniques like "Just-in-time" enables production activities to be disseminated around the world ending up with lower costs and higher benefits. As a direct consequence, logistics companies must invest in new technologies, ways of transportation and faster delivery services to meet customer's expectations, accomplishing outstanding results in various areas. [TK16]

Forecasts predict that the number of parcels delivered will experiment a quick grow in the upcoming years, nowadays, it is possible to purchase a product in Portugal and receive it in Austria within a day. As it can be seen in Figure 2-1, new business models like E-commerce delivery next day play a significant role in this trend growth. [TK16]

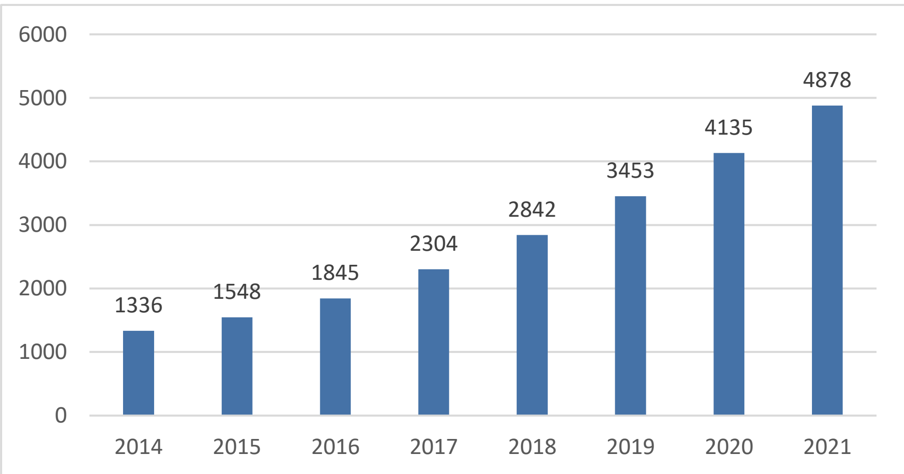


Figure 2-1: E-commerce sales worldwide from 2014 to 2021 (billion $) [STA19]

This growth has turned logistics into a very complex field, in part due to the strong dependency of production industry on logistics and transportation systems. This situation is double-edged in terms of sustainability. For instance, a high number of orders leads to the need of faster transportation, therefore, the transportation costs rise due to the fuel price. The same occurs with the greenhouse emissions which are directly linked to the use of means of transport, together with fuel costs, the ecological footprint of logistics companies has reached high levels. [MON11]

As shown in figure 2-2, freight road transportation represents the highest percentage of greenhouse emissions in the European Union.

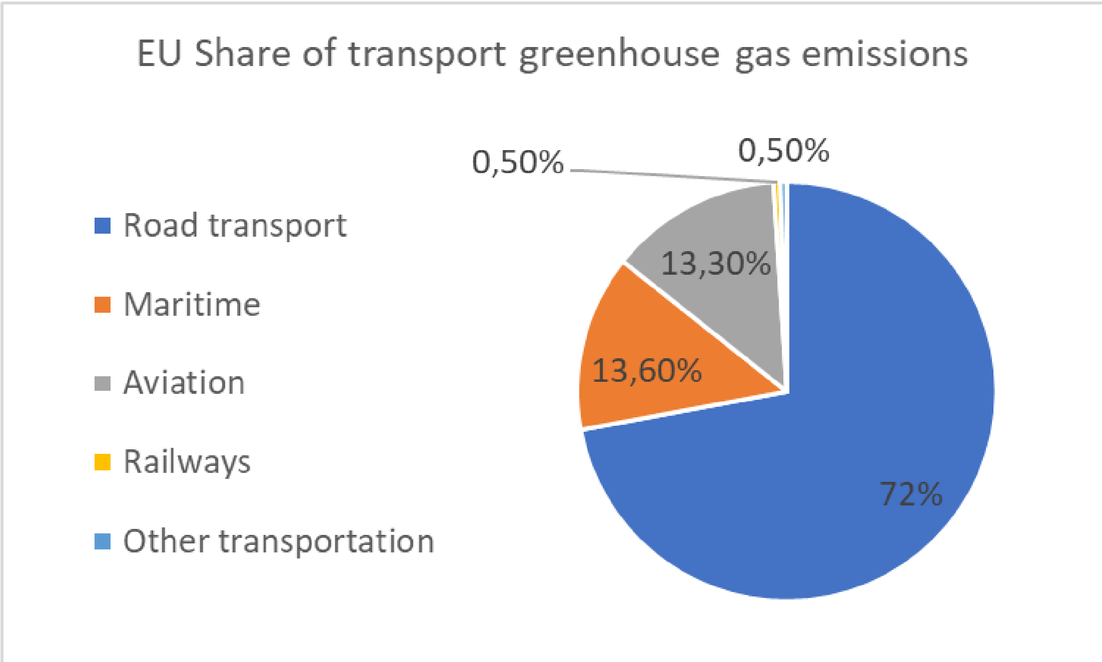


Figure 2-2: Share of transport greenhouse gas emissions [EEA19]

Moving goods has become an extremely expensive activity. Besides the increasing price of fuel, it occurs very often that the means of transport mainly transport air due to wrong packaging design, what is more, empty travels have become the norm rather than the exception. This leads to a wrong or inefficient use of logistics facilities together with high packaging material wastage. [MON11]

Economic and environmental inefficiencies are not the only challenges that logistics is facing. Social aspects experience a negative impact as well, regarding freight transportation, truck drivers have become the modern cowboys, spending long time in the road, as a result, their family life and social life, as well as, their personal health have suffered an important decrease. As a significant indicator, US National Transportation Safety Board study found that 58 % of the accidents reported by drivers were deemed to be fatigue and sleep deprivation related. [MON11]

All these factors have led to the development of the 13 symptoms of Unsustainability presented by Benoit Montreuil as shown in Figure 2-3.

	Unsustainability symptoms	Economical	Environmental	Societal
1	We are shipping air and packaging	●	●	
2	Empty travel is the norm rather than the exception	●	●	
3	Truckers have become the modern cowboys	●		●
4	Products mostly sit idle, stored where unneeded, yet so often unavailable fast where needed	●		●
5	Production and storage facilities are poorly used	●	●	
6	So many products are never sold, never used	●	●	●
7	Products do not reach those who need them the most	●		●
8	Products unnecessarily move, crisscrossing the world	●	●	
9	Fast & reliable intermodal transport is still a dream or a joke	●	●	●
10	Getting products in and out of cities is a nightmare	●	●	●
11	Networks are neither secure nor robust	●		●
12	Smart automation & technology are hard to justify	●		●
13	Innovation is strangled	●	●	●

Figure 2-3: Unsustainability symptoms [BMM14]

As a response to these symptoms and the limitations of current logistics system, a new model for an open global logistics system was developed. This model is based on universal interconnection of logistics services, meaning the creation of a logistics "network of networks" called Physical Internet. [BMM14]

The main idea behind the term PI is the interconnection of networks, which turns into a network of networks. This proposal is based on the Digital Internet, mainly its way of creating an interconnection of IT networks by standardizing the connections, using an addressing system and an intermediate protocol layer (TCP/IP). [BMM14]

The similarities between the Digital Internet and the PI are relevant but not absolute. Because, the information transfer protocols cannot be directly transferred to goods. [BMM14]

The main components for the fulfillment of PI are [BMM14]:

- Range of standardized containers (PI Containers)
- Open and secure information infrastructure
- Suitable handling tools

- New economic models
- New operational processes
- Suitable regulatory and legal frameworks

The PI definition not only shows the different elements in logistics operations, but also opens a new way for breaks from the current organization of logistics. [BMM14]. The major differences between the PI and the present logistics can be appreciated in Table 2-1.

Table 2-1: Major differentiating aspects between PI and present logistics [BMM14]

Function	Physical Internet	Present Logistics
Shipping	Containers	Goods
Network	Network of open and shared networks	Specific services
Trip	Dynamic routing	Logistics services
Information System	Internet of Things Platform of services on the cloud	Proprietary
Standard	Market movement to agreement on interfaces, identification and protocols	Proliferation of standards
Storage	Deployment logic	Time-intensive (centralized)
Capacity Management	Market based	Private

2.2 Definition of Terms

In this section, the main terminology and its definitions are presented. To reach a better understanding of the terms and the context in which they are used, clarifications have been added below the existing definitions. Some descriptions were already precise and suitable for the thesis context, so no clarifications are needed.

- **Buffer areas**

  Buffer areas are temporary storage for products. It is this short time storage that distinguishes it from final storage rooms. [INT19]

  *Note: In this master thesis, buffer areas refer to zones in which goods or PI-containers are stored for a short period of time between inner operations in the hub, in case the next process is not ready.

- **Conveyor**

  A conveyor is a technical equipment that transports materials, products and loads from one position to another. They enable large volumes of material to move rapidly within a facility and reduce labor costs by eliminating travel time. [MHI19a]

  *Note: In this master thesis, a conveyor moves goods from one place to another one.

- **Hub**

  Hub is a logistics center in charge of transferring freight from one logistics facility to another. [BMM14]

  *Note: In this master thesis, a hub refers to any logistics facilities, regarding goods distribution such as depots, terminals, service center, urban hubs, distribution center etc

- **Identification system**

  An identification system is used for product recognition. Establishes a distinct code for each tracked item. They contain the basic information about the items.

There are many different identification systems: barcodes, RFID, NFC chips. [ITA19]

*Note: In this master thesis, identification system refers to identification of goods by using tags and reading devices. The tags contain data about the goods.

- **MHE**

  Acronym for material handling equipment

- **PI**

  Acronym for Physical Internet

- **Physical Internet**

  Global logistics system based on the interconnection of logistics networks by a standardized set of collaboration protocols, modular containers and smart interfaces for increased efficiency and sustainability. [BMM14]

- **PI Composite**

  PI Composite is a unit load of interlocked PI Containers. [MMB10]

- **PI Container**

  PI container is a modular box containing goods that is manipulated, stored and routed through the systems and infrastructures of the PI Container main characteristics are the following ones [BMM14]:

  - Unique international identification to ensure traceability
  - Standardized size
  - Possibility of locking between containers
  - Physical protection of the content
  - Standardized mechanical strength which enables them to be stacked and handled

- **PI Hub**

  PI Hub is a PI node having for mission to enable the transfer of PI containers from incoming PI movers to outgoing PI movers. PI Hubs enable unimodal PI Container crossdocking operations. [MMB10]

  *Note: In this master thesis, a PI Hub groups all the kinds of logistics facilities handling PI Containers and PI Composites in PI.

- **PI Mover**

  PI Mover is equipment used for transporting, conveying, handling, lifting and manipulating PI Containers. The main types of PI Movers include: PI Transporters, PI Conveyors and PI Handlers. [MMB10]

- **PI Node**

  PI Node is a location exclusively designed to perform operations on PI Containers like receiving, testing, moving, sorting handling, storing, picking, monitoring shipping etc. [MMB10]

- **Planning Software**

  Planning software is a program or system that integrates the information, transportation, inventory, warehousing, material-handling and packaging and sometimes security activities of logistics facilities. [GLO19a]

  *Note: In this master thesis, a Planning software refers to a system for tasks related to inner logistics management, like route planning, moving goods, storage.

- **RFID**

  RFID (radio frequency identification) is a technology whereby digital data encoded in RFID tags or smart labels are captured by a reader via radio waves. It has three main components: RFID tags, RFID read and RFID antenna. [ABR19]

- **Sorter**

  Sorter is a system which carries sortation of goods according to their destinations. They are unique types of conveyors. [WIK19a]

  *Note: In this master thesis, a sorter is a material handling system which sorts goods in the logistics hub.

- **Store**

  A store is a service unit where goods are stored during a certain period of time. There are many kinds of stores depending on their purpose. [LOG19a]

  *Note: In this master thesis, a store saves goods for short and long periods of time between processes in the inside of hubs.

- **Unit load**

  A unit load is either a single unit of an item, or multiple units so arranged or restricted that they can be handled as a single unit and maintain their integrity. [BMM14]

- **Warehouse management system**

  A warehouse management system is a software and processes that allow organizations to control and administer warehouse operations from the time goods or materials enter a warehouse until they move out. [SEA19]

2.3 Physical Internet Hubs

As mentioned in Chapter 2.2, a PI Hub is the routing center of PI and it will be present during different phases of the supply chain network. The main goal of the PI Hubs is to conduct shipments of sizes appropriate to the demand more directly to customers, in order to limit the storage. The efficacy of PI Hubs is higher than the hubs in the classic supply chain as it can be seen in the Figure 2-4, in which the Y-axes represent the speed of the routes. This speed varies depending on the means of transport used. [BMM14]

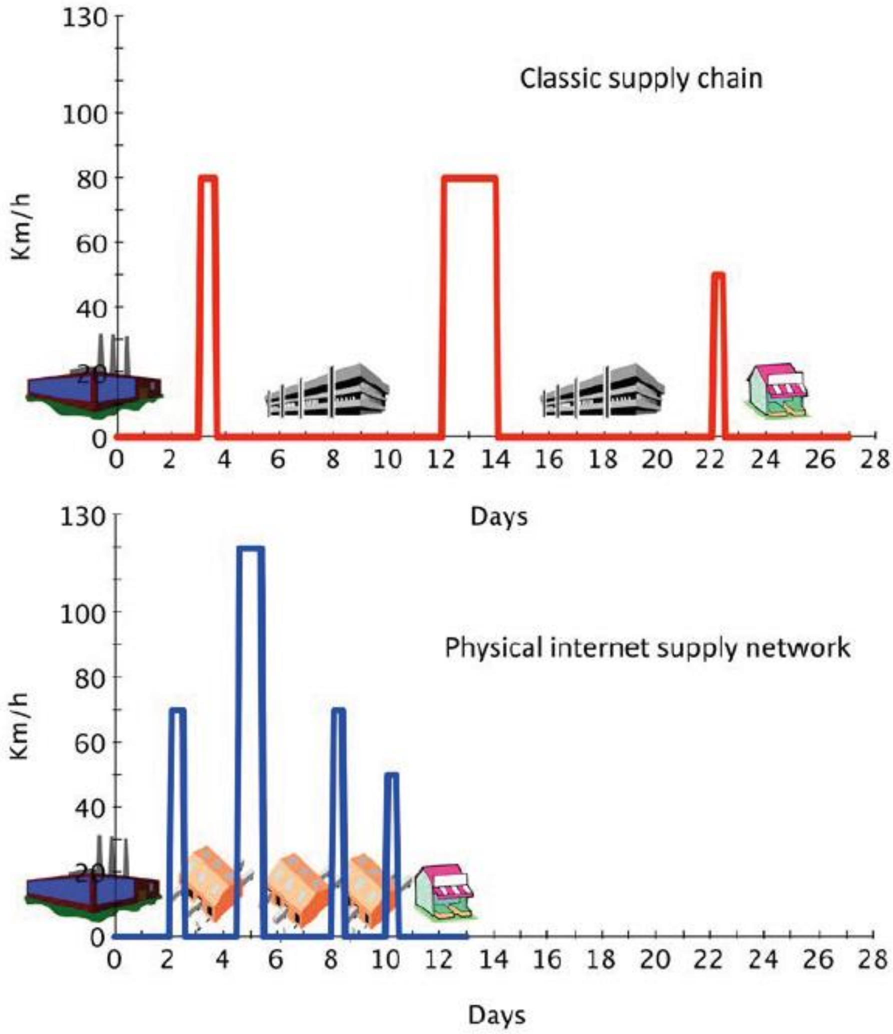


Figure 2-4: Acceleration of flows sought by the Physical Internet [BMM14]

2.3.1 Different types of PI Hubs

PI Hubs are designed in different dimensions depending on the size of the PI Containers accepted. There are three types of Hubs [BMM14]:

- **Hub size S**: handles small PI Containers or boxes.
- **Hub size M**: handles PI Containers of around 1 m^3
- **Hub size L**: handles PI Container of cross-section compatible with heavy means of transportation

On Urban environments, the majority of the PI Hubs would be handling S small PI Containers, however, in case of maritime usage, rail or waterway corridors, the PI Hub will have big dimensions since it will be handling PI Containers in the largest category. [BMM14]

It is possible to observe in Figure 2-5 that there would be 22 types of unimodal and bimodal hubs, without adding the extra differences connected to the scale of the traffic that would affect the design or the various possible technologies. Tri-modal hubs are also feasible for construction. [BMM14]

Hub types	Ship	Train	Barge	Aircraft	Truck	Light vehicle	Manual*
Ship	L: ✓ M: S:	L: ✓ M: S:	L: ✓ M: S:	Ø	L: ✓ M: ✓ S:	Ø	Ø
Train		L: ✓ M: S:	L: ✓ M: S:	L: ✓ M: ✓ S:	L: ✓ M: ✓ S:	L: ✓ M: ✓ S:	Ø
Barge			L: ✓ M: S:	Ø	L: ✓ M: ✓ S:	L: ✓ M: ✓ S:	Ø
Aircraft				L: M: ✓ S: ✓	L: M: ✓ S: ✓	L: M: ✓ S: ✓	L: M: S: ✓
Truck					L: ✓ M: ✓ S: ✓	L: ✓ M: ✓ S: ✓	L: ✓ M: ✓ S: ✓
Light vehicle						L: ✓ M: ✓ S: ✓	L: M: ✓ S: ✓
Manual*							L: M: S: ✓

Figure 2-5: Types of hub between modes and according of the size categories [BMM14]

Multimodal platforms already exist, they are designed to transfer present large containers between road and rails. However, these platforms have been designed according to the constraints of the rail mode and not the goods flow. [BMM14]

PI has adopted multimodal platforms and it proposes new hub concepts, which are made out of a combination of the different elements presented in Figure 2-5. For instance, hubs using train and road vehicles (trucks and light vehicles) or water transport (ships, barges) and road vehicles (trucks, light vehicles). These hubs are explained in detail in the sections 2.3.2 and 2.3.3 of this Chapter to give an example for a possible lay out of a future PI Hub.

2.3.2 Road/rail hub

A road/rail PI Hub is organized around a single track and splitting the PI Hub's operations into four functional zones. In this way, a train is handled sequentially with at least one unloading movement and then loading sequence or several linked sequences, each handling just a fraction of the train. [BMM14]

Figure 2-6 shows a model of a road/rail hub which is organized around a bimodal road/rail zone, a bimodal rail/road zone, a unimodal post-rail zone and a unimodal pre-rail zone. The last two zones are designed for implementing container rail transfers. The bimodal and unimodal zones are distributed on the side of the rail track. [BMM14]

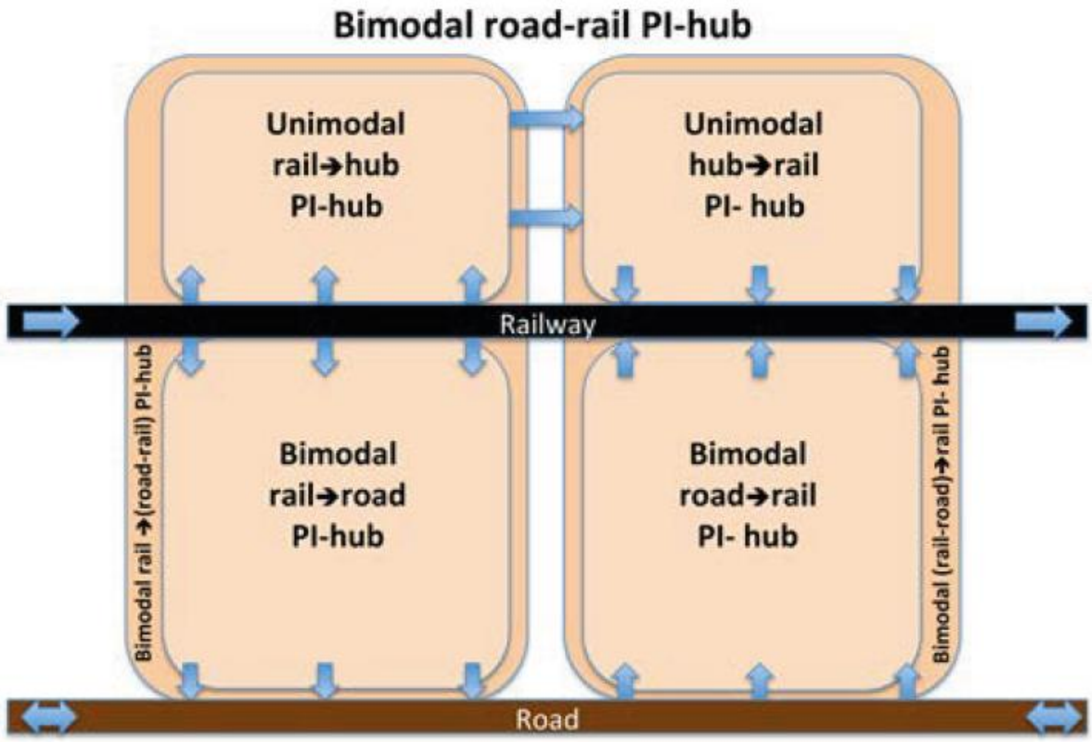


Figure 2-6: Simplified conceptual model of a road/rail PI Hub [BMM14]

An overview of the material flow in a road/rail PI Hub is shown in Figure 2-7.

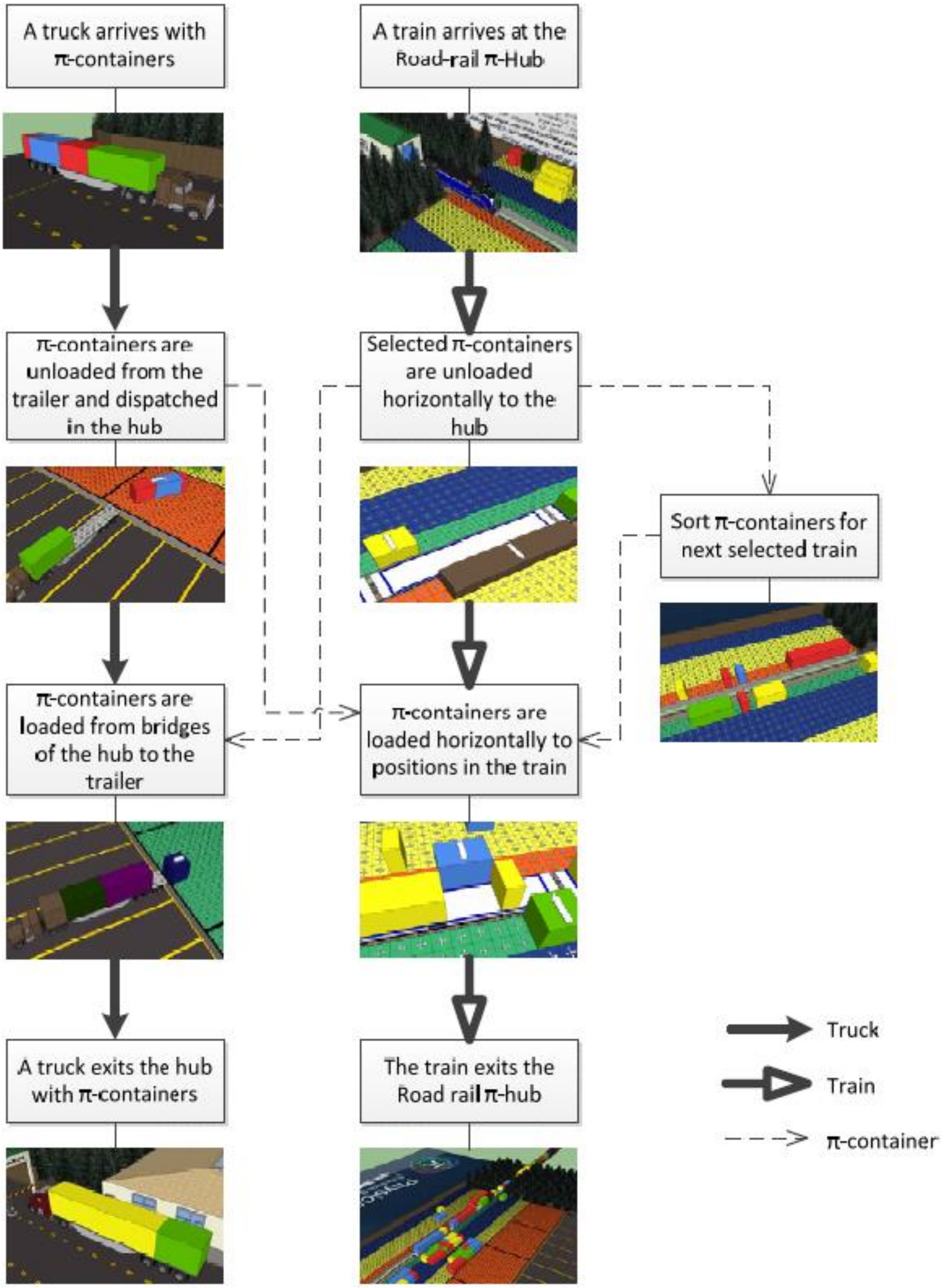


Figure 2-7: Overview of the flow of trucks, trains and π-containers in the road/rail PI Hub [BMT12]

2.3.3 Water/road hub

Similar to what it was exposed about the road/rail hubs, it is a water/road hub for maritime freight transport. They may differ in the size of the PI Containers handled within the hub, for example they may handle only larger PI Containers having a width and a height of 2.4m, with lengths of 1.2m, 2.4m, 3.6m, 4.8m, 6m and 12m. An example of water/road hub is shown in Figure 2-8. [MMB10]

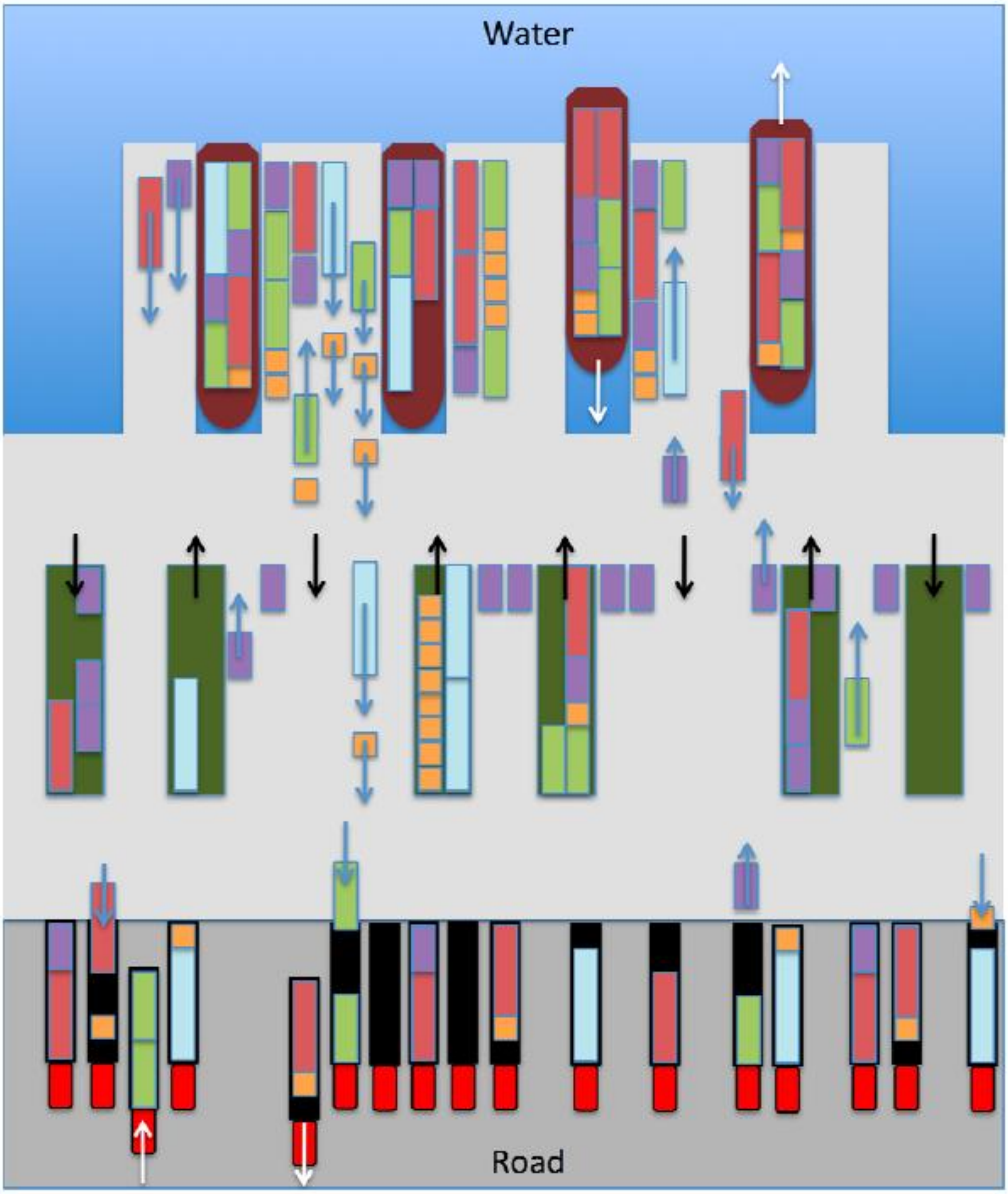


Figure 2-8: Water/road PI Hub [MMB10]

2.4 System boundary outlining

To get a more precise insight of the focus of this master thesis, it is necessary to set up the boundary system of the research.

As it was mentioned in Chapter 1.2, the object of investigation is the material handling equipment used for inner processes inside of the hubs. PI Hubs will be the routing centers of PI, therefore, they will be present in the different phases of the logistics network.

For this reason, the term "hub", which was described in Chapter 2.2, has been chosen as the boundary system. A hub groups all kinds of distribution centers (terminal, urban hub, depot, regional distribution centers etc.). This generalization was chosen to include several types of logistics facilities *and assuming that the equipment for material handling is the same in each of them.*

Despite the different kind of hubs presented in Chapter 2.3, the selected boundary is a *road hub* as it is shown in Figure 2.9.

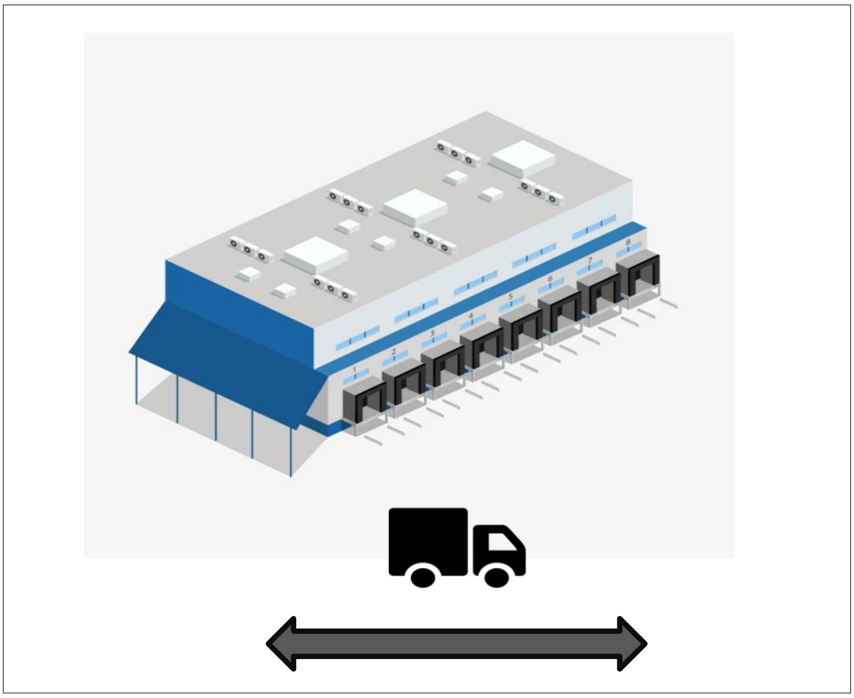


Figure 2-9: Selected boundary, hub

Setting up the boundary stablishes the limits of the present research which is focused in the material handling equipment used in the inner processes of the Hub, therefore, an identification of the processes is necessary. For that purpose, the Distribution Centre Reference Model (DCRM) was chosen.

2.5 Distribution Center Reference Model (DCRM)

To address the fundamental processes inside the hubs, the *Distribution Center Reference Model* (DCRM) was selected and it worked as the system boundary. The aim of the DCRM is to systematize the processes in the distribution center and to provide a basis for objective evaluation. [WAR19]

The DCRM has a hierarchical structure with four levels. The level "processes" is composed by 6 processes identified in distribution centers. They are illustrated in the Figure 2-10 [WAR19]:

1. Receiving
2. Storage and Picking
3. Consolidation and Packing
4. Shipping
5. Add value
6. Overhead

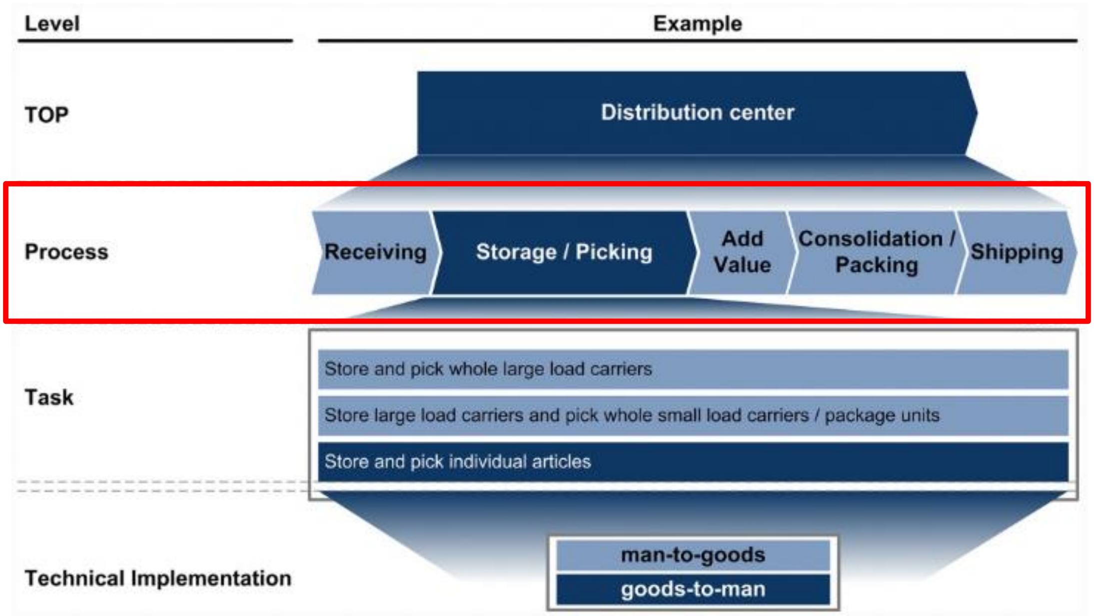


Figure 2-10: Main processes of DCRM [WAR19]

For this thesis, only the following processes are relevant because they are the most suitable for the research questions:

1. **Receiving**
2. **Storage and Picking**
3. **Consolidation and Packing**
4. **Shipping**

The system boundary processes are shown in Figure 2-11.

Figure 2-11: System boundary processes

Therefore, they are the main processes of the distribution centers, but it is important to notice that not all the distribution centers must have all processes. [WIS09] Figure 2-12 illustrates the different areas where the main processes are carried out.

Figure 2-12: Areas of the main processes [WAR19]

2.5.1 Receiving

The starting process in the material flow of a distribution center is the goods reception. This process includes all the activities related to goods receiving. The first activity of the process is unloading the external means of transport like trucks or transporters. The next important tasks are identification of goods and their assignment to receipt points, where they are subjected to quality controls. If the goods are defective, a rework is done. Receiving process finishes with the consent for further processing. [WIS09]

2.5.2 Storage and Picking

Storage and picking are the two major processes of a distribution center and they are summarized together, as one can't happen without the other. The process starts with the transport of goods from the Provision area of the receiving process to the storage and picking zone. In addition, the process involves the storage, picking the goods out of the store and elimination of packaging. The process finishes with placing of goods in the disposal area for the next processing. [WIS09]

2.5.3 Consolidation and Packing

The consolidation and packing processes are also developed together due to their connection. The starting point of the process is the transport of goods from the disposal area of the storage and picking process to the consolidation and packing area. The next task is the consolidation of goods, this can be done directly in the buffers of the packaging stations. In addition, goods are identified, packed and labeled for shipping. The process finishes with placing of goods in the disposal area for further processing. [WIS09]

2.5.4 Shipping

The final process is shipping. The process starts moving the goods from the disposal area of consolidation and packing to the shipping area. The next steps are sorting, identification and loading of goods in the external means of transport like trucks, transporters etc. Once the goods are loaded, the process finishes. [WIS09]

2.6 Overview of the PI Hub processes

The representation of the processes helps to get a better understating of the intralogistics of PI Hubs and the equipment used.

For the visualization, eEPC (extended event driven process chain) was the chosen and it will be further explained in Chapter 3.5. The processes are based on the DCRM (distribution center reference model) which is presented in Chapter 3.1 as well as the definitions of the processes.

Only the main processes shown in Figure 2-13 are represented in detail in the further diagrams.

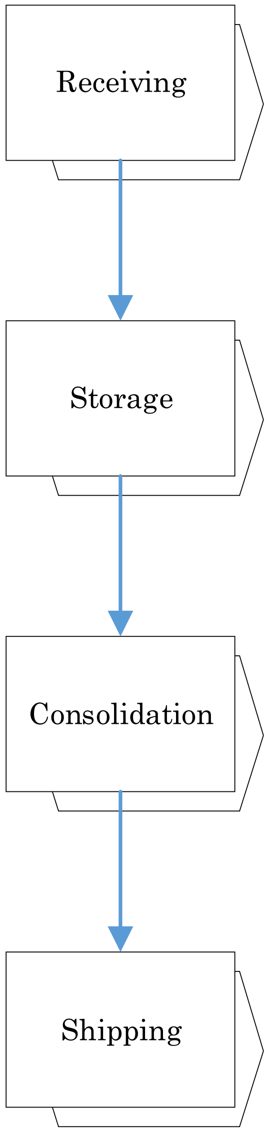
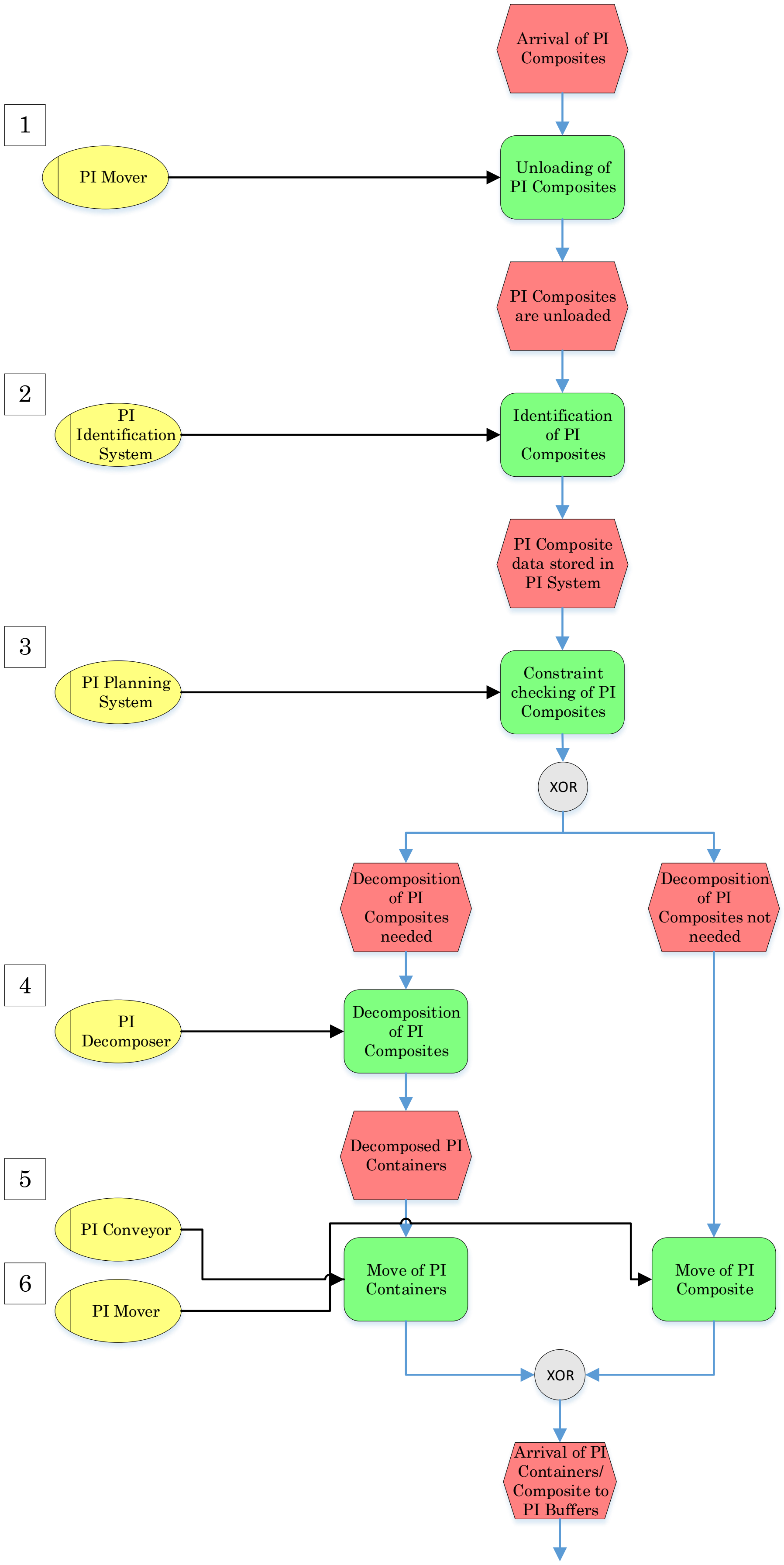
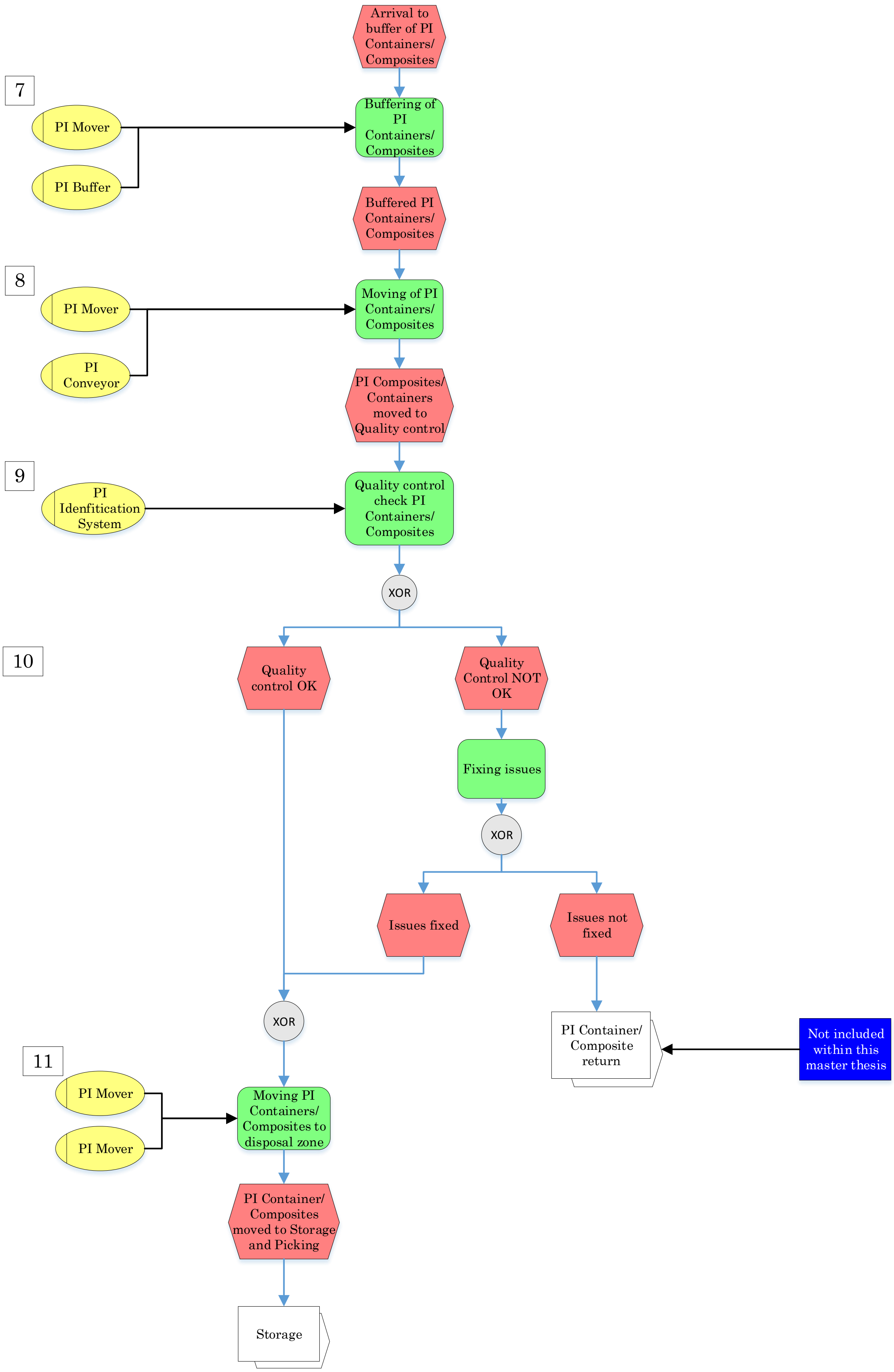


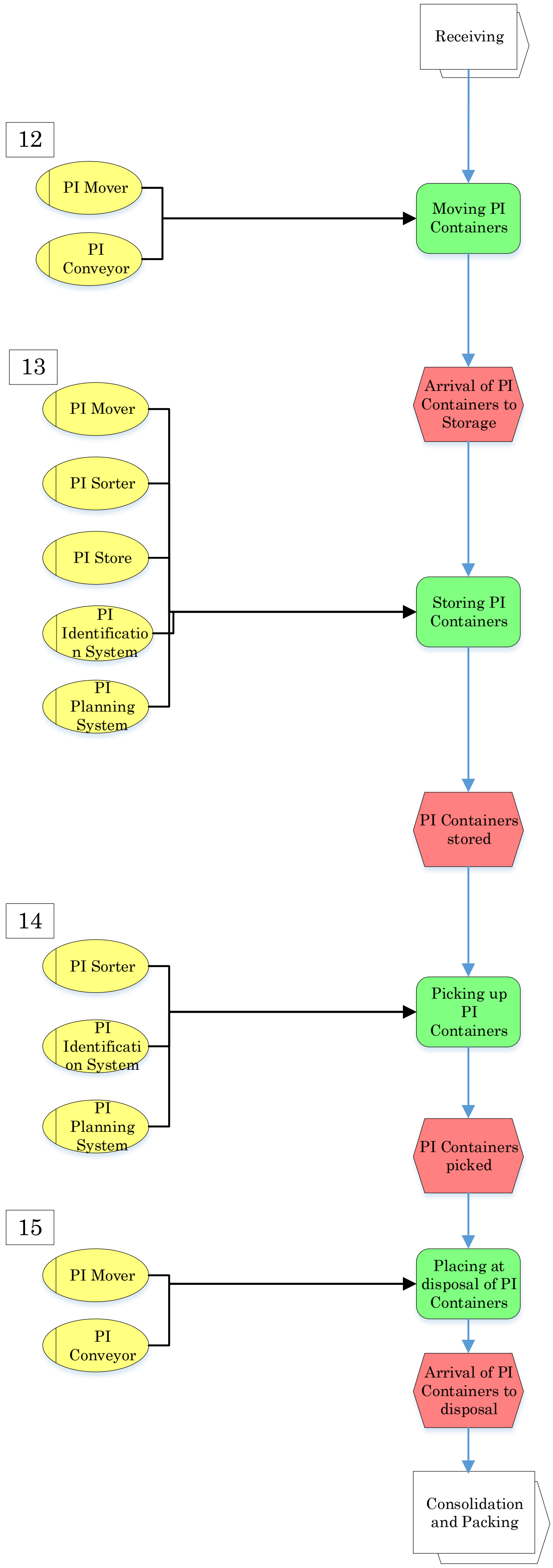
Figure 2-13: PI Hub main processes

2.6.1 Receiving

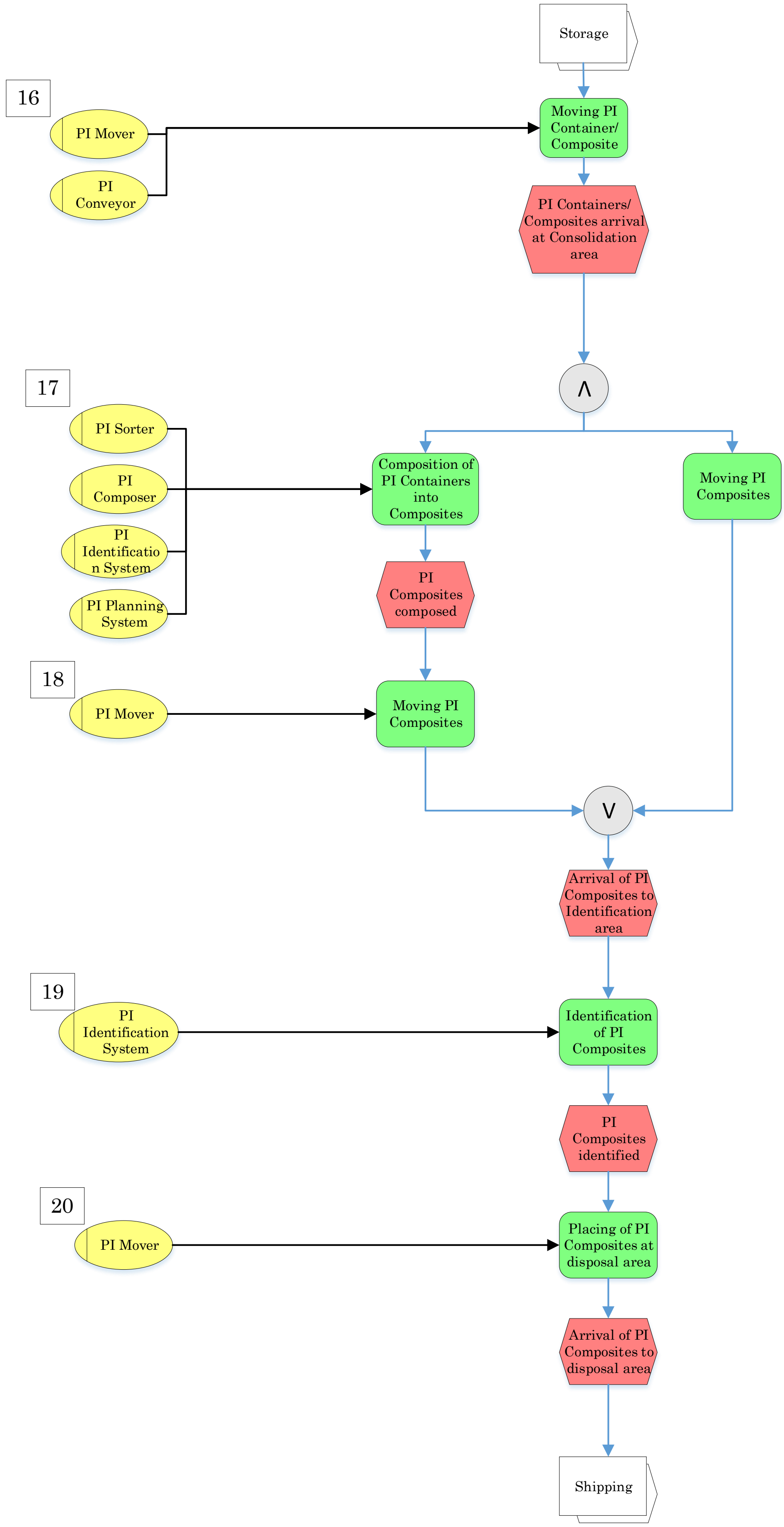



Arrival to buffer of PI Containers/ Composites
7
PI Mover
PI Buffer
Buffering of PI Containers/ Composites
Buffered PI Containers/ Composites
8
PI Mover
PI Conveyor
Moving of PI Containers/ Composites
PI Composites/ Containers moved to Quality control
9
PI Idenfitication System
Quality control check PI Containers/ Composites
XOR
10
Quality control OK
Quality Control NOT OK
Fixing issues
XOR
Issues fixed
Issues not fixed
XOR
PI Container/ Composite return
Not included within this master thesis
11
PI Mover
PI Mover
Moving PI Containers/ Composites to disposal zone
PI Container/ Composites moved to Storage and Picking
Storage

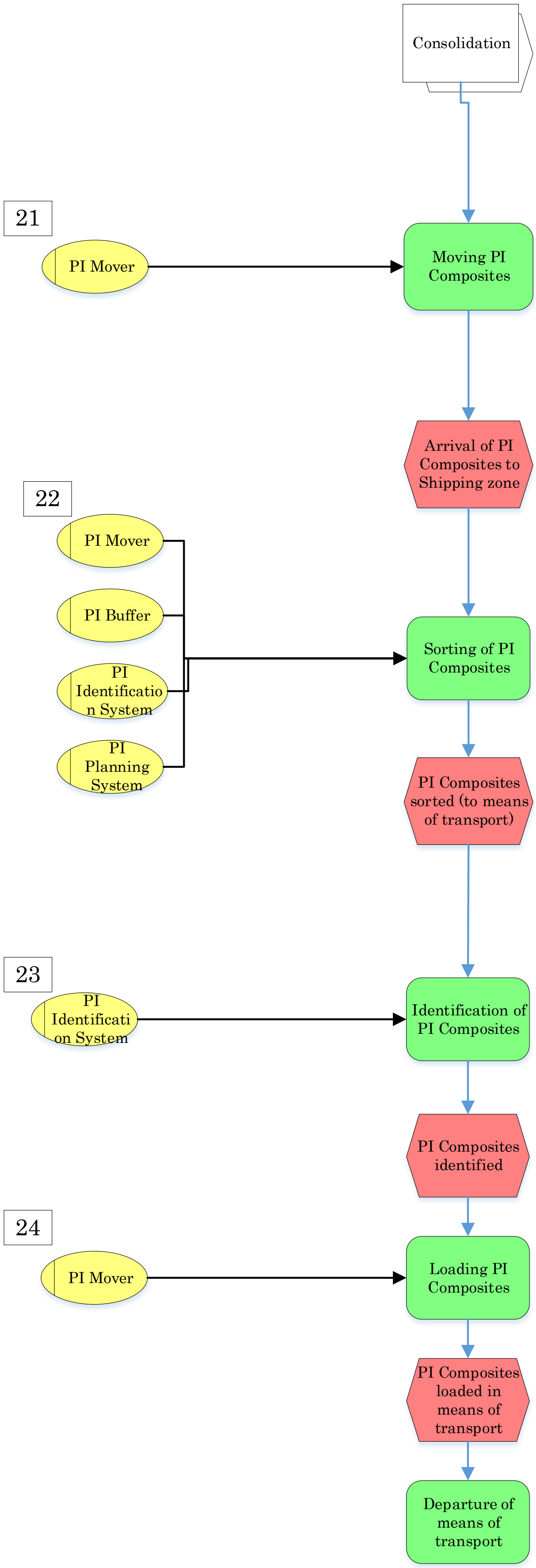
2.6.2 Storage


Receiving
12
PI Mover
PI Conveyor
Moving PI Containers
13
PI Mover
PI Sorter
PI Store
PI Identification System
PI Planning System
Arrival of PI Containers to Storage
Storing PI Containers
PI Containers stored
14
PI Sorter
PI Identification System
PI Planning System
Picking up PI Containers
PI Containers picked
15
PI Mover
PI Conveyor
Placing at disposal of PI Containers
Arrival of PI Containers to disposal
Consolidation and Packing

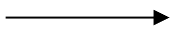
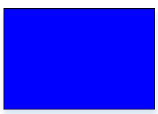
2.6.3 Consolidation



2.6.4 Shipping



2.6.5 Symbols and definitions

PI Conveyor	Conveyor for moving PI Composites/Containers from one place to another.
PI Identification System	System for the identification of PI Containers. It writes and reads information on the PI Container and about the PI Container.
PI Planning System	Management system for all the PI Processes and tasks.
PI Mover	Transports PI Composites/Containers from one place to another and between processes.
PI Sorter	Sorts the PI Containers according to certain criteria.
PI Buffer	Stores PI Containers/ PI Composites for a short period of time.
PI Store	Stores PI Containers/ PI Composites for a long period of time.
PI Composer/ Decomposer	Builds PI Composites out of PI Containers and decomposes PI Composites into PI Containers
	Information flow
	Material flow
1	Number of functions
	Information dialog

3 Research methodology approach

In this chapter, the chosen research strategy, study methods applied to approach the RQ1, rating scale, modelling process and main KPIs for evaluation are presented.

3.1 Research strategy

Once the system boundary has been formulated and clarified, a research strategy must be defined. A research strategy is a carefully constructed plan of action that is rationally designed and likely to offer the best prospects of success. It is different from a research method. Research methods are the tools for data collection. [DES98]

Choosing a strategy can be a difficult task, in order to select the strategy that will work better, it is necessary to consider three key questions:

- Inductive or deductive approach?
- Quantitative or qualitative?
- Is it suitable?

The answers to these questions will point out the most suitable strategy for the present research. [DES98]. Table 3-1 shows the different strategies that were evaluated before the selection.

Table 3-1: Different types of research strategies [DES98]

Strategy	*Purpose of research*
Phenomenology	• Describe the essence of specific types of personal experience • Understand things through the eyes of someone else
Grounded theory	• Clarify concepts or produce new theories • Explore a new topic and provide new insights
Action research	• Solve a practical problem • Produce guidelines for best practice
Mixed methods	• Evaluate a new policy and gauge its impact • Compare alternative perspectives on a phenomenon • Combine aspects of other strategies

After reading the research questions presented in Chapter 1, the first impression is that a qualitative method would be very appropriated for this thesis but taking a closer look into them concludes that this research should be classified as Quantitative, because it is based on analysis of numbers and the study is done following the major steps of *Deductive approach*.

The *Deductive approach* explores a known theory or phenomenon and tests if the theory is valid in given circumstances. This theory leads to a new hypothesis, which is put to the test by confronting it with observations in order to reject or confirm the hypothesis. [RES19]

Figure 3-1 shows the main steps of the deductive approach.

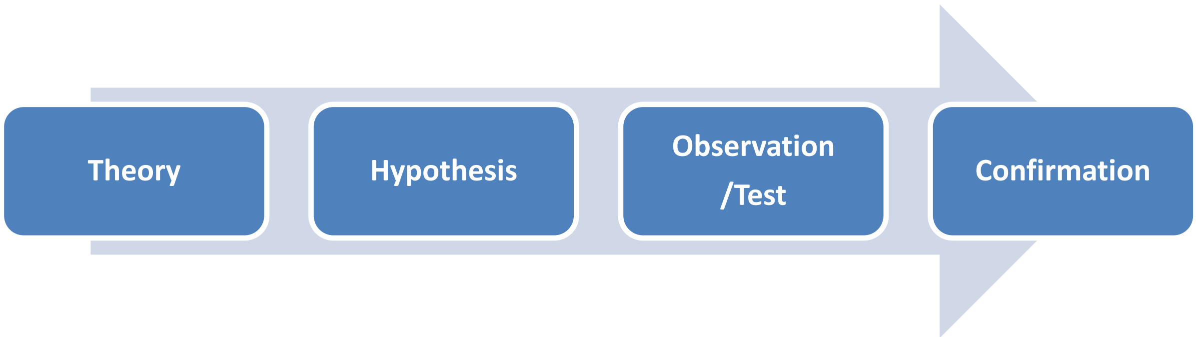


Figure 3-1: Deductive approach steps [RES19]

1. **Formulate a theory** based on literature, observations, findings…
2. **Develop a hypothesis** out of the theory
3. **Test the hypothesis** with the application of research methods.
4. **Confirm or reject** the hypothesis

All the aspects mentioned above contributed to the selection of the **mixed methods approach** as research strategy for this study. [RES19]

3.1.1 Mixed methods approach

The term mixed methods apply to research that combines alternative approaches within a single research project. The mixed methods approach has three main characteristics that can be summarized as follows [DES98]:

- Use of qualitative and quantitative approaches within a research project
- Explicit focus on the link between approaches (triangulation)

- Emphasis on practical approaches to research problems (pragmatism)

The mixed methods approach tends to involve the use of qualitative and quantitative methods, seeing facts from alternative perspectives, thereby getting a better overview of the object of study. The benefit of this method is that the data produced by various methods can provide different angles that combined, go further towards an all-embracing vision of the subject. [DES98]

The chosen method makes a distinction between QUAL and QUAN where:

→ **QUAL:** stands for qualitative data in form of text or pictures that provide the basis for interpretations of the meaning. [DES98]

→ **QUAN:** stands for quantitative data in form of numbers that provide objective measurements of observed events. [DES98]

The mix of QUAL and QUAN offers many possibilities and makes possible to build a complex range of them. This means that quantitative data can be converted into narrative that can be analyzed qualitatively and that qualitative data can be converted into numerical codes, so it can be analyzed statistically. [SLT09]

An overview of the chosen methods for each research question is given in the table 3-2.

Table 3-2: Selected research methods for research questions

QUESTION	RESEARCH METHOD
RQ1: What are the material handling processes and the corresponding material handling systems within the present hubs?	Questionnaire and Interviews
RQ2: What are the PI Hub main elements and their characteristics regarding material handling processes?	Literature research
RQ3: What are the technological gaps between the current material handling systems and the potential systems for Physical Internet?	Evaluation and comparison between RQ1 and RQ2 based on collected results.

3.1.2 Primary data collection

Once the research strategy is selected, the method for gathering primary data has to be chosen. Some of the data collection methods have been evaluated to select the most suitable regarding the research questions and the goals.

The evaluated methods are the following ones:

- Examination of secondary sources
- Observation
- Semi-structured interviews
- Unstructured interviews
- Questionnaires

Considering the characteristics and needs of this master thesis, **questionnaires** appealed as the most appropriate method because they provide an effective way of gathering responses among a large group of respondents. [SLT09]

Figure 3-2 shows the different kinds of questionnaires attending to how they are administered and the level of contact with the respondents. [SLT09]

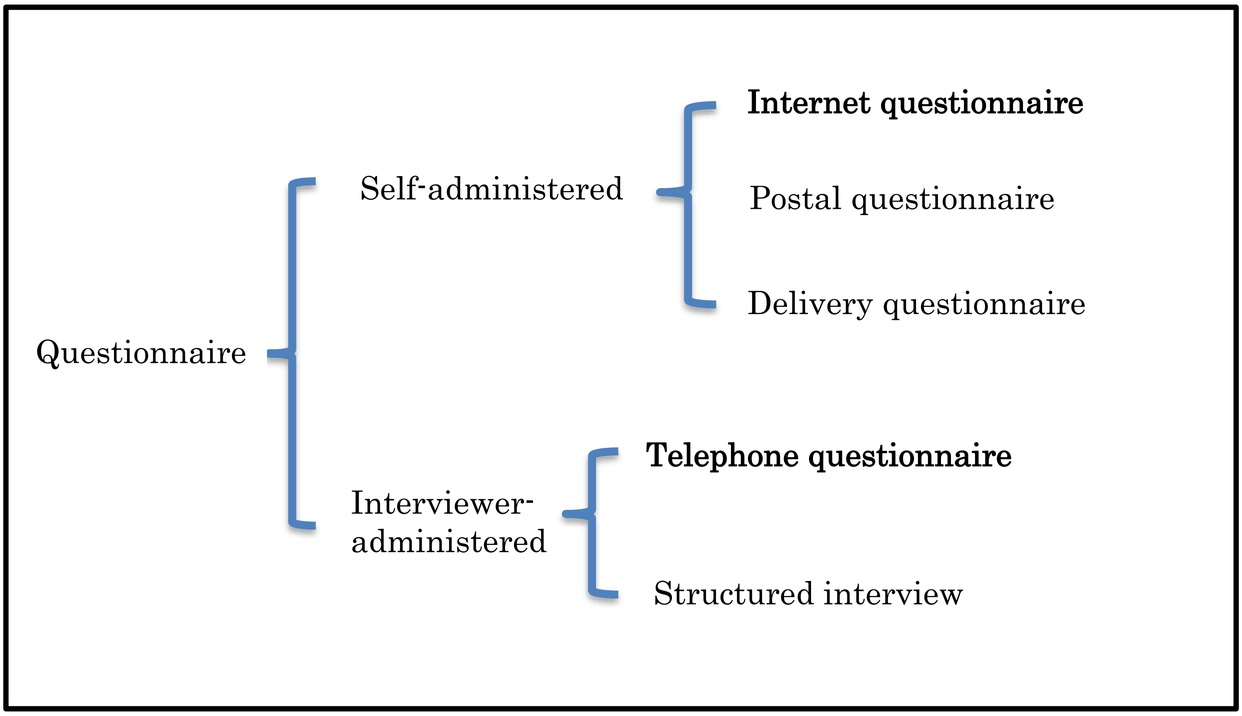


Figure 3-2: Different kinds of Questionnaires [SLT09]

questionnaires via email offers the possibility of getting in contact with a higher number of respondents and from different locations as well as it gives the users the opportunity to forward the questions to colleagues or other people who can contribute with their knowledge to the master thesis. Telephone questionnaires were used when the respondents had difficulties answering the questions or if the author knew the respondent, as a way of getting further information, the responses were recorded.

3.2 Questionnaire approach

Initially, an analysis of the material handling equipment used inside of current hubs and PI Hubs was done by collecting data from related literature in accordance with the research questions presented in the Chapter 1.

Following this analysis and due to the vast quantity of material handling technologies currently available, a survey strategy was selected. Questionnaires and interviews were used to collect information from a sample of respondents out of logistics companies. Questionnaires gather primary data, which is the data that is needed to answer RQ1. [SMA13]

The PI literature study presented in Chapter 4.1 was used for identifying PI key elements and its characteristics, acting as a guideline for developing the survey.

A list of questions was designed to reach a clear picture and provide first-hand information about the material handling equipment used in present hubs. The collected answers are influenced by the nature of the hubs contacted and therefore it's important to point out that results cannot be extrapolated.

3.2.1 Design of the questionnaire

Questionnaires are a well-established way of collecting data. They are designed to collect information which can be used subsequently as data for analysis. The results rely on written information supplied directly by people in response to questions asked by the researcher. [DES98]

The following steps were applied to design an appropriated questionnaire:

1. Literature research and information gathering
2. Identify the gaps that cannot be covered with literature and would need first hand data from companies
3. Based on those gaps, write first draft of questions

4. Revision of the draft by the thesis supervisor
5. Pre-test the questionnaire with colleagues to verify that questions are clear, understandable and straight to the point
6. Last rectification and revision of questions before releasing them

Three different types of questions have been used to build up the questionnaire:

- **Open questions**
- **Quantity questions**
- **Multiple choice questions**
- **Closed ended questions**

Open questions allow the respondents to give further information than "yes" or "no", quantity questions in which the response is a number, multiple choice questions have multiple reply options and for closed ended questions only one response can be chosen. [DES98]

Independently from the category of the question (open, closed, multiple choice etc.), most of the questions have an extended option "Other" to give the respondent the chance to add any additional information that could be taken into consideration or any missing information among the available options.

3.2.2 Development of the questionnaire

The questionnaire was built based on PI literature study presented in Chapter 4.1 and the boundary definition presented in Chapter 2.4. It's important to point out that the processes inside current hubs were also analyzed, to create a common level of comparison in the end.

The main operations presented in this master thesis were derived from the DCRM processes, like receiving (unloading, identification of goods), storage (sorting equipment), packing (unit load composition) and shipping (loading, transportation), these operations are shown in Figure 3-6 and served as a guidance for the development of questions.

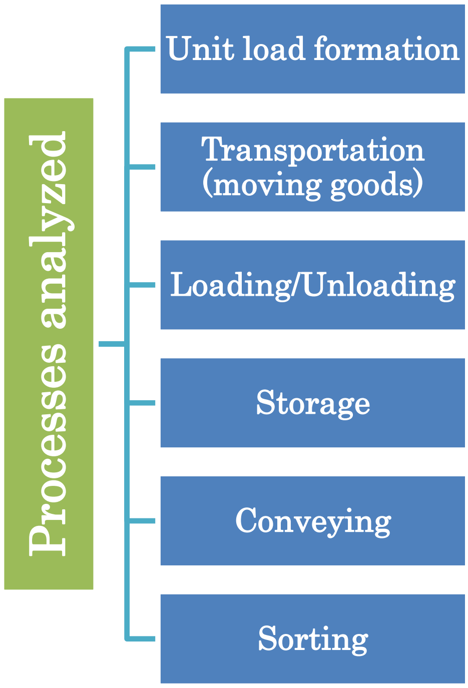


Figure 3-3: Analyzed activities derived from DCRM main processes

Following the research method and its steps, eighteen questions were developed. The sequence of the questions corresponds to the main activities presented in Figure 3-3. Firstly, general questions about characteristics of the logistics facility were asked to support a better identification of the investigated hub. Secondly, questions about the material handling equipment used in the inner processes were presented and lastly, what can be improved or what can be done different to be more efficient in the facility.

3.2.3 Distribution of the questionnaire

Once the questionnaire is ready, the next step is to distribute it among different companies within the logistics sector. For the present master thesis, the distribution of the questionnaire was via Internet. The questionnaire was attached in an email, so the respondent only needs to complete the answers and then send back the questionnaire. Also, some of the questionnaires were handed in directly to the respondent, in this case, any doubt regarding the questions was immediately clarified. For privacy reasons, the survey is anonymous, therefore, names of firms and respondents won't be shown in the thesis. [DES98]

The contacted companies belong to the field of:

- Express couriers

- Private sector firms
- Logistics providers and Mobility sector
- Urban delivery services
- Distribution services enterprises
- Transport companies

An overview of the distribution process is given in the Figure 3-4.

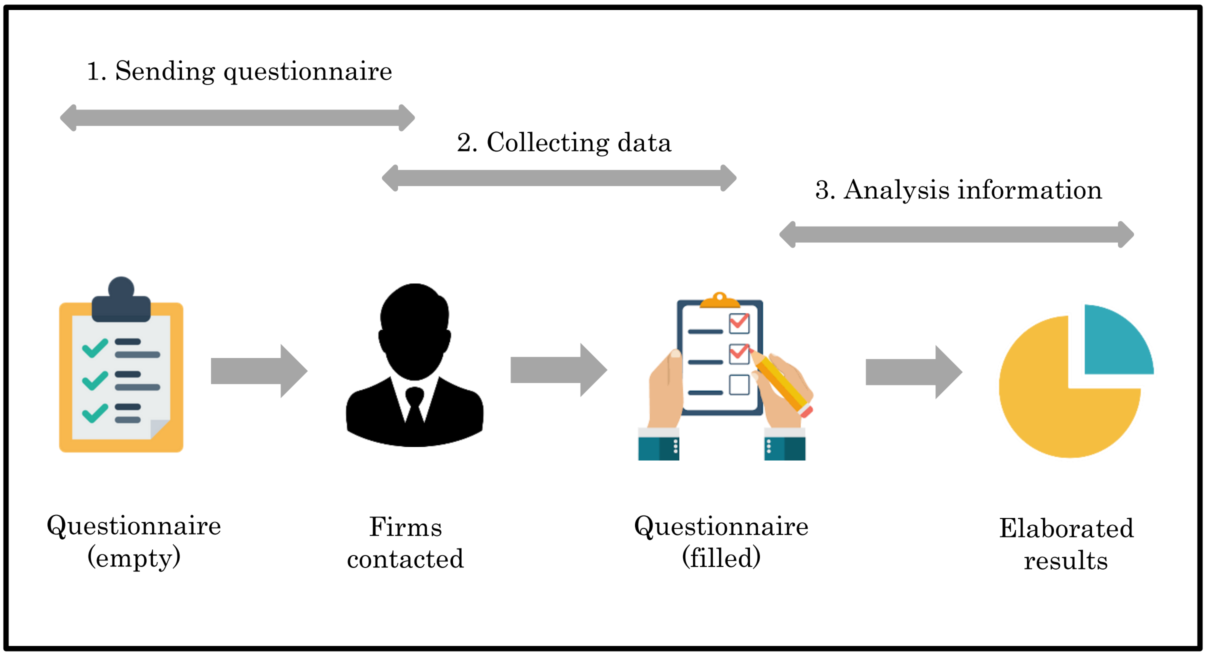


Figure 3-4: Questionnaire distribution process

Forty-two companies in the logistics field were contacted in Austria and Spain. Twenty three out of forty-two replied the questionnaire. But only eleven of them provided completed responses that can be used for this master thesis, the rest couldn't be used because of the lack of consistency in the answers or empty responses. From the chosen eleven responses, two respondents provided information about two different facilities within their companies and the rest gave information about one facility each.

3.3 Rating scale

It is necessary to set up a rating scale in order to grade the evaluation of the material handling equipment. A rating scale is a tool used to associate a qualitative measure with various aspects of processes, tasks or procedures. There are four types of rating scales [QUE19]:

- Numerical rating scale

- Graphic rating scale
- Descriptive rating scale
- Comparative rating scale

For this thesis, a graphic rating scale of 1-3 has been selected as it is shown in Table 3-3.

Table 3-3: Rating of readiness

Rating	Readiness
Poor	There are none or minor similarities between present hubs and PI Hubs. (Less than 20 % accordance)
Fair	There are some similarities between present hubs and PI Hubs. (Around 40% accordance)
Good	There are many similarities between present hubs and PI Hubs. (More than 60% accordance)

3.4 Selected KPIs for the evaluation

To determine and evaluate the readiness of the material handling equipment, the performance of it should be measured, for that purpose, certain key indicators have to be stablished.

A *key performance indicator* is a quantifiable measure used to evaluate the success, in this case of the material handling equipment, to meet the objectives of the PI [OXF19]. The performance in this master thesis was measured based on economic, environmental, design and physical aspects.

The main KPIs considered for this master thesis were the following:

- Design and complexity of the systems
- Main physical characteristics of the systems
- Level of accuracy when handling PI Containers
- Level of automation
- Equipment costs
- Environmental footprint

3.5 Process modelling

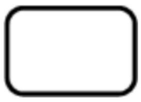
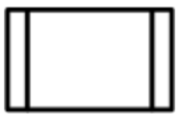
After gathering the results of RQ1 and RQ2, a process model was necessary to illustrate the processes in which the material handling equipment has been investigated. For this reason, the extended Event-driven Process Chain (eEPC) was selected. eEPC allows a full and clear visualization of the workflow of inner processes in the hubs.

3.5.1 Extended Event-driven Process Chain

The extended Event-drive Process chain is a method used to visualize succeeding events and functions by which the logical timing of a business process is shown. Consequently, eEPC is the descriptive method of the dynamic part of business processes. It has become a widely-used process for business modelling in organizations. [WUA19]

The main elements of eEPC are the ones shown in Table 3-4.

Table 3-4: eEPC main elements [VIS19]

Elements		Characterization
EVENT		Describes an event that occurs after a specific function has finished.
FUNCTION		Describes the transformation from a start-state to a target-state
ORGANIZATIONAL UNIT		Describes which person or organization within the structure of an enterprise is responsible for a specific function.
INFORMATION OBJECT		Describes the input or the output of a function.
AND **OR**	 	Describe the logical connections between events and functions.

XOR 	Describe the logical connections between events and functions.

4 Proceedings

This chapter presents a PI literature study, the information collected through the questionnaires about material handling equipment used in the present hubs, after this, to cover the possible information gaps of the questionnaires, a further research about the existing technologies is exposed.

4.1 Physical Internet literature study

The focus of this thesis is on the material handling equipment used in the intralogistics processes of PI Hubs, therefore, the equipment for handling material on each activity inside of the hub will be discussed in this section. Warehouse management system and Identification system are also presented in this chapter, but they won't be taken into consideration for the evaluation as they are not relevant for the focus of the thesis.

The PI Hub processes are the following:

- Unit load formation
- Loading and Unloading means of transport
- Conveying
- Sorting
- Conveying
- Storing
- Identification and management system

4.1.1 Composition and decomposition of PI Containers (Unit load formation)

PI Composers are used to build composites of PI Containers, based on a 3D layout specified by the final customer, or for being more efficient decomposing PI Composites of PI Containers into smaller PI Composites or individual PI Containers depending on customer's specifications. [MMB10]

The composition and decomposition of the composite PI Containers will be done by interlocking together various sizes of PI Containers or by *unsnapping* composites of PI Containers into smaller PI Containers. [MMB10]

In Figure 4-1, a conceptual illustration of PI Composer's functionality is shown, P Containers of different sizes are attached together to form a PI Composite. [MMB10]

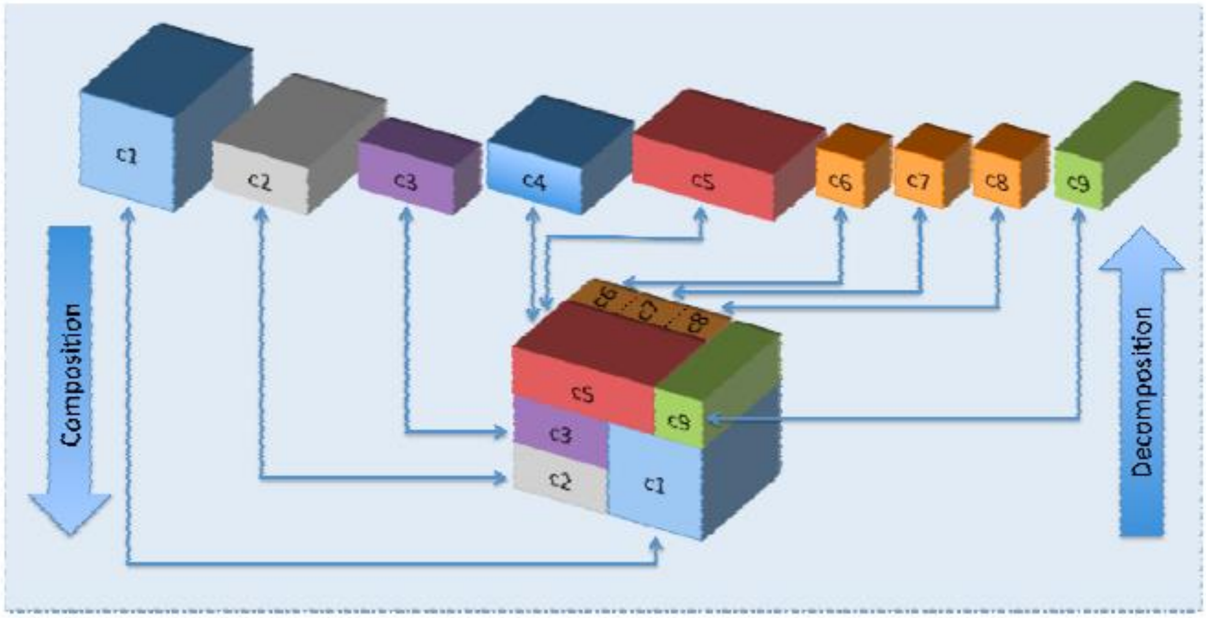


Figure 4-1: Conceptual illustration of a PI Composer's functionality [MMB10]

The spatial modularity of PI Containers simplifies the assembling of PI Containers into PI Composites, although, sometimes, it's a complicated work to build a perfect fit like the one shown in Figure 1. In those cases, holes are left as long as they don't have a negative impact in the structure of the composite of PI Containers, in case of negative impact, empty PI Containers are used to fill in the holes. [MMB10]

The PI Composers will be designed for composing/decomposing composites of PI Containers at high speed. As a normal requirement, a PI Composer will be able to compose a 1.2x1.2x6 m^3 PI Composite out of twenty smaller PI Containers within few minutes. [MMB10]

PI Composers are major candidates for automation, integrating PI Conveyors and PI Sorters. They have a role similar to current palletizers and depalletizers, but with an interlocking functionality. In general, PI Composers are in charge of fragmentation and defragmentation operations on PI Composites, without opening PI Containers. [MMB10]

4.1.2 Loading and Unloading

Loading and unloading operations of PI Containers are closely linked with PI Movers. These PI Movers transport, convey, hand, lift and manipulate PI Containers from one place to another. In some cases, they store PI Containers temporarily. [MMB10]

There are three main types of PI Movers:

- PI Conveyors
- PI Transporters
- PI Handlers

As mentioned before, PI Containers are designed to interlock and stack together, this means, they can attach themselves to a PI Mover without being placed on a platform. [MMB10]

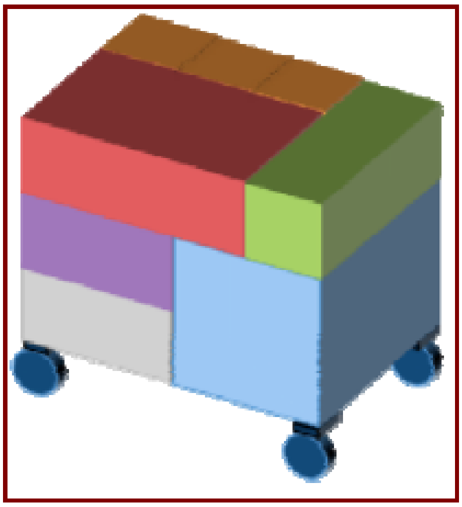


Figure 4-2: PI Mover moving PI Composites [MMB10]

In Figure 4-2, a composite of PI Containers is moved by a PI Mover with four wheels snapped underneath it to allow its manual displacement by a PI Handler. The set of four wheels could also be motorized and smart-sensor enabled to allow its autonomous travel. [MMB10]

In Figure 4-3, a PI Lift truck is lifting a composite of PI Containers without using any forks or pallets. [MMB10]

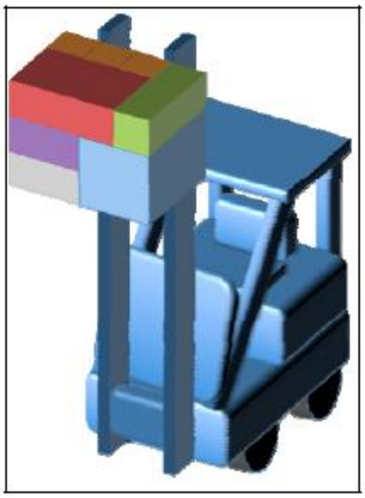


Figure 4-3: PI Lift truck lifting a composite of PI Containers [MMB10]

PI Movers will need a proper system design suitable for handling PI Containers, therefore, a snapping device will have to be designed and included, to allow the attachment of composites of PI Containers with PI Movers. [MMB10]

4.1.3 Conveying and Sorting

4.1.3.1 Conveying

PI Conveyors are conveyors specialized in the continuous flow of PI Containers along certain paths without using PI Vehicles or PI Carriers. Current conveyors use belts and rollers, with their underlying mechanics, are a significant part of the overall cost and therefore influence in the physical footprint of the conveyor. [MMB10]

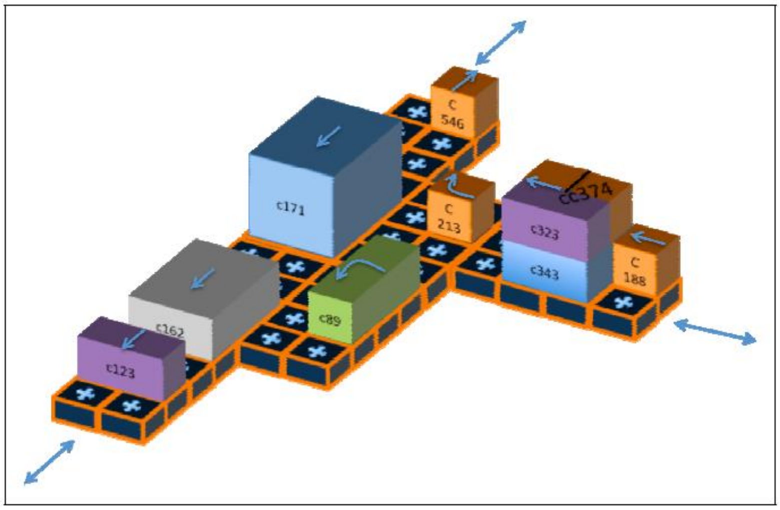


Figure 4-4: PI Conveyor grid composed of flexible conveying PI Cells [MMB10]

PI-conveyors are specifically designed for PI Containers, PI Conveyors are different from current ones by not having rollers or belts. Like the example shown in Figure 4-4, which represents a recently included flexconveyor technique. To explode the full PI Conveyor potential, they should be able to move PI Containers in the 4 cardinal directions. [MMB10]

4.1.3.2 Sorting

PI Sorters receive PI Containers from one or various entry points, and sort them to ship each of them from a specified exit point, following a specific order. PI Sorters should be able to move PI Containers in the 4 cardinal directions [MMB10]

Figure 4-5 illustrates a PI Sorter built in matrix form with 12 rows and 16 columns. This matrix style PI Sorters represent an important option due to the modular dimensions of PI Containers. [MMB10]

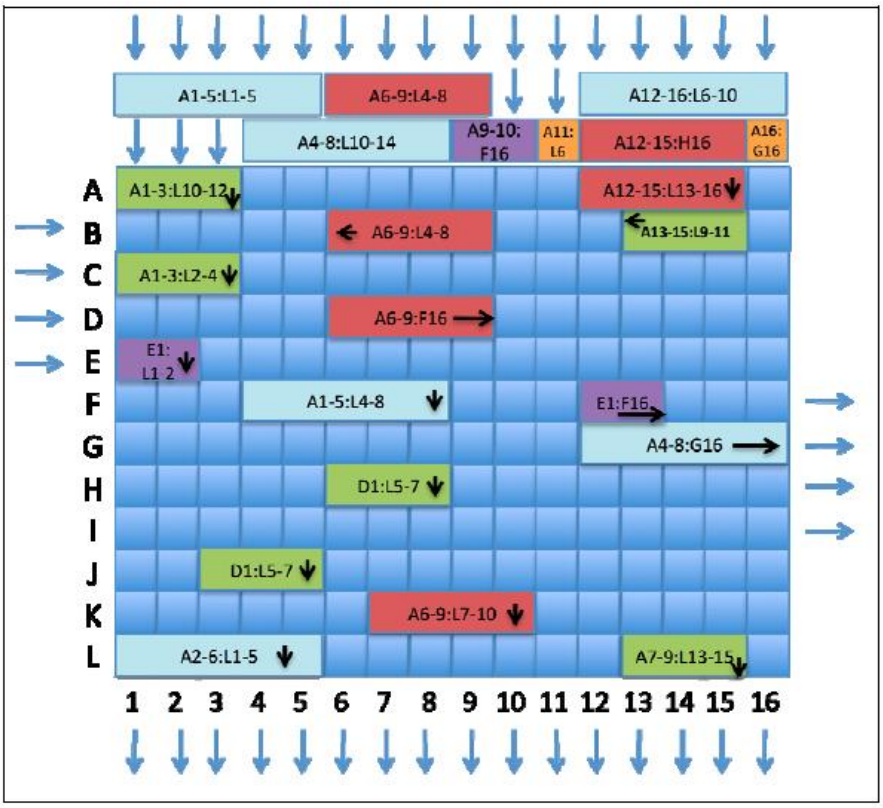


Figure 4-5: Matrix-style PI Sorter [MMB10]

4.1.4 Storing

PI Store allows the storage of PI Containers during certain amount of time, previously agreed with clients. For short or long period of time, as best fits the situation. PI Stores are very different from current warehouses, because they can interlock, stack and snap the PI Containers, moreover, they don't work with products as stock-keeping units (SKU's), but focus on PI Containers, that are managed and tracked to ensure the quality of the service. [MMB10]

Figure 4-6 shows the snapping and stacking possibilities of PI Stores, this is feasible thanks to the functionalities of PI Containers design. Based on this, current storage technologies won't have any value for the PI Facilities. [MMB10]

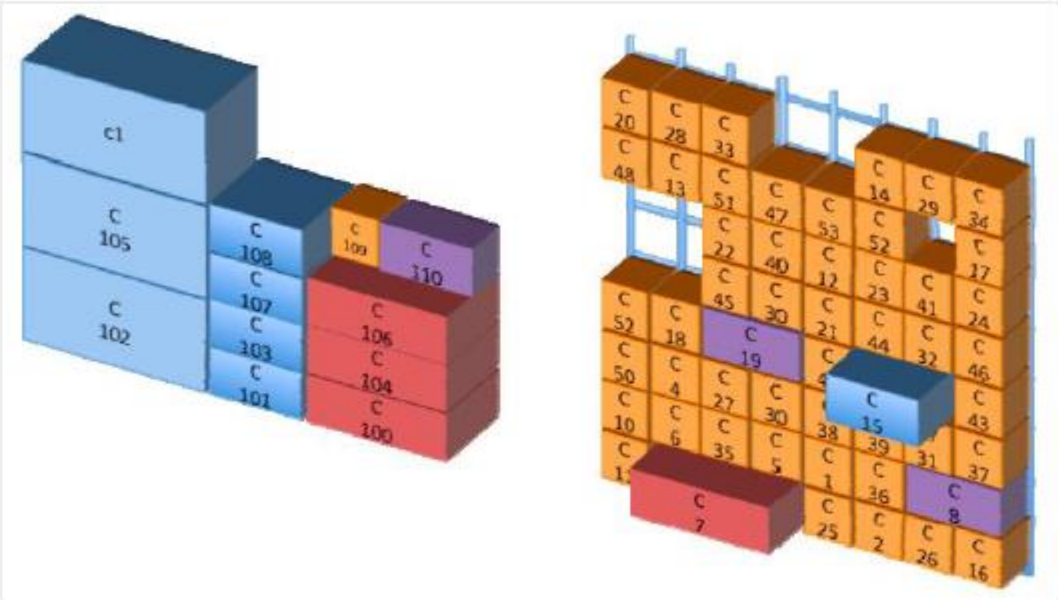


Figure 4-6: PI Store functionalities [MMB10]

4.1.5 Identification and management system

4.1.5.1 Identification system

PI Containers will be equipped with a unique physical number and a smart tag, as well as other technologies related to Internet of Things as they become available. The smart tags allow the routing and identification of PI Containers through networks. RFID technology is appropriate for the PI Containers tags. [BMM14]

The information contained in the tags is very different, some examples are:

- Identifier of the customer that uses it;
- Identifier of the owner;
- Dimensions and maximum weight;
- Geolocation
- Status of the container on the tag or in immediate proximity (signal and over-limit warning: time, temperature, vibration, humidity, etc.);
- Functionalities (handling, storage, etc.);
- Status of the container on the tag or in immediate proximity (signal, fault identifier, seal integrity);

The information stored in the PI Containers is protected by an encryption/decryption key. [BMM14]

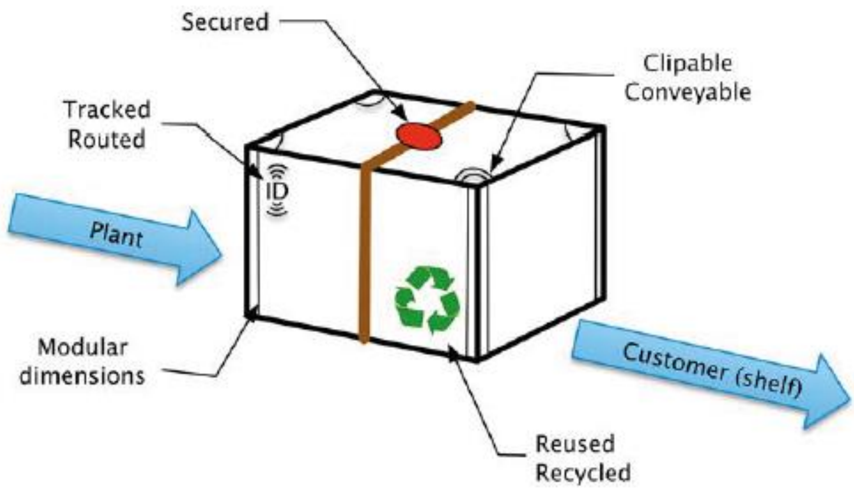


Figure 4-7: PI Container with smart tag [BMM14]

Figure 4-7 illustrates a PI Container with an identification system to track many relevant information about the PI Container route and status. [BMM14]

4.1.5.2 Management system

Structuring services in layers based on standardized protocols has an important role in the service development. Protocols are a group of professional rules that are observed by the stakeholders in a network (handler, facilities, truck driver…). [BMM14]

Here it's possible to observe similarities between the Digital Internet and the PI. The Digital Internet is structured into seven layers according to the Open System Interconnection (OSI) reference model, which was adopted by the International

Standardization Organization (ISO). The PI introduced the Open Logistics Interconnection (OLI) reference model. [BMM14]

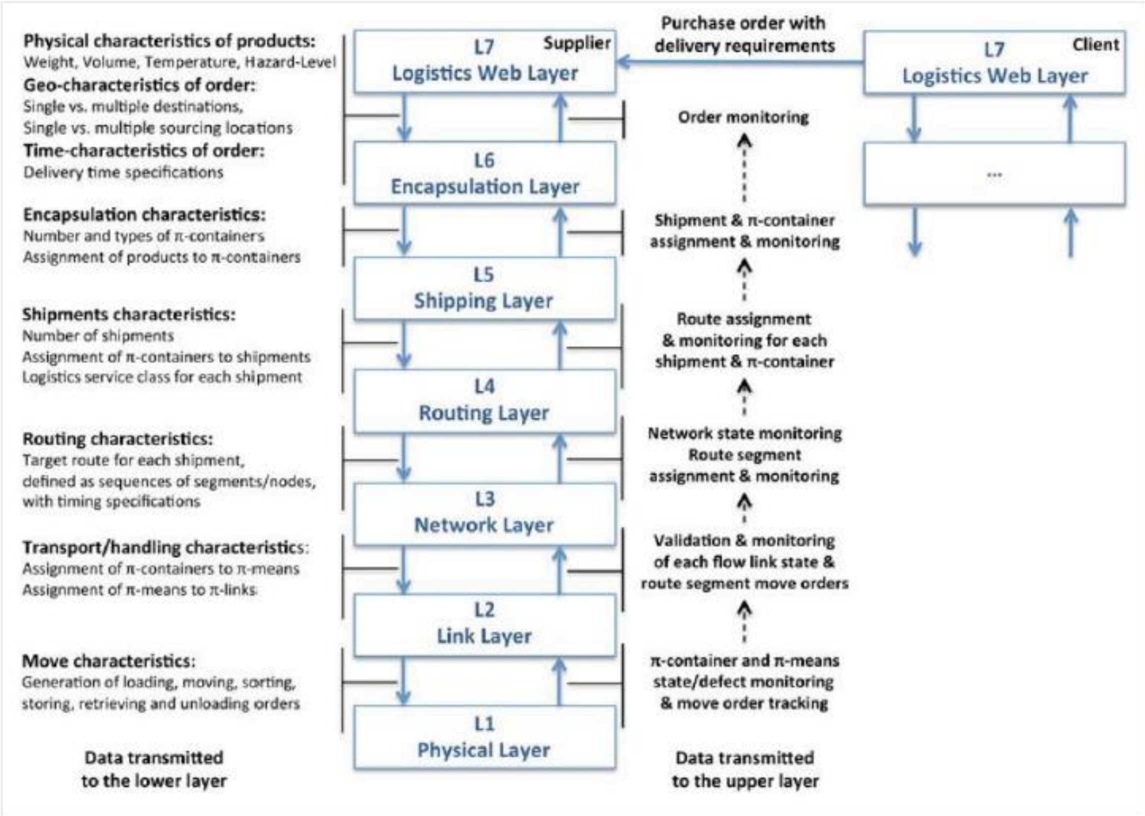


Figure 4-8: OLI model [BMM14]

As illustrated in Figure 4-8, the OLI model is an abstract description aiding the protocol design for logistics flow networks, including in activities like procurement, handling, realization, storage and transportation. [BMM14]

The OLI model establishes the following seven layers:

1. Physical
2. Link
3. Network
4. Routing
5. Shipping
6. Encapsulation
7. Logistics web

The examination of PI Hubs is possible thanks to the structuring components of PI. The service layers are developed for each user of PI, PI Nodes guarantee that PI Containers are monitored and routed. [BMM14]

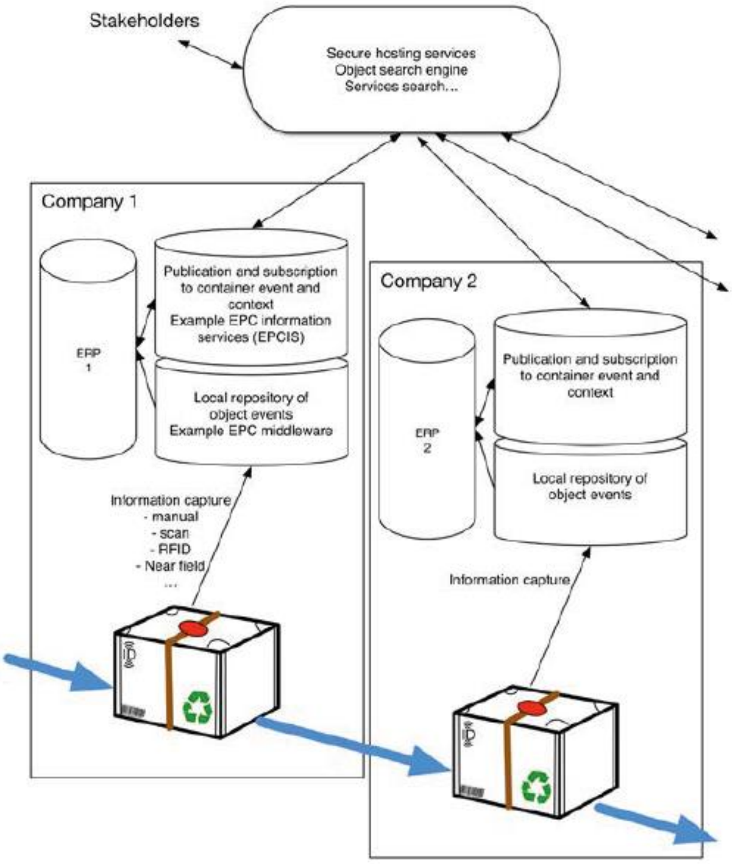


Figure 4-9: Information architecture for monitoring PI Containers [BMM14]

Figure 4-9 shows the information architecture for monitoring PI Containers. All the communication is done by using Digital internet. [BMM14]

4.2 Physical Internet hubs: Key elements

After concluding the analysis of the material handling equipment used in the inner processes of PI Hubs, it is possible to list up the key elements of material handling equipment in PI Hubs:

- PI Mover
- PI Conveyor
- PI Composer
- PI Sorter
- PI Store

The Table 4-1 establishes an equivalence between the processes and the PI equipment used to carry out that process, as well as its main characteristics.

Table 4-1: PI elements used in the processes

Process	**PI Element**	**Characteristics**
Transporting (moving)	PI Mover	- Manual or automated moving PI Containers - Snapping device, interlock PI Container/composite with PI mover
Loading /Unloading		
Conveying	PI Conveyor	- Flows PI Containers along certain paths - No need of PI Vehicles or PI Carriers - PI-containers moved in 4 cardinal directions
Unit load formation	PI Composer PI Container	- High speed composing/decomposing - Snapping device, to interlock PI Containers with PI Composites
Sorting	PI Sorter	- PI Matrix platform composed by PI Cells - PI Containers moved in 4 cardinal directions
Storing	PI Store	- Interlock, stack and snap PI Containers - Doesn't work with SKU's - Unique design for PI Containers

4.3 Questionnaire results about Present Hubs

The most significant information gathered through questionnaires is shown here as well as other relevant facts and variables. As explained in Chapter 3.4, the questions cover the material handling equipment used in the different processes inside of the contacted facilities.

1. What kind of logistics platform is the facility?

As indicated in Figure 4-10, almost half of the contacted facilities are Distribution centers, followed by Terminals and the rest correspond to Depots, Urban hubs, Services centers and Hubs.

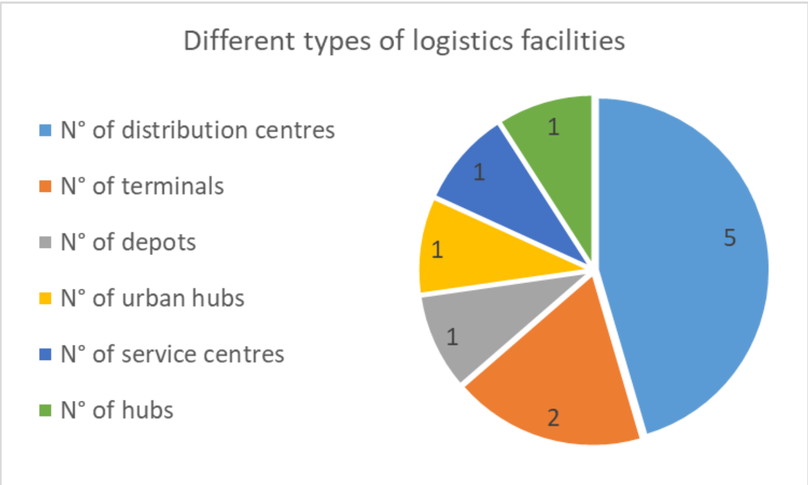


Figure 4-10: Types of Logistics facilities

Table 4-2: Consulted facilities and its corresponding logistics platform type

Facility	Type of Logistics Facility
No.1	Service centre
No.2	Distribution centre
No.3	Depot
No.4	Urban hub
No.5	Distribution centre
No.6	Distribution centre
No.7	Terminal
No.8	Hub
No.9	Distribution centre
No.10	Terminal
No.11	Distribution centre

2. How many goods per day are handled in the facility?

All the facilities provided information about goods handled per day except facility No.8 that didn't give any response.

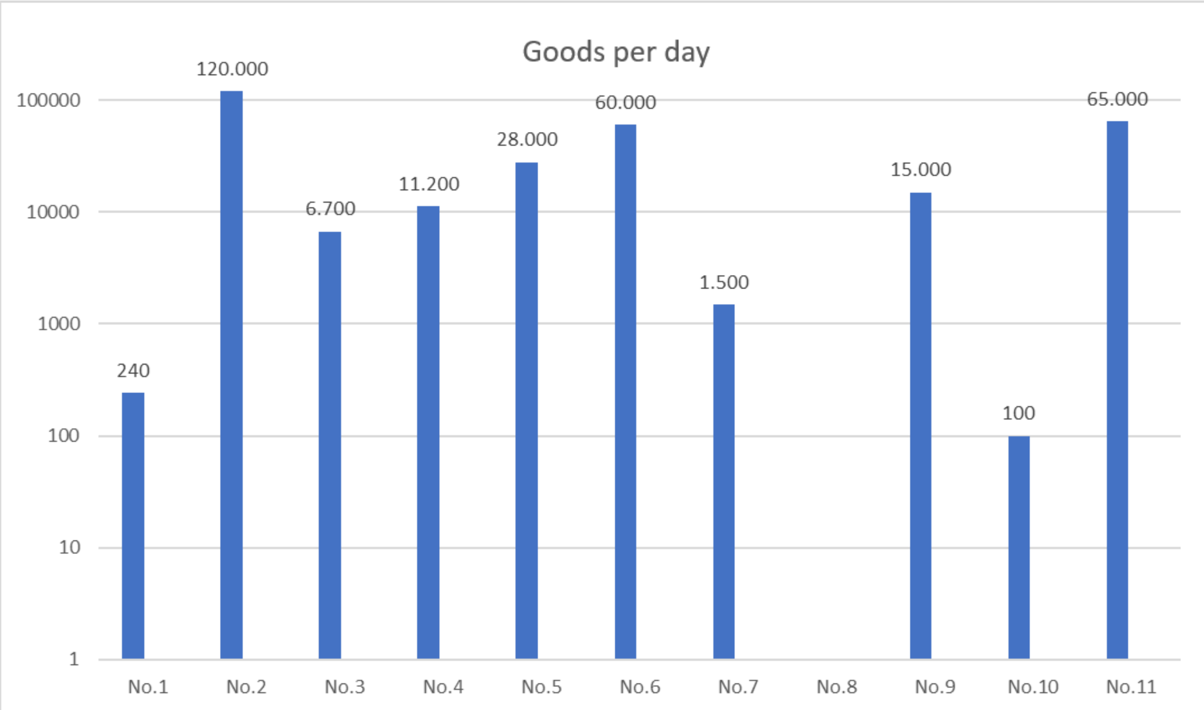


Figure 4-11: Goods per day handled within the contacted facilities

Table 4-3: Goods per day handled within the contacted facilities

Facility	Parcels per day
No.1	240
No.2	120.000
No.3	6.700
No.4	11.200
No.5	28.000
No.6	60.000
No.7	1.500
No.8	-
No.9	15.000
No.10	100
No.11	65.000

3. What type of goods are handled within the logistics facility?

Figure 4-3 provides a general overview of the goods handled in the facilities. The most common are Unit loads, Parcels and Large letters.

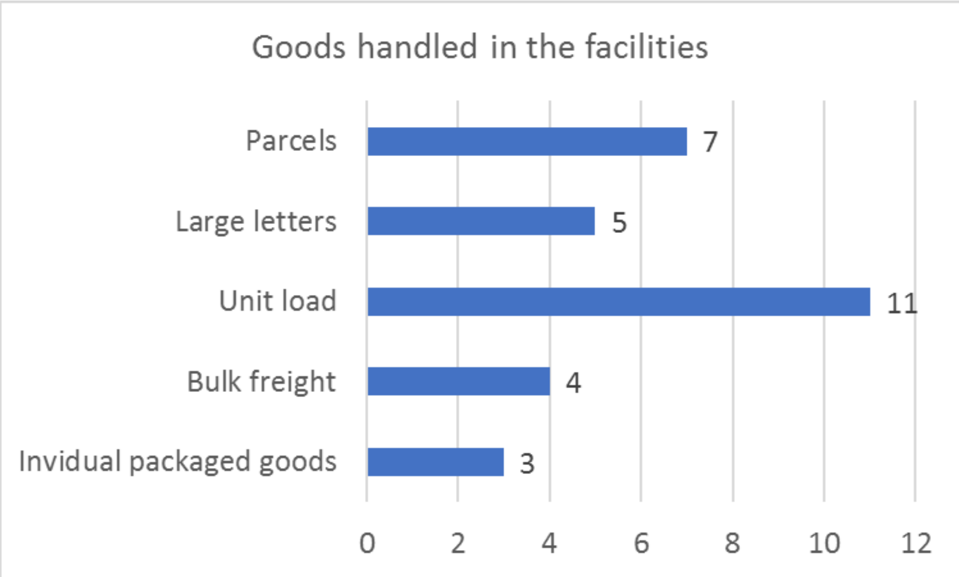


Figure 4-12: Number of facilities handling the different goods

A detailed overview of each type of freight handled per contacted facility is given in the table 4-4.

Table 4-4: Goods handled in the facilities

Facilities	Individual packaged goods	Bulk freight	Unit load	Large letters	Parcels
No.1			■	■	■
No.2			■		
No.3	■		■	■	■
No.4	■	■	■	■	■
No.5		■	■		
No.6			■	■	■
No.7			■	■	■
No.8			■		■
No.9		■	■		
No.10	■	■	■		■
No.11			■		

4. Is the facility serving only one customer or is it shared with more customers?

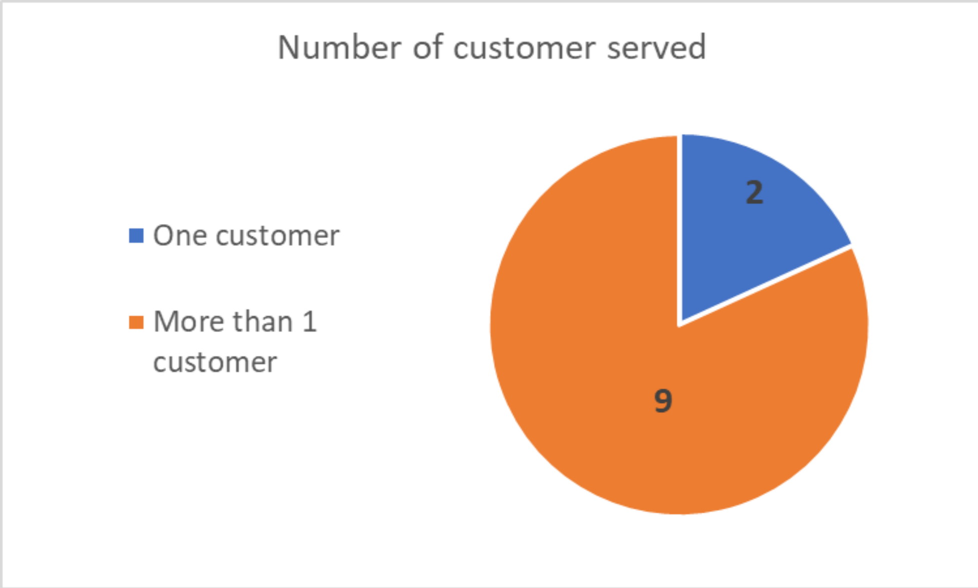


Figure 4-13: Number of customers served

The majority of the analyzed facilities are serving more than one customer, only two of them are working with only one customer. Among the facilities serving more customers, one of them is using E-commerce delivery.

Table 4-5: Facilities serving one or more customers

Facility	1 customer	More than 1 customer
No.1	■	
No.2		■
No.3	■	
No.4		■
No.5		■
No.6		■
No.7		■
No.8		■
No.9		■
No.10		■
No.11		■

As “Customer” is a wide term, it is necessary to point out that, in this question, customer refers to the different companies using the services of the logistics facilities.

5. Which unit load devices are used for unit load formation?

The most popular unit load devices among the consulted logistics facilities are tote pans, cartons and pallets.

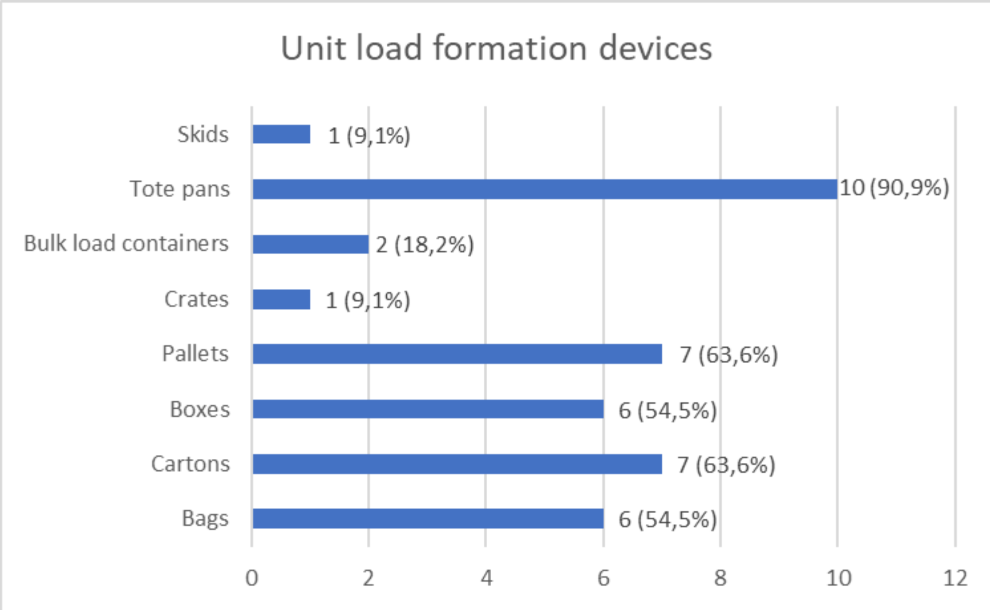


Figure 4-14: Unit load formation devices used in the facilities

Table 4-6: Unit load devices per logistics facilities

Facility	Skids	Tote Pans	Bulk load containers	Crates	Pallets	Boxes	Cartons	Bags
No.1		■			■	■	■	■
No.2		■						
No.3		■			■	■	■	■
No.4		■	■	■	■	■	■	■
No.5		■	■		■			
No.6		■					■	■
No.7		■		■		■	■	■
No.8	■				■	■	■	■
No.9		■						
No.10		■			■		■	
No.11		■				■		

6. Which equipment is used for sorting operations?

The most popular sorting equipment is the Belt conveyor together with the Shoe sorter and manual sorting.

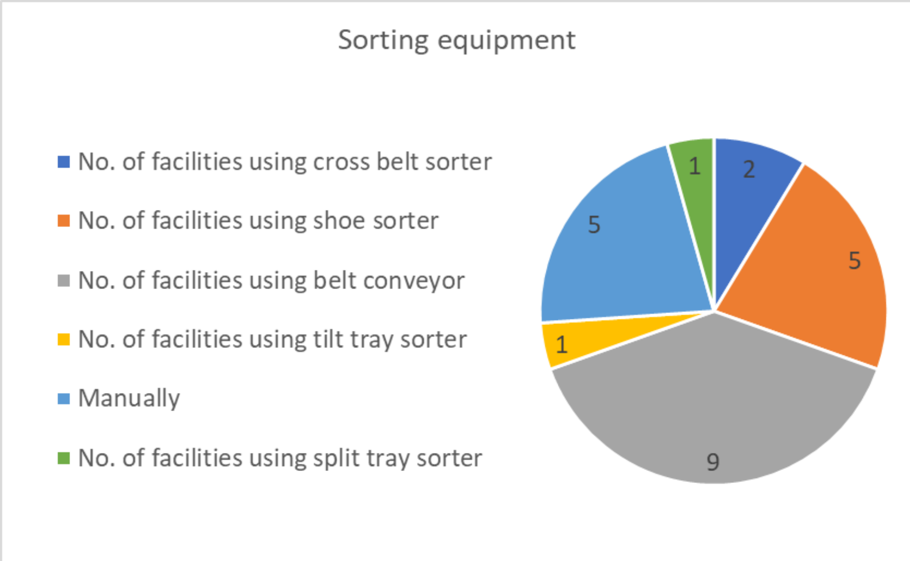


Figure 4-15: Sorting equipment

Table 4-7: Sorting equipment used in the contacted logistics facilities

Facility	Cross belt conveyor	Shoe Sorter	Belt conveyor	Tray sorter	Manually	Tilt tray sorter
No.1		■	■			
No.2						
No.3		■	■			
No.4	■	■	■	■	■	■
No.5	■		■		■	
No.6						
No.7		■	■			
No.8		■	■		■	
No.9			■			
No.10			■		■	
No.11			■		■	

Facility No. 2 didn't provide any information regarding sorting equipment while facility No. 6 uses equipment which was not among the available options in the given list: split tray conveyor.

Based on the definitions exposed in Chapter 2.2 and within the context of this master thesis, the main function of a conveyor is to move goods from one place to another and a sorter sorts goods inside of the logistics facility.

7. Does the facility serve as storage?

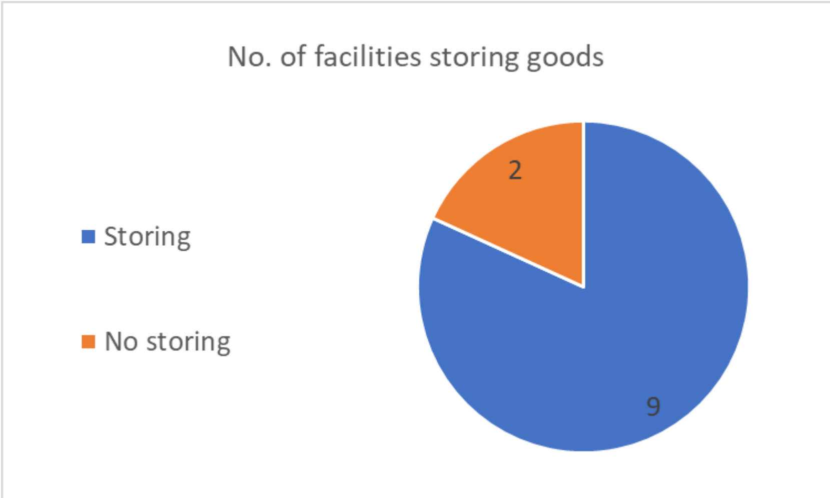


Figure 4-16: Number of facilities storing goods

7.1 If yes, which storage equipment is used for storing operations?

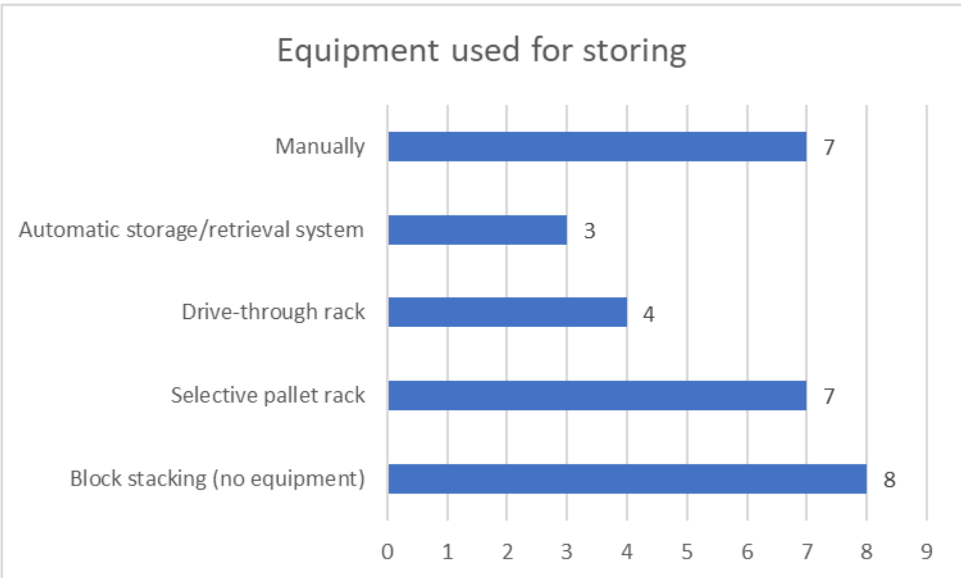


Figure 4-17: Number of facilities using storing devices

Table 4-8: Equipment used in storing operations by each facility

Facility	Manually	Automatic Storage/retrieval system	Drive-through rack	Selective pallet rack	Block stacking (no equipment)
No.1				■	■
No.2	■	■	■	■	■
No.3			■	■	■
No.4	■		■	■	■
No.5	■			■	■
No.6	■	■			■
No.7					
No.8	■		■		■
No.9	■	■		■	■
No.10					
No.11	■			■	

All the contacted facilities are working as a storage except for facilities No.7 and No.10.

The facilities storing goods don't have a specific area for that purpose, they use a random area of the facility where they storage goods with the help of the equipment mentioned in the Table 4-8 or manually, which means simply done by hand by an operator.

8. Are there short-term storage areas such as Buffers within the facility?

All the contacted facilities are using short-term storage areas like buffers.

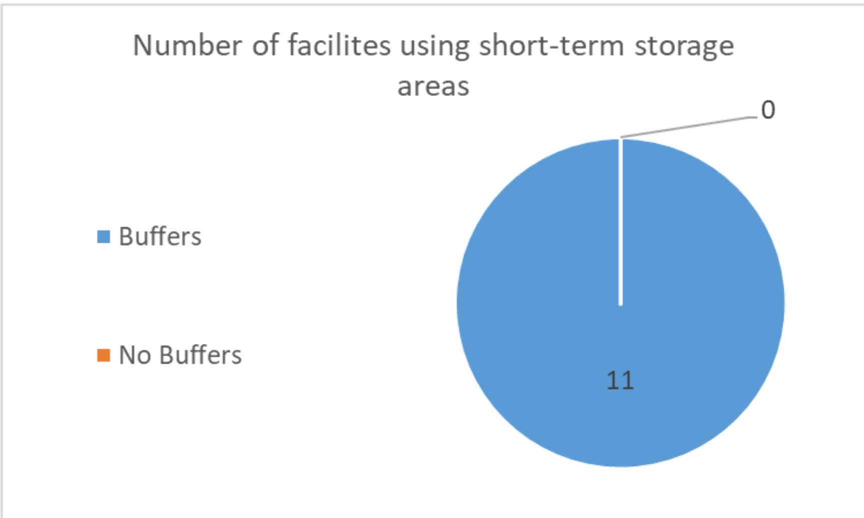


Figure 4-18: Facilities using buffers

8.1 If yes, is the storage in the buffer manual or automated done?

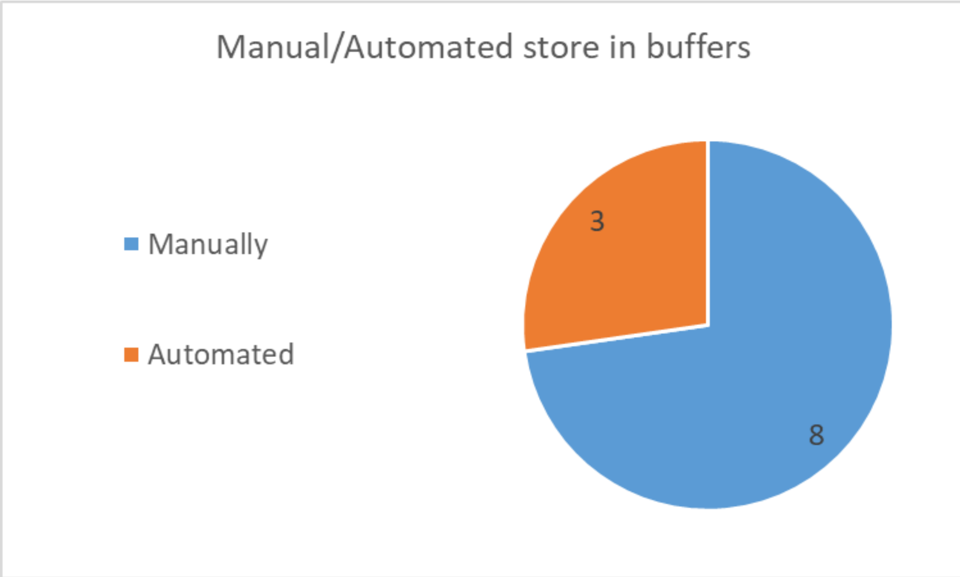


Figure 4-19: Number of facilities using manual and automated store in buffers

Table 4-9: Facilities with manual and automated store in buffers

Facility	Manually	Automated
No.1	■	
No.2	■	
No.3	■	
No.4	■	
No.5	■	
No.6	■	
No.7	■	
No.8		■
No.9		■
No.10		■
No.11	■	

Facilities No.8, No.9 and No.10 are the only ones with an automated system, they didn't provide further details about the equipment, but having an automated storage means that the storage operations are done by an automated storage system without the support of human operators. On the other side, the rest of the facilities have a manual storage, so the process is only done by human operators without any automated system.

9. How are the goods transported (moved) inside of the facility?

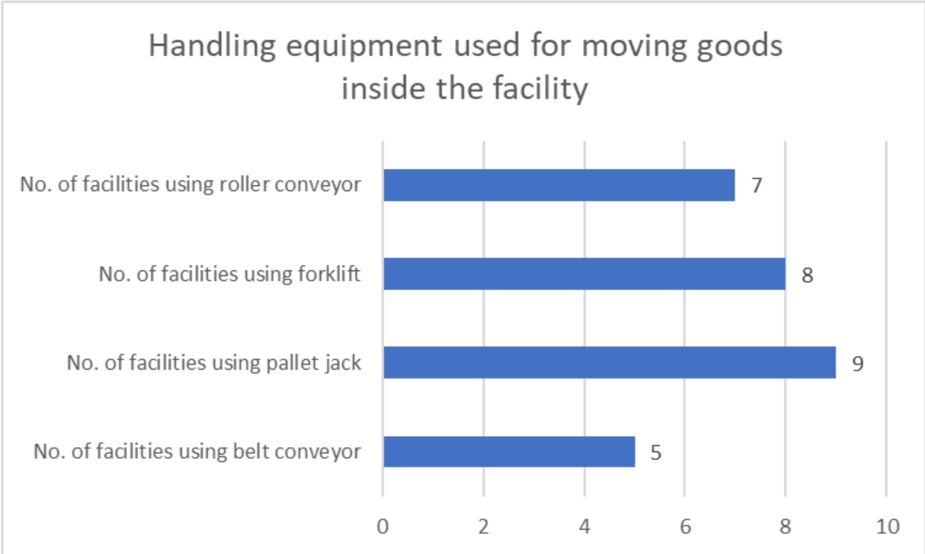


Figure 4-20: Handling equipment for moving goods inside the facility

The goods need to be transported around different locations inside of the facility and the most popular material handling equipment for this task are pallet jacks and forklifts.

Table 4-10: Handling equipment used to move goods inside the facility

Facility	Roller conveyor	Forklift	Pallet jack	Belt conveyor
No.1	■	■	■	■
No.2	■	■	■	■
No.3			■	■
No.4	■		■	
No.5	■	■	■	■
No.6	■			
No.7		■	■	
No.8		■	■	■
No.9	■			
No.10		■	■	
No.11	■	■	■	■

10. Are the means of transport unloaded manually or automated?

Even though not all the contacted facilities provided an answer to this question, it is possible to observe that the majority of them prefer to unload goods manually.

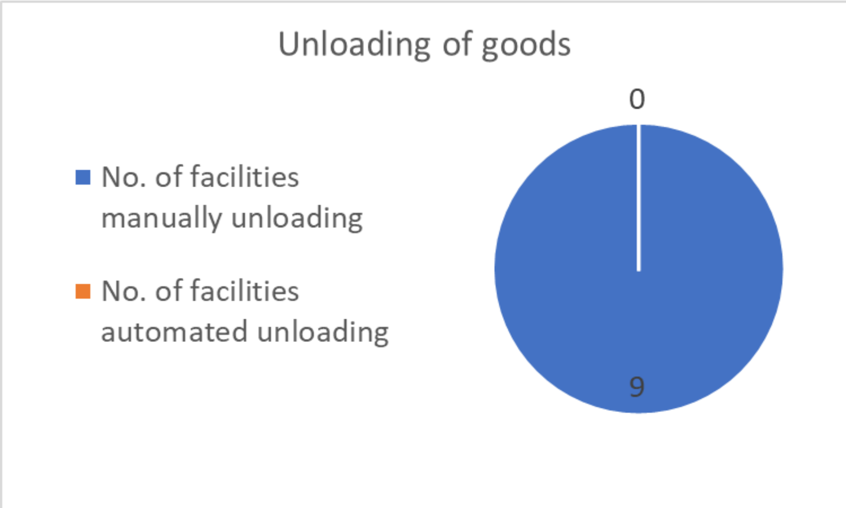


Figure 4-21: Unloading of goods overview

10.1 Which equipment is used for unloading goods?

A more detailed overview of the equipment used for unloading is given in Figure 4-22 and Table 4-11.

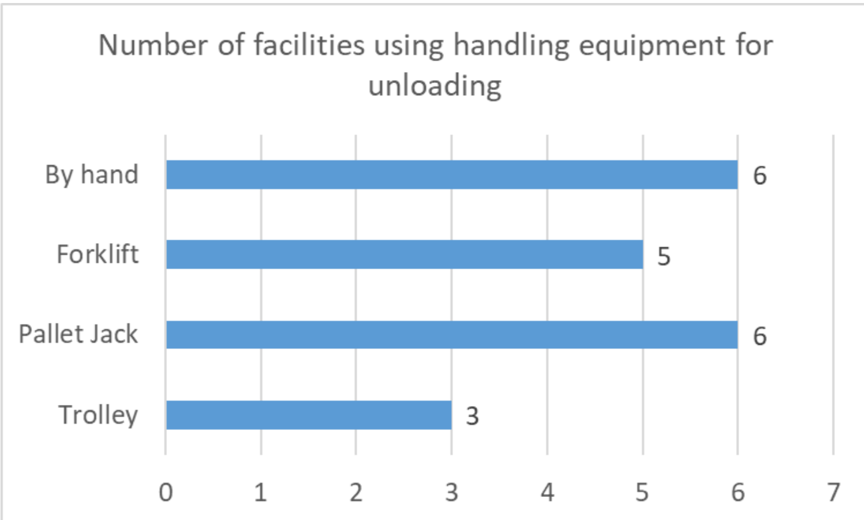


Figure 4-22: Number of facilities using forklifts, pallet jacks, trolleys or by hand

Table 4-11: Handling equipment used for unloading

Facility	By hand	Trolley	Pallet jack	Forklift
No.1		■	■	■
No.2				
No.3		■	■	■
No.4	■		■	
No.5	■			
No.6	■			
No.7	■		■	■
No.8	■		■	■
No.9				
No.10	■	■		
No.11			■	■

Facilities No.2 and No.9 didn't provide information about the equipment used for unloading goods. The rest of the facilities unload goods using exclusively manual means, human operators are needed to execute the tasks.

11. Are the means of transport loaded manually or automated?

Not all the facilities gave feedback to this question, but the ones that did, used manually loading as main mean of loading goods.

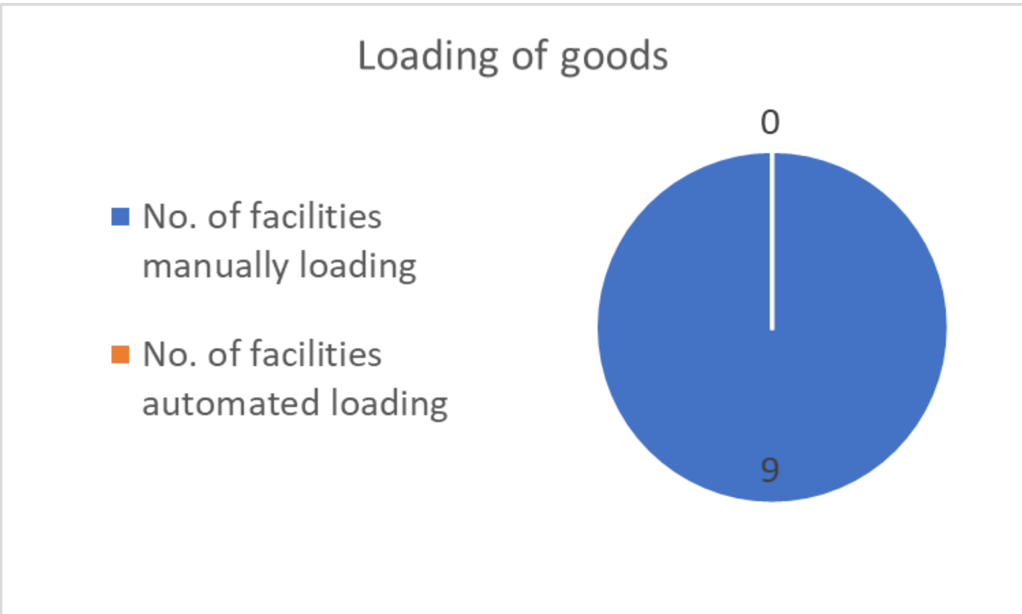


Figure 4-23: Loading of goods

11.1 Which equipment is used for loading goods?

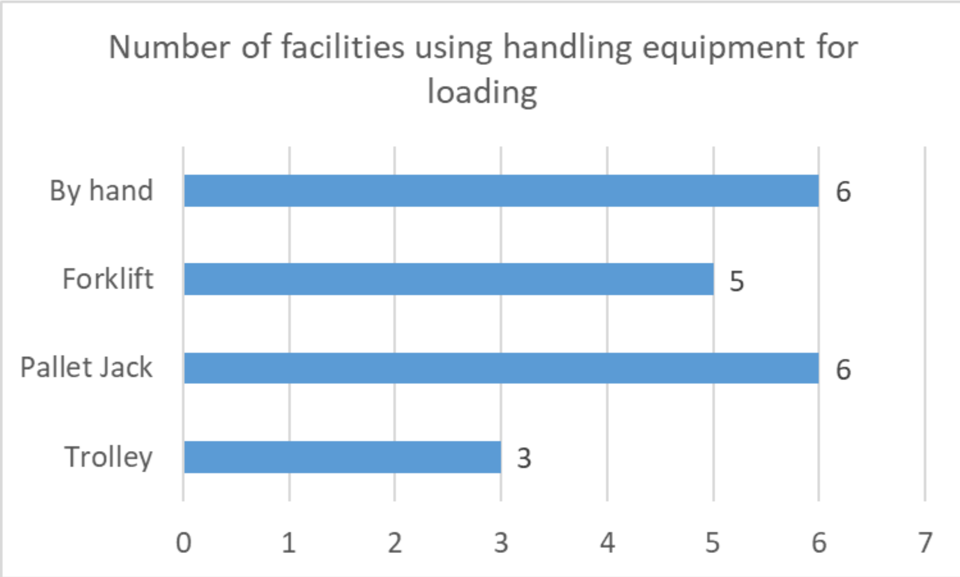


Figure 4-24: Number of facilities using forklifts, pallet jacks, trolleys or by hand.

Table 4-12: Handling equipment for loading means of transport

Facility	By hand	Trolley	Pallet jack	Forklift
No.1		■	■	■
No.2				
No.3		■	■	■
No.4	■		■	
No.5	■			
No.6	■			
No.7	■		■	■
No.8	■		■	■
No.9				
No.10	■	■		
No.11			■	■

Facilities No 2 and No 9 didn't give any information about which handling equipment they use for loading means of transport. The rest of the contacted logistics facilities use manual equipment or by hand which rely on human operator work.

12. Is the facility using different external means of transport for arrival operations?

Ten out of eleven logistics facilities provided feedback to this question.

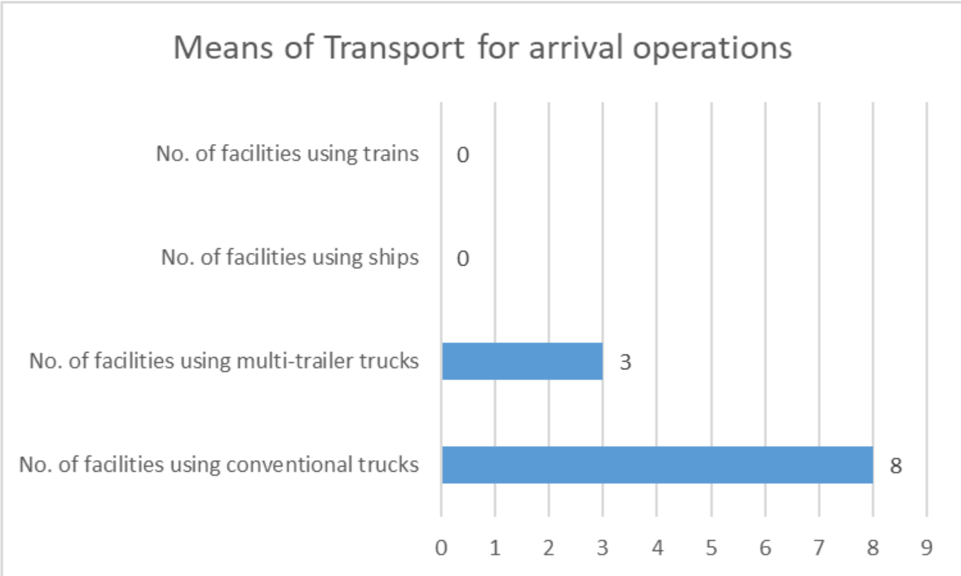


Figure 4-25: Means of transport used for arriving operations

Table 4-13: Main means of transport used for arrival operations

Facility	Ship	Train	Conventional Truck	Multi-trailer truck	Other
No.1			■		
No.2					
No.3			■	■	
No.4			■	■	
No.5			■		
No.6					■
No.7			■	■	
No.8			■		
No.9			■		
No.10					■
No.11			■		

Facility No.2 didn't an answer. Facilities No.6 and No.10 use vans as main mean of transport. Based on the feedback obtained, it is possible to conclude that conventional truck and multi-trailer truck are still the most popular options when it comes to arrival operations, ship are train are still options that haven't been reflected in the answers obtained through this questionnaire.

13. Is the facility using different external means of transport for departing operations?

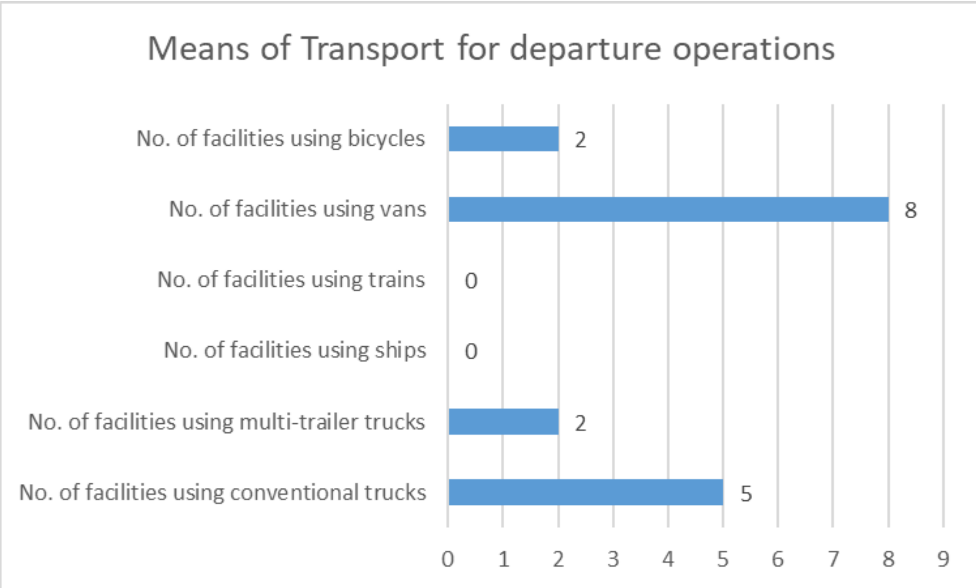


Figure 4-26: Means of transport used for departure operations

Table 4-14: Detailed view of means of transport used for departure operations

Facility	Bicycle	Van	Train	Ship	Conventional Truck	Multi trailer Truck	Other
No.1					■		
No.2		■					
No.3					■	■	
No.4		■			■		
No.5		■					
No.6							■
No.7		■			■	■	
No.8	■	■			■		
No.9		■					
No.10	■	■					
No.11		■					

Facility No.6 uses motorbikes for departure operations. Ships and trains are still not in use in the contacted facilities, vans and conventional trucks are the options chose for the majority. Bicycles represent a new trend in the freight transportation.

14. Are the processes inside of the hub managed by a Warehouse Management System?

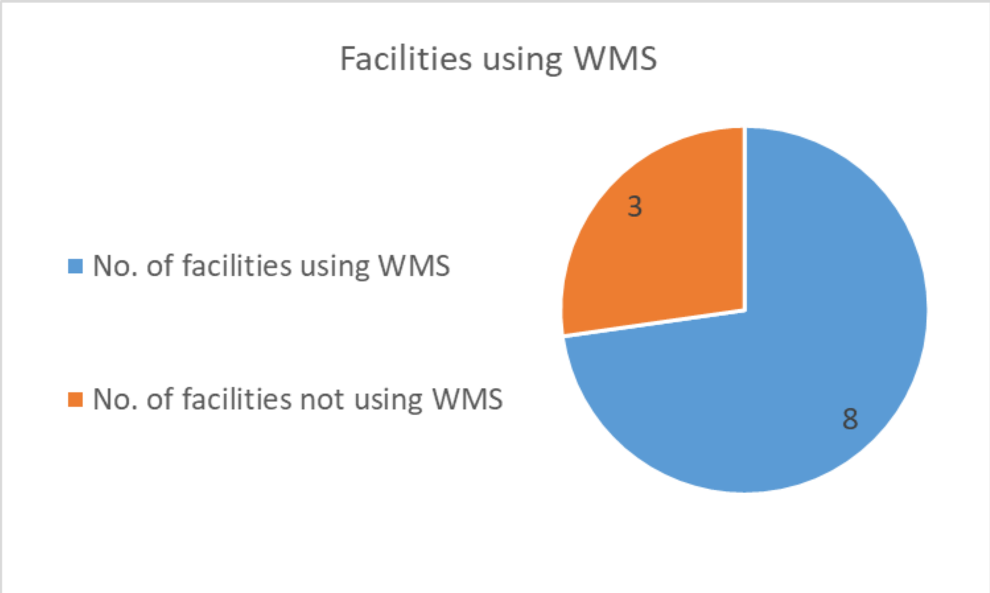


Figure 4-27: Facilities using WMS

Table 4-15: Facilities with/without WMS

Facility	WMS	No WMS
No.1		■
No.2	■	
No.3	■	
No.4		■
No.5	■	
No.6		■
No.7		■
No.8	■	
No.9	■	
No.10	■	
No.11	■	

14.1 If yes, which one?

The definition of WMS is exposed in Chapter 2.2.

Facilities **No.1**, **No.6** and **No.7** don't use any Warehouse Management System.

Facilities **No.2**, **No.3**, **No.4** and **No.8** use WMS but didn't specify which one.

Facilities **No.5**, **No.9**, **No.10** and **No.11** use WMS and the systems have been detailed in the table below.

Table 4-16: Different WMS used by some of the contacted companies

Facility	WMS
No.5	Delage
No.9	SAP
No.10	SAP
No.11	Own development

15. Is there a Planning Software used for assignment of leaving goods?

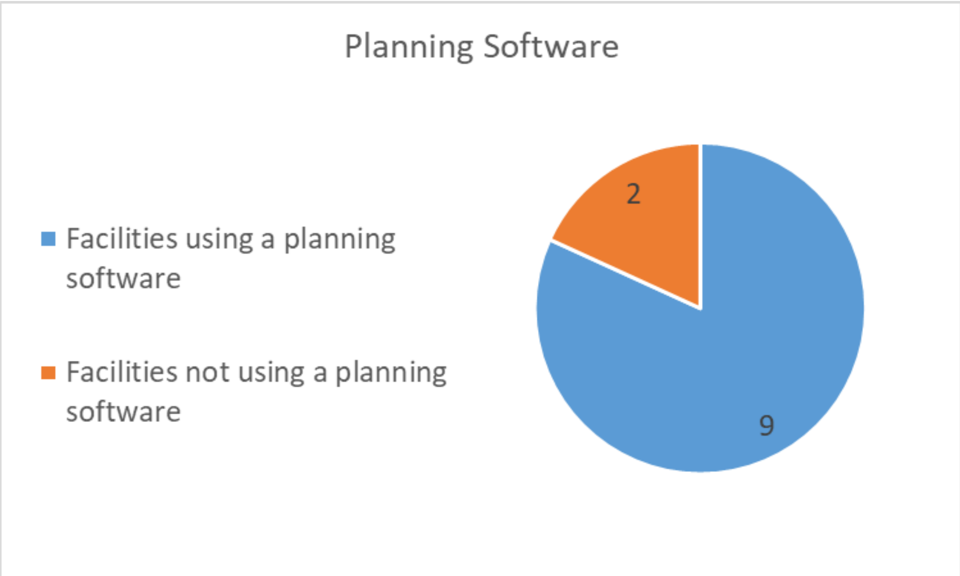


Figure 4-28: Number of facilities using/not using Planning Software

There is a correlation between the facilities using WMS and Planning Software, therefore, facilities with WMS use planning software. Facilities not using WMS don't have a planning software either.

16. Is there any kind of Identification System used for incoming goods?

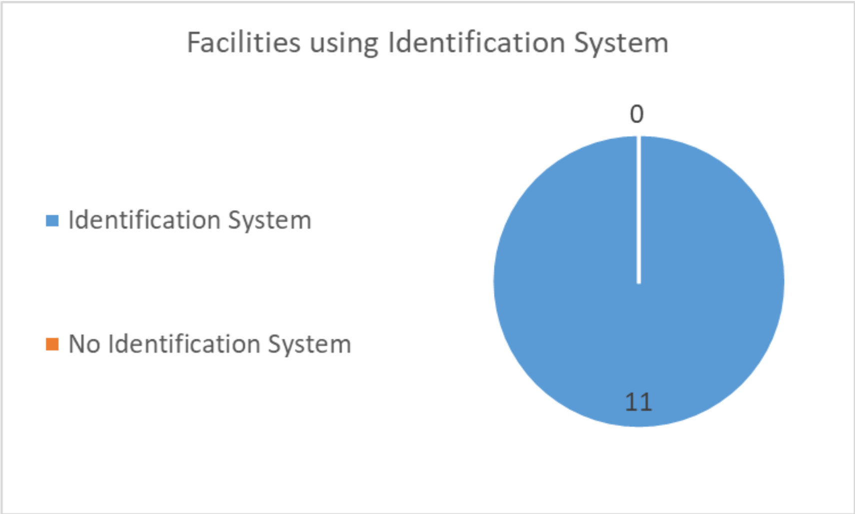


Figure 4-29: Number of facilities using Identification System

The totality of the consulted facilities have an Identification System for the incoming goods.

16.1 Which identification systems are used?

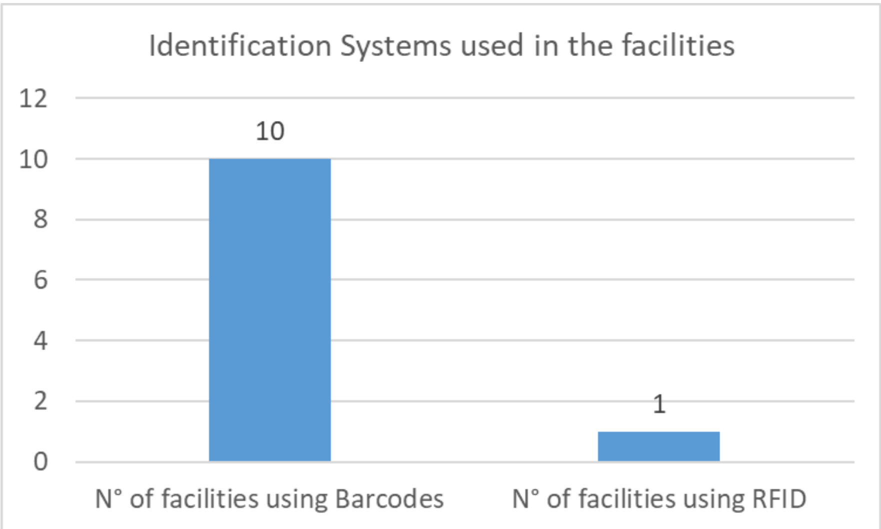


Figure 4-30: Facilities using Barcodes and RFID

All the consulted facilities were using with Barcodes as Identification System, except for facility No.6, which is using RFID technology as well.

17. Is the good's Identification manual or automated done?

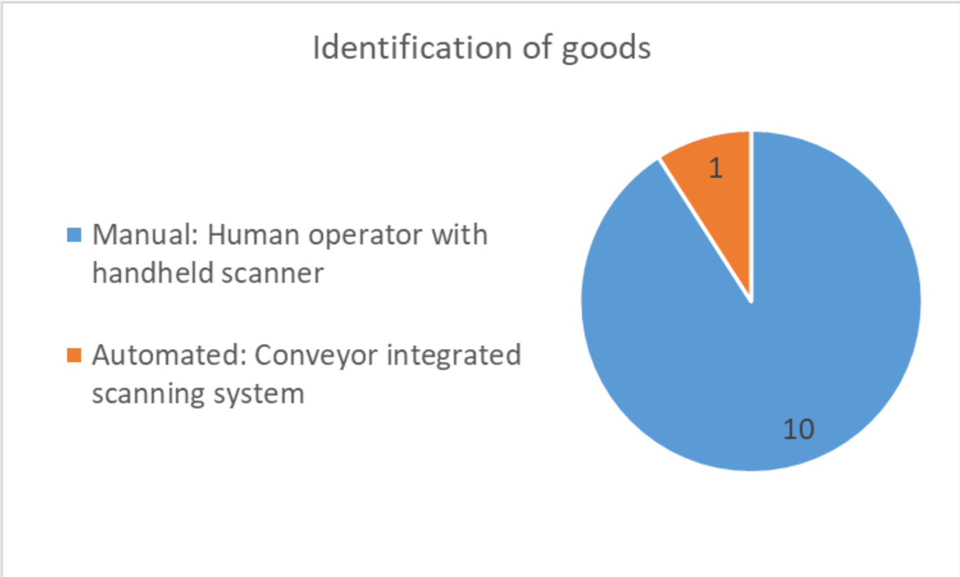


Figure 4-31: Manual/Automated identification of goods

All the investigated facilities, except facility No.6, were identifying goods manually, which means a human operator with a handheld scanner scans the goods. Facility No.6 identifies goods with an automated system, this system consists in a conveyor with an integrated scanning system which reads the data when the goods are passing the scanners automatically, human interaction is not necessary in this case.

18. In your opinion, which are the potential improvements for the current processes carried out in the hubs?

Not all the reached facilities gave an answer to this question. Among the collected responses the main improvements for the current processes are the following:

- → Higher automation in the processes
- → More standardization. Better WMS
- → Reduction of waiting times between processes
- → Different way of packaging goods

18.1 What needs to be done differently for being more efficient?

The major suggestions regarding the improvement of efficiency were:

- → Eliminate manual work through the processes
- → Automated replenishment of goods
- → Automated tracking of pieces for identification of goods

4.4 Research about existing material handling equipment

The questionnaire helped to get an approach of the material handling equipment used in the present logistics facilities. This research reveals the techniques used in the intralogistics processes nowadays. The processes and its corresponding MHE based on Table 4.1 are:

1. **Unit load formation**

The main devices for unit load formation used in the contacted facilities were:

- Boxes
- Bags
- Cartons
- Tote pans
- Bulk load containers
- Pallets
- Crates
- Skids

Unit load formation can be divided in two categories, composers and containers. Composers for building the unit loads and containers that contain the goods, equivalent to PI Containers and PI Composers.

→ **Composers**

→ **Shrink-wrap/stretch-wrap:** used for stabilization. Allows irregular load to be stabilized. In shrink-wrapping a film or a bag is put over the load, after that, heat is put in to shrink the film or bag; the majority of shrink-wrap is being replaced by stretch wrap, which is a film wrapped around the load while it is stretched, the costs for material, labor and energy are lower. A sketch of the stretch-wrap machine is presented in Figure 4-32. [KAY12]

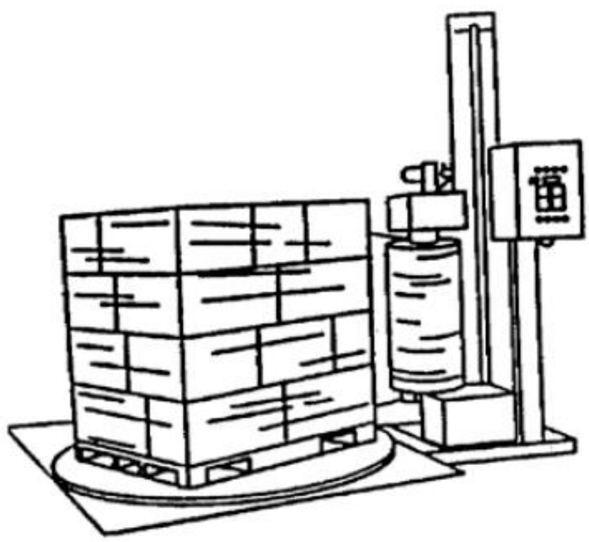


Figure 4-32: Stretch-wrap machine [KAY12]

→ **Robotic palletizer**: automated device used to form the unit load. Most utilized when flexibility is required. Picks up goods and then located them at desired location. Figure 4-33 shows a robotic palletizer. [KAY12]

Figure 4-33: Robotic palletizer [BAST19]

→ **Conventional stripper plate palletizers:** automated device used to form unit loads. Most common if a high throughput of identical loads is required. Figure 4-34 shows a conventional stripper plate palletizer. [KAY12]

Figure 4-34: Conventional stripper plate palletizer [AMP19]

→ <u>**Containers**</u>

→ **Intermodal containers:** used to unitize the load and for transferring load between road, rail, and sea transport. This container can be unloaded from a cargo ship and loaded into a truck. They are not used for air transport due to size and weight restrictions. Figure 4-35 shows an intermodal container. [KAY12]

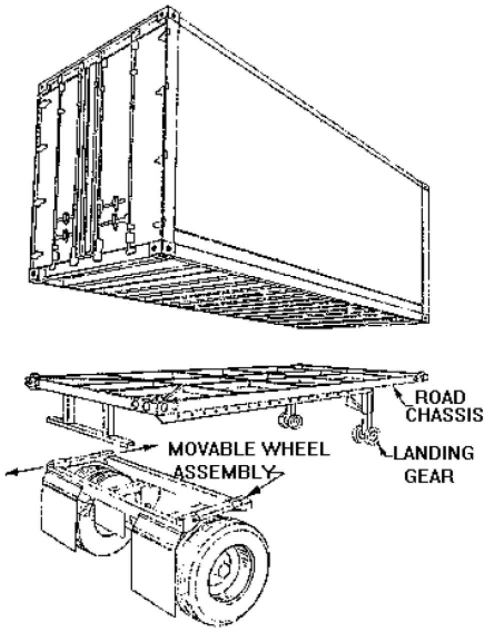


Figure 4-35: Intermodal container [KAY12]

→ **Smart containers:** companies around the world are taking advantage of the Internet of Things and starting to develop smart containers for logistics. A smart container is shown in Figure 4-36. [SMR19] [CMA19]

Figure 4-36:Smart containers [SMR19]

These containers are designed safe and temperature-controlled containers that can aid the transport of goods (especially sensitive goods like food or medicines). They send real-time data of the containers' movement and condition for more transparency, safety and cost-efficiency. The benefits of smart containers are shown in Figure 4-37. [SMR19] [CMA19]

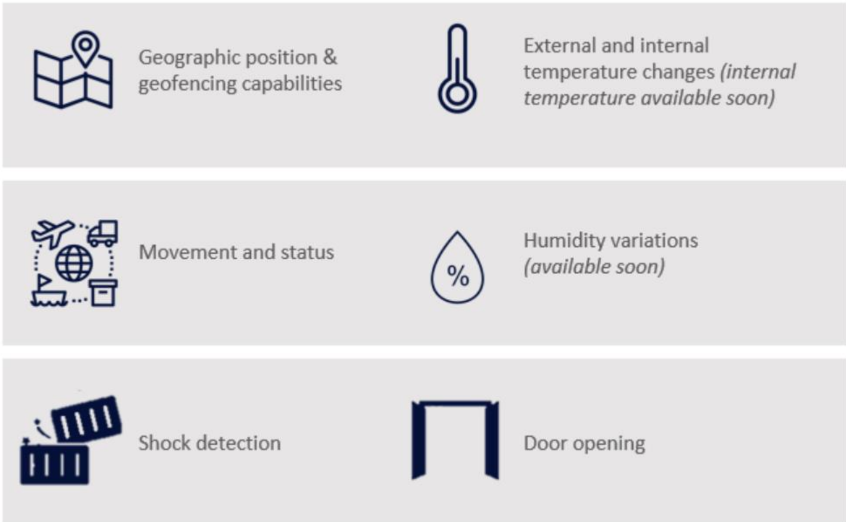


Figure 4-37: Benefits of smart containers [CMA19]

2. <u>Storing and buffering goods</u>

The main elements for storing and buffering goods used in the contacted facilities were:

- Block stacking
- Selective pallet rack
- Drive-through rack
- Automatic storage/retrieval system
- Manually

Further research has found the following devices:

→ **Storage carousel:** involves a set of horizontally or vertically storage baskets or bins, that allows a high number of items to be picked at a high rate. [KAY12]

As it can be appreciated in Figure 4-38, an operator picks up to 4 carousels to reduce the waiting time while other carousels keep moving. Each level of the carousel rotates independently in clockwise or counter-clockwise direction. [KAY12]

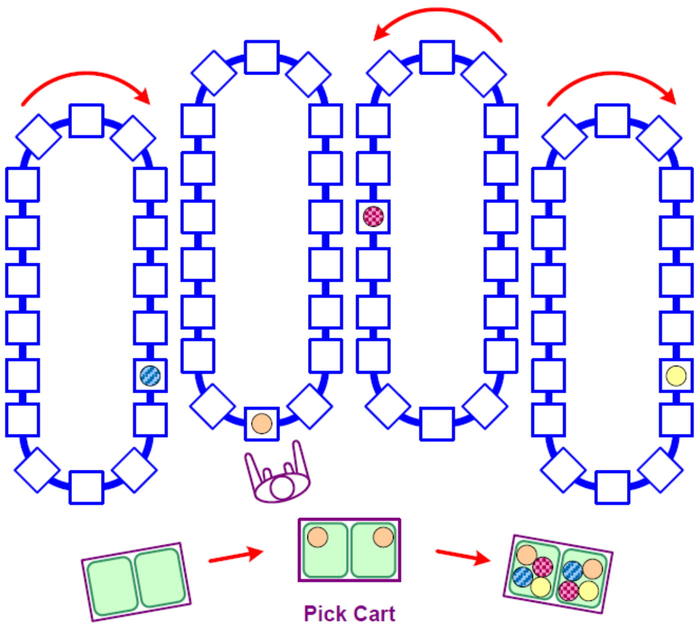


Figure 4-38: Storage carousel [KAY12]

→ **Vertical lift module:** goods are stored in trays inside a multi-bay enclosure that are delivered to the opening of a bay for picking by a servo-driven lift carriage. It has a dense storage because the height of trays can change. It provides high security compared to other storage methods, because the module is often controlled by computers, which makes the costs higher. Figure 4-39 shows a vertical lift module. [KAY12]

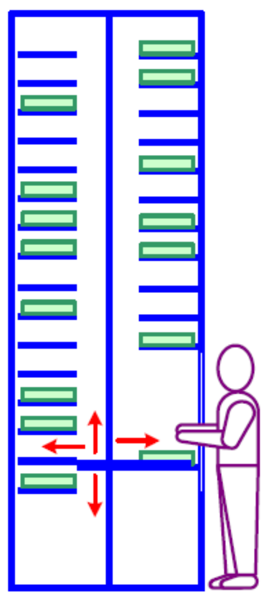


Figure 4-39: Vertical lift module [KAY12]

→ **A frame:** Units are disposed in parallel array of vertical angled channels onto a belt conveyor that moves them into a container. It has a high picking rate but requires manual replenishment. A frame storage is shown in Figure 4-40. [KAY12]

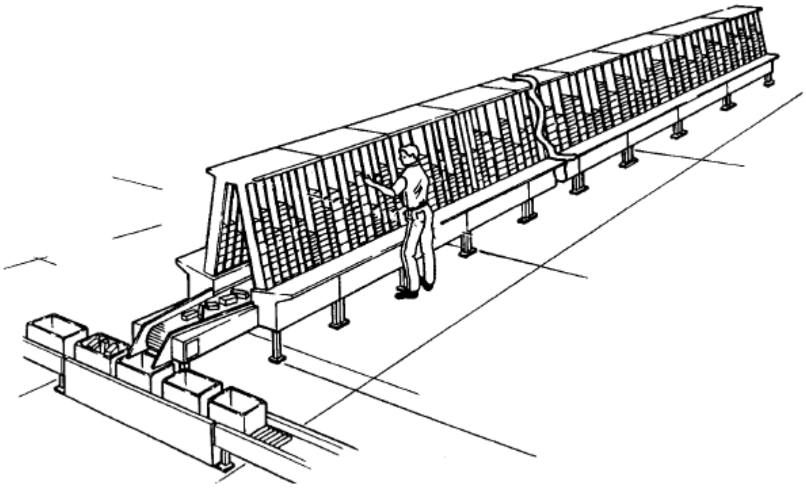


Figure 4-40: A frame [KAY12]

→ **Mezzanines:** they are mainly a platform built in the warehouse floor space, which provides another level of storage. The costs are high, but it is possible to dismantle them in case of relocation of the facility. Figure 4-41 shows mezzanines storage. [GLO19b]

Figure 4-41: Mezzanine [GLO19b]

→ **AutoStore systems:** it is a space efficient warehouse system. It has no shelves but instead stacks bins in a self-supporting modular aluminum grid. The frameworks simultaneously serve as rails for the AutoStore robots. This cubical automated system takes the merchandise to the locations where products are loaded and unloaded. A highly sophisticated control system is armed with warehouse management data and coordinates the order picking process in a fully automated manner. [IXT19]

It provides better use of available space than any other automated system thanks to its unique design that enables direct stacking of bins on top of each other and storage of multiple SKUs in a single bin. [IXT19]

Figure 4-42: AutoStore robots [IXT19]

Figures 4-42 and 4-43 show an autoStore system and the robots used for picking bins.

Figure 4-43: Autore systems [IXT19]

→ **3D Matrix Solution:** the matrix consists of three elements: shuttle vehicles, lifts and conveying systems. The shuttle vehicles work on the X-axis in the depth of the storage channels. Lift systems provide vertical transport on the Y-axis. The conveyor systems handle the horizontal transport on the Z-axis and provide the goods directly to the connected picking or dispatch work stations. All the movements which transport devices carry out in the facility are in the X, Y and Z axes, which allows them all to be carried out in parallel. [SSI19] Figure 4-44 shows a 3D Matrix solution.

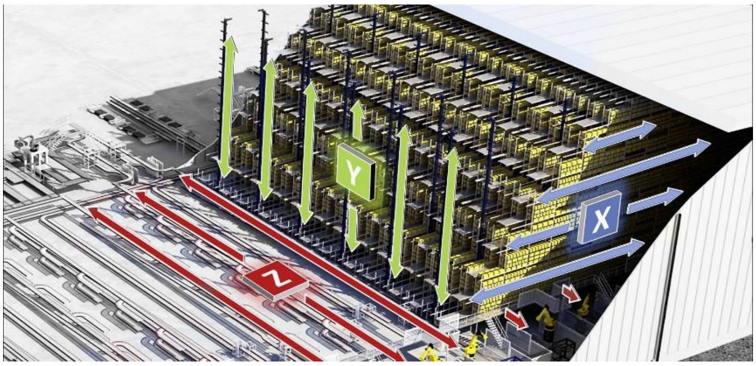


Figure 4-44: 3D Matrix Solution [SSI19]

3. <u>Conveying</u>

The main elements for conveying goods used in the contacted facilities were:

- Belt conveyor
- Roller conveyor
- Manually

Further research has found the following devices:

→ **Vertical conveyor:** Utilized for low frequency vertical transfers a load to another floors and mezzanines. Unlike freight elevators it is not designed or certified to carry people. They can be manually or automatically loaded and controlled and can interface with horizontal conveyors. A vertical conveyor is shown in Figure 4-45. [KAY12]

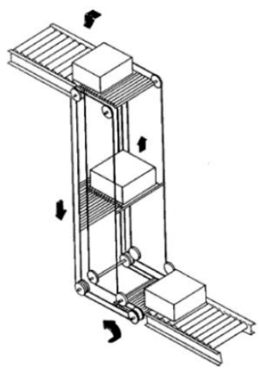


Figure 4-45: Vertical conveyor [KAY12]

→ **Slat conveyor:** uses discretely spaced slats connected to a chain, the units being transported keeps its position. The orientation of the load is controlled. A sketch of a slat conveyor is shown in Figure 4-46.[KAY12]

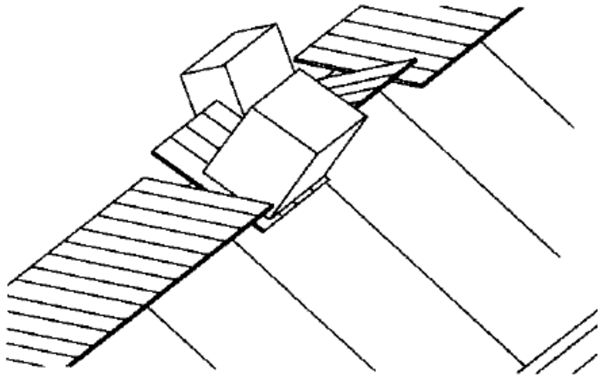


Figure 4-46: Slat conveyor [KAY19]

→ **Omnidirectional conveyor:** it is a highly flexible modular conveying and positioning system that is based on the approach of cellular conveying technology. Small hexagonal modules contain specially arranged omnidirectional wheels, which are individually and selectively controlled. This enables the logistics operator to move and to position several objects simultaneously and independently on any track. They can move objects in any direction. Figure 4-47 shows an omnidirectional conveyor.[CELL19]

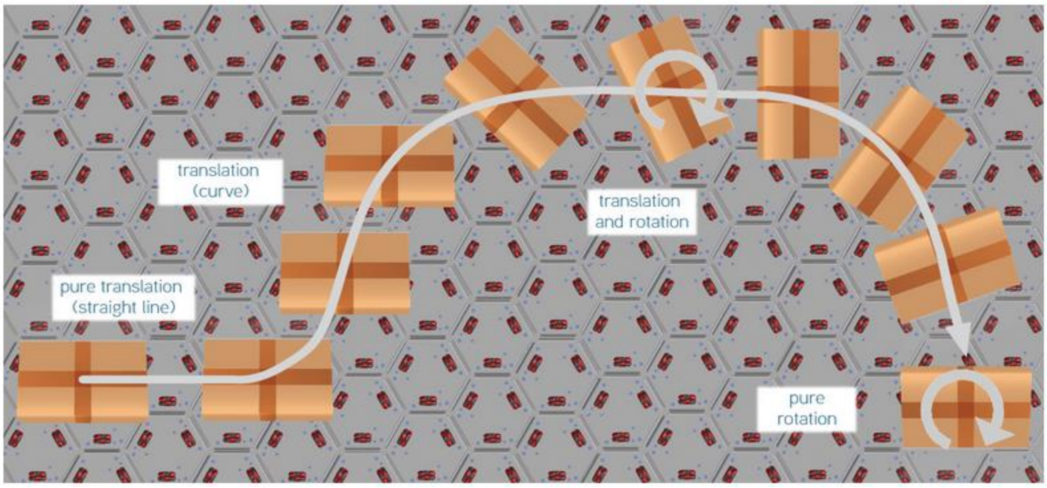


Figure 4-47: Omnidirectional conveyor [CELL19]

→ **Flexible conveyors:** They are ideal for environments with ever changing material handling conveyor situations. They are designed to be flexible and expandable as required. Figure 4-48 shows a flexible conveyor. [WEC19]

Figure 4-48: Flexible conveyor [IND19]

→ **Overhead conveyors:** uses a continuous chain running on a stationary, flanged rail. Individual carriers spaced along the length of the conveyor are suspended from the chain. The chain pulls the carriers. Vertical support is derived from the fact that the carriers are also connected to a small trolley with wheels that roll cross sections, trolleys and carriers. Overload conveyors are shown in Figure 4-49. [SOL19]

Figure 4-49: Overhead conveyors [PAC19]

4. Loading/unloading means of transport

The main elements for loading/unloading means of transport used in the contacted facilities were:

- Forklift
- Trolley
- Pallet jack
- Manually

Further research has found the following devices:

→ **Autonomous vehicles for loading/unloading:** they don't just transport goods but also load and unload to increase the efficiency of an entire process. Self-driving vehicles can also significantly increase safety in transport and loading processes. [HK14]

Examples of autonomous vehicles are the following:

Auto Pallet Mover. It is an autonomous forklift that travels to pre-defined locations using laser navigation technology. This self-driving pallet mover can be used throughout the warehouse, from receiving goods all the way through to transition points close to the shelves. [HK14]

Figure 4-50: Auto Pallet Mover [HK14]

A separate control system ensures infrastructure planning, vehicle coordination, and traffic flow optimization. Extensive safety features contribute to collision-free operation in any warehouse environment. [HK14]

Recent developments go beyond pure navigation to also integrate features such as barcode scanning, pallet detection, and pallet stacking, as well as autonomous stops and slow-down. Figure 4-50 shows an auto pallet mover [HK14]

→ **Robotic truck loading/unloading:** In the distribution systems, floor loading of road trailers and shipping containers is common. To automate the process, robotic technology to automatically load and unload cases as well as other products have been developed: [WYN19]

Palletized AGV trailer loading: An automated solution for loading trailers with palletized products. Integrated guided vehicles, capable of safely and automatically loading road trailers. [WYN19]

Robotic truck unloading: The robot drives intro the trailer using navigation sensors. A telescoping conveyor is attached to the back of the robot and follows it in and out of the trailer. [BAST19]

Robotic truck loading: Same functionality as robotic truck unloading, this system can stack directly onto the floor of a truck or a container. The robotic truck loading is shown in Figure 4-51. [WYN19]

Figure 4-51: Robot for automated loading/unloading of trucks [BAST19]

5. **<u>Transporting (moving) goods inside the facility</u>**

The main elements for transporting goods inside the facility used in the contacted facilities were:

- Belt conveyor
- Roller conveyor
- Pallet jack
- Forklift

Further research has found the following devices:

→ **Rolltainer:** is a load carrier with rollers for rapid cargo handling, provided by two or four lateral support walls with a tubular steel construction that is used for transporting load inside the facility and to the means of transport. Figure 4-52 shows a rolltainer [WIK19b].

Figure 4-52: Rolltainer [LOG19b]

→ **Platform truck:** utilized to move non-palletized loads. It has good lifting capacity, better than fork trucks because the platform provides a greater lifting surface to support a load. [KAY12]

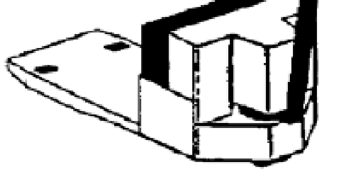


Figure 4-53: Platform truck [KAY12]

→ **Autonomous vehicles for transporting (moving) goods inside the facility:** self-driven vehicles move goods inside the facility.

Some examples of self-driven vehicles are the following:

MultiShuttle move. A swarm of self-driving vehicles handling small load carriers and pallets, and operating almost anywhere. Vehicles communicate and coordinate tasks among themselves each using radio interface communication and laser navigation technology. The overall system is able to adapt its capacity to seasonal and daily fluctuations, and to changing orders, customer's preferences and product structures. Figure 4-54 shows swarming vehicles. [HK14]

Figure 4-54: Swarming vehicles move swiftly and autonomously [HK14]

KARIS PRO System. This system displays a flexible and scalable number of small autonomous vehicles that either transport small goods alone or connect with other vehicles to form a flexible conveyer system. It was developed by the KIT in Karlsruhe, Germany and it is shown in Figure 4-55. [HK14]

Figure 4-55: Small autonomous vehicles in the KARIS PRO System [HK14]

6. Sorting goods

The main elements for transporting goods inside the facility used in the contacted facilities were:

- Cross belt sorter
- Shoe sorter
- Belt conveyor
- Tilt tray sorter
- Manually

Further research has found the following devices:

→ **Pocket sorter:** The sorter is connected to a track system with roller adapters and transports a variety of different sized articles, to simultaneously increase throughput and provide dynamic access to products. A pocket sorter is shown in Figure 4-56. [MAT19]

Figure 4-56: Pocket sorter [MAT19]

→ **Slide tray sorter:** sorts a wide range of products to predefined destinations. The trays enable bi-directional (right-left) sorting, which maximizes the number of exits in a small footprint. There are two types of this sorter: with single and double tray. The selection of model is made based on products dimensions and capacity needs. Figure 4-57 shows a slide tray sorter. [EQU19]

Figure 4-57: Slide tray sorter [EQU19]

→ **Pusher/Puller sorter:** this system works with the support of push arms mounted on the line. It pushes and separates products with the help of pneumatic cylinder or motor. [WEB19]

→ **Pop up transfer sorter:** they use different types of rollers that rise up to grip and divert products in either direction at 90 or 30 degrees to deliver positive and accurate sortation for a variety of product types and sizes. This sorter is ideal for small spaces and high throughput is required. [SDI19]

→ **Bombay sorter:** uses multiple trays on a large sorting wheel that either splits in the middle, drops one side or uses a pushing arm to push product out of the tray at the destination lane. Figure 4-58 shows a Bombay sorter. [CON19]

Figure 4-58: Bombay sorter [CON19]

5 Validation and Evaluation

The present chapter first evaluates the answers obtained through the questionnaires, after, an evaluation of current existing technologies (that were not covered by the questionnaires) is done and last, an overview of the evaluation of present equipment and PI systems is done.

The ultimate purpose of this evaluation is to identify the technology gaps between present material handling equipment and PI systems for handling goods.

The Table 4.1 presented in Chapter 4.2 is used as a reference to develop Table 5.1, which shows for which processes the present Material Handling Equipment is evaluated and the corresponding PI Element.

As mentioned in Chapter 4.1, the WMS and the Identification systems are excluded from the evaluation since they don't have relevance for the present investigation.

Table 5-1: Processes in which the MHE is evaluated and the corresponding PI element

Process	**PI Element**
Transporting (moving)	PI Mover
Loading /Unloading	
Conveying	PI Conveyor
Unit load formation	PI Composer PI Container
Sorting	PI Sorter
Storing	PI Store

The material handling equipment obtained through research and questionnaires is evaluated in the next sections of this chapter.

5.1 Evaluation of material handling equipment used in the contacted facilities

5.1.1 Unit load formation

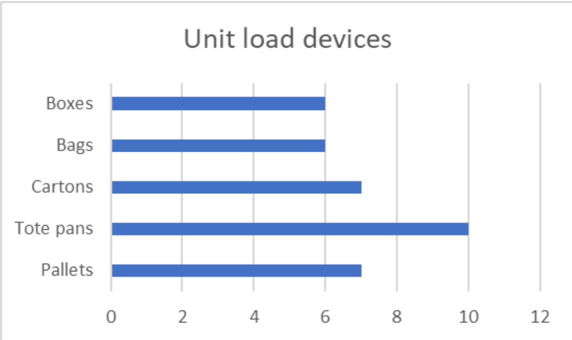
<table>
<tr><th>Present hubs</th><th>PI Hubs</th></tr>
<tr><td>


Figure 5-1: Unit load devices

The main devices are palletizers, boxes, bags, cartons, tote pans and pallets used for unit load formation.
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In the PI the only device used for containing goods are the *PI Containers*, which are smart and ecofriendly modular boxes exclusively designed for PI. [MMB10]

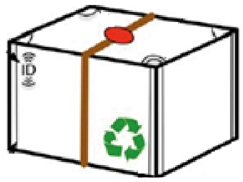

Figure 5-2: PI Conatiner [MMB10]

PI Containers can be stacked and interlocked together to get different sizes. PI Composers are in charge of constructing a composite of PI Containers. [MMB10]

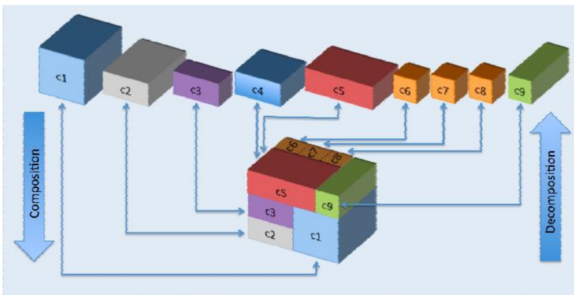

Figure 5-3: PI Composer [MMB10]
</td></tr>
<tr><th colspan="2">Evaluation of PI - Readiness</th></tr>
<tr><td colspan="2">
As mentioned in Chapter 4.2, unit load formation is divided in Containers and Composers. The ultimate function of PI Containers is the same one than the unit load devices mentioned above (boxes, bags, tote pans…) contain goods for handling and transportation. PI Composers have a similar purpose than present palletizers but with the possibility of interlocking PI Containers. It is not possible to determine if
</td></tr>
</table>

PI will use palletizers, and the same occurs with the interlocking devices of PI Containers, as it is not clear the design of the PI Containers and how it will modify the unit load formation process.

The present devices from the consulted hubs don't have any of the characteristics of the PI Containers, which means, for instance, the interlocking and snapping functions are missing. Another important point is the level of automation in the contacted facilities, which in general is very low, and PI will need a higher level of automation, therefore, the evaluation can be rated as *poor*.

5.1.2 Transportation (moving) goods inside the facility

Present hubs

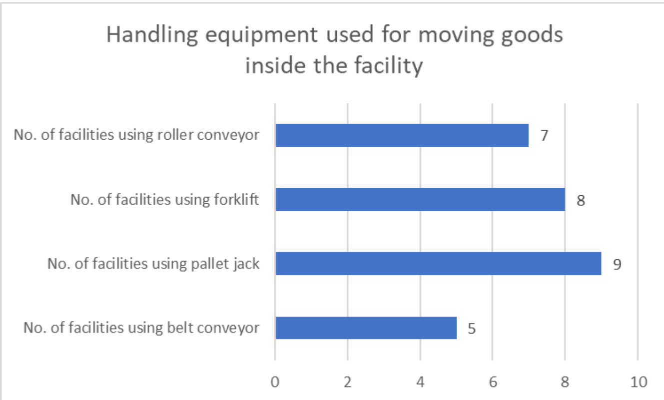

Figure 5-4: Handling equipment used for moving goods inside the facility

The most popular equipment used in the consulted facilities to move goods are roller conveyors, belt conveyor, forklift and pallet jacks.

PI Hubs

In PI Hubs, PI Movers will transport PI Containers from one part of the facility to another.

PI Movers will have to be adapted to the characteristics of PI Containers having features like snapping devices and even smart sensors.

The level of automation of PI Movers is not determined yet and if it would be automated or manually done.

Evaluation of PI - Readiness

The level of automation of PI Movers is not determined yet but it will be higher than in the contacted facilities, which is quite low in the present. PI Movers will be used exclusively for moving PI Containers from one side of the facility to another, therefore, they will have to be adapted to the PI Containers main features. The present equipment don't have the needed characteristics to achieve the movement of PI Containers like stacking devices. In this case, the evaluation can be rated as *poor*.

5.1.3 Storing and buffering goods

<table>
<tr><th>Present hubs</th><th>PI Hubs</th></tr>
<tr><td>

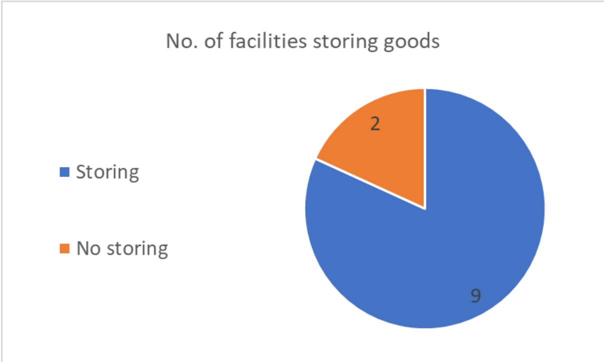

Figure 5-5 Facilities storing goods

The material handling equipment used for storing goods are block stacking, pallet racks, automatic storage/retrieval system and manually. The store in the buffer zones is mainly done manually by a human operator.

</td><td>

PI will have a storage and buffer system but for the moment, it is not very clear what kind of system is going to use. The design and development of PI Stores revolves around PI Containers.

PI Stores will be able to store PI Containers during short or long periods of time and they will be able to interlock, stack and snap the PI-containers, moreover, they don't work with products as stock-keeping units (SKU's). [MMB10]

</td></tr>
<tr><th colspan="2">Evaluation of PI - Readiness</th></tr>
<tr><td colspan="2">

The majority of the consulted facilities are storing goods and all of them have buffers, despite this, it is complex to establish a relationship between present store/buffer areas and PI Stores mainly because present facilities don't have a specific system or zones for this purpose, they simply store goods in specific places or the facility's floor (for buffers). Another important aspect is, as mentioned above, that the PI Store will have to be designed to meet the characteristics of PI Containers, which are completely different from the current unit load devices. Based on this, current storage techniques won't have any value for PI Hubs and therefore the the evaluation is rated as *poor*.

</td></tr>
</table>

5.1.4 Loading/unloading means of transport

Present hubs

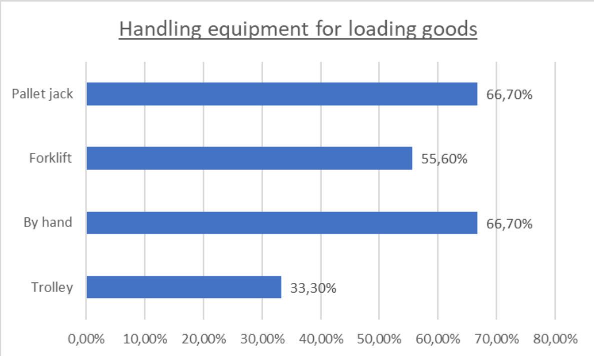

Figure 5-6: Handling equipment for un-loading/loading

Based on the questionnaire results, pallet jacks, forklifts, trolleys and manually by human operator are the most popular techniques for loading/unloading goods.

PI Hubs

PI Movers systems are conditioned by the PI Containers. The design of PI Movers will have to be suitable for handling PI Containers, therefore, a snapping device will have to be designed and included, to allow the attachment of composites of PI Containers with PI Movers. [BMM14]

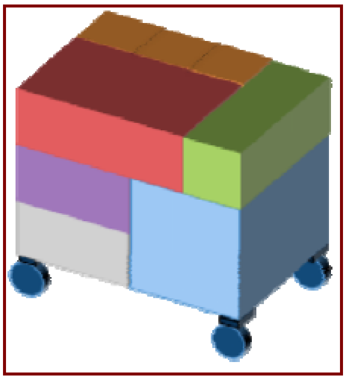

Figure 5-7: Simple PI Mover

Evaluation of PI - Readiness

The most popular equipment for unit load formation are pallets, therefore, the equipment used for loading/unloading the means of transport is adapted to the pallets characteristics. PI will have to design new PI Movers because pallets won't be used anymore, so the current systems used in loading/unloading operations are not suitable for these operations in the PI and based on what is exposed before, the evaluation can be rated as *poor*.

5.1.5 Sorting

Present hubs	**PI Hubs**

Present hubs

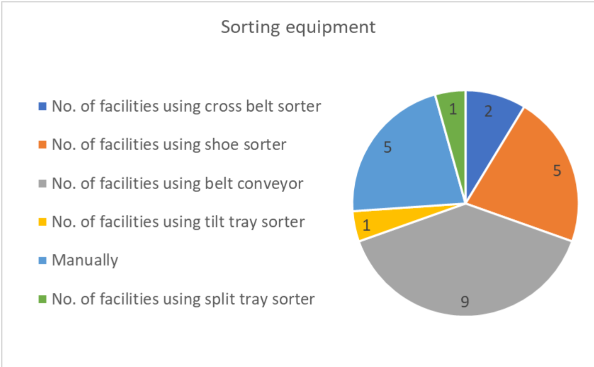

Figure 5-8: Sorting equipment

The most popular equipment for sorting operations among the consulted facilities are cross belt sorters, shoe sorters, tilt tray sorter, split tray sorter and manual sorting by a human operator.

PI Hubs

PI Sorters take part in more complex operations and receive PI Containers from one or various entry points, and sort them to ship each of them from a specified exit point. [MMB10]

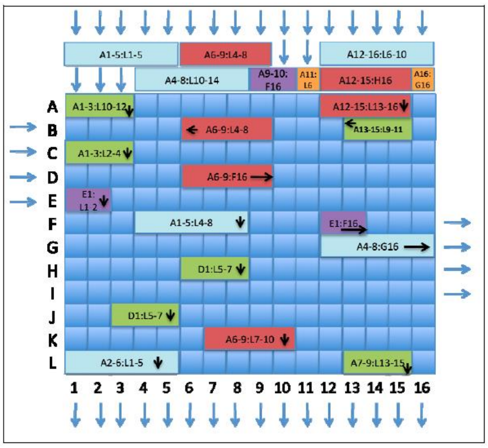

Figure 5-9: Matrix PI Sorter[MMB10]

Evaluation of PI - Readiness

The consulted facilities use sorters for sorting operations and some of them also perform this process by hand with a human operator. But the facilities moving big volumes of goods (more than 30.000 parcels/day) tend to use sorters rather than conveyors.

It is feasible that current sorters could move PI Containers, but PI Sorters will be designed to only move PI Containers, it would impossible for them to move current freight.

In this case, the evaluation can be rated as *poor*, physical design and layout of current sorters is different from PI Sorters, and they don't have the needed devices to handle PI Containers flow.

5.1.6 Conveying

<table>
<tr><th>Present hubs</th><th>PI Hubs</th></tr>
<tr><td>

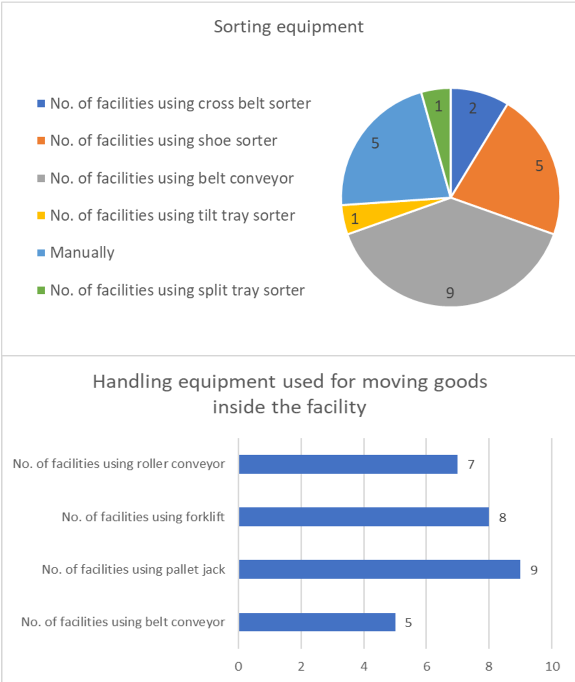

Figure 5-10: Conveyors used in the contacted facilities

The most popular equipment for conveying among the consulted facilities are belt conveyors and roller conveyors.

</td><td>

PI Conveyors are specifically designed for PI Containers, PI Conveyors are different from current ones by not having rollers or belts. PI Conveyors are able to move PI Containers in the four cardinal directions. Their design is simpler because they only need to connect themselves to the tracking mechanics of the conveyor. [MMB10]

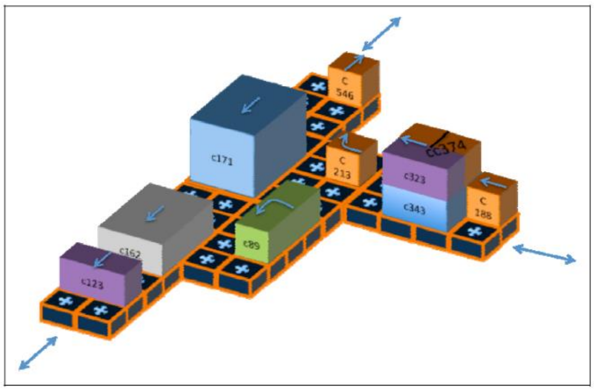

Figure 5-11: PI Conveyor [MMB10]

</td></tr>
<tr><th colspan="2">Evaluation of PI - Readiness</th></tr>
<tr><td colspan="2">

The consulted facilities use conveyors for conveying operations and some of them also perform this process by hand with a human operator. The facilities with small volumes (less than 300 parcels/day) use conveyors or manual techniques with human operators.

It is possible that current conveyors could move PI Containers, but PI Conveyors will be designed to only move PI Containers, it would impossible for them to move current freight.

PI principle is founded on economic and environmental impact reduction, PI Conveyors will be designed without rollers or belts that are a significant part of the overall cost and therefore influence in the environmental footprint of the conveyor.

</td></tr>
</table>

In this case the evaluation can be rated as *poor* because current conveyors differ from the physical characteristics of the PI Conveyors, and PI Conveyors won't be able to move current freight as they are exclusively design for PI Containers.

5.2 Evaluation of existing material handling equipment

The information about the current material handling equipment obtained through questionnaires may not be enough to evaluate the readiness of current technology in the PI Systems, in other words, there is a chance that some existing technologies are not reflected in the gathered data, therefore, an extra investigation about the topic is necessary to assure a complete evaluation about the material handling equipment. The results of the investigation are compiled in Chapter 4.4.

Concerning Unit load formation, automation and the use of robots to form loads are the most relevant trends in logistics at the moment, which is a big step towards the future of logistics, but the main issue to meet the PI requirements regarding unit load formation is the use PI Containers. The investigation done in Chapter 4.4 has shown that some companies around the world, especially those working with food and pharmaceutical goods, have substituted the classic boxes, bags, tote pans, pallets etc. for a new concept of storing goods called "smart containers". These containers are able to control the temperature, humidity, shock detection, geolocation and transmit information about it. Yet they are not real PI Containers with fully functionality but it is a step closer to the idea that the PI is looking for.

In the store and buffer of goods operations, autoStore systems have been developed. These systems use a huge grid of bins which are possible to stack on the top of each other and an automate robot is in charge of moving and picking them. The snapping and stacking possibilities are similar to the ones used by the PI Stores.

For conveying goods, omnidirectional conveyors represent a revolutionary advance in terms of conveyors moving goods in four cardinal directions just like PI Conveyors do. Flexible conveyors are very useful in changing material handling conveyor situations. The grid of omnidirectional conveyors and the flex conveyors have an important value for the future development of PI Conveyors.

Regarding sorting goods, the majority of the sorters include rollers which won't be part of the PI Sorters as well as sorting goods only in one direction. PI Sorters may incorporate a network of PI Sorters to achieve their task.

Respecting loading/unloading tasks, autonomous vehicles are being used for this purpose. Self-driven vehicles open new possibilities increasing the efficiency and safety of the processes and they go beyond of simply navigation, for example autonomous forklifts not only include pure self-movement but also integrate features such as barcode scanning, pallet detection, and pallet stacking.

Concluding with the process of moving goods inside the facilities, as mentioned for loading/unloading processes, self-driven vehicles represent the latest innovation in the field, which could be applied in the development of PI Movers, since these systems need a higher level of automation.

5.3 Evaluation results

To sum up the information introduced in the sections 5.1 and 5.2 of this chapter and provide a more solid representation of the evaluation, a final compilation of information has been done and presented in the Tables 5-2, 5-3, 5-4, 5-5, 5-6 and 5-7.

Table 5-2: Unit load formation

Equipment used for	Source	Readiness	Notes
Unit load formation	**Questionnaires**	*Poor*	• Current devices don't have any of the features of PI Containers. • In the present hubs, palletizers are in charge of load composition and the level of automation is very low, in the PI, PI Composers have that function and higher level of automation.
	Research	*Fair*	• Smart containers have some of the main characteristics of PI Containers (humidity control, smart tags with geolocation, customer data, etc.). • Palletizer robots, as mentioned above, pallets won't be used in the PI, the robots represent a higher level of automation which can be used in the PI.

Table 5-3: Transportation (moving) goods inside the facility

Equipment used for	Source	Readiness	Notes
Transportation (moving) goods inside the facility	**Questionnaires**	*Poor*	• PI Movers will have to be adapted to the physical features of PI Containers with stacking and interlocking devices, which makes current equipment not feasible for moving operations. • The level of automation needed for PI Movers is higher than the one in the current facilities which is very low or no existing.
	Research	*Fair*	• Self-driven vehicles represent a big step towards the automation, key element of the PI and it could be applied in the design and development of PI Movers.

Table 5-4: Storing and buffering goods

Equipment used for	Source	Readiness	Notes
Storing and buffering goods	**Questionnaires**	*Poor*	• PI Stores will be designed and developed for PI Containers, so they won't be able to store current freight. • The current facilities don't have a specific area for storing, they mainly use the floor as a store or buffer area.
	Research	*Fair*	• Higher level of automation as the PI requires. • Grid with bins stacked with each other, design that could be used in the PI for the storing the PI Containers.

Table 5-5: Loading/unloading goods

Equipment used for	Source	Readiness	Notes
Loading/unloading goods	**Questionnaires**	*Poor*	• The majority of the current equipment is designed to move pallets or current freight, they don't have the needed features to handle PI Containers. • The PI Systems have to be designed to handle PI Containers.
	Research	*Fair*	• Self-driven equipment for loading/unloading represent a big innovation regarding automated systems which will be implemented in the PI. • Some of them include stacking features which can be used with PI Containers

Table 5-6: Sorting goods

Equipment used for	Source	Readiness	Notes
Sorting	**Questionnaires**	*Poor*	• Present sorters don't have any of the needed devices to handle PI Containers, even though they could move PI Containers, but the PI Sorters won't be able to sort current freight. • PI Sorters will be designed to move only PI Containers
	Research	*Poor*	• The majority of the sorters include rollers which won't be used in the PI Sorters and they may include a network of PI Sorters to achieve the task.

Table 5-7: Conveying goods

Equipment used for	Source	Readiness	Notes
Conveying	**Questionnaires**	*Poor*	• Present conveyors move current freight using rollers or belts, which won't be used in the PI. • PI Conveyors will be designed to move only PI Containers and the design is more simple because they only need an interface to connect themselves to the tracking mechanics of the conveyor.
	Research	*Fair*	• Omnidirectional conveyors that are able to move goods in any direction just like the PI Conveyors will do moving goods in the 4 cardinal directions.

6 Conclusion and summary for future research

As it was shown in Chapter 5, some system features of the PI are already implemented in some of the current hubs and they have reached a higher level of automation, the final compilation of the evaluation results is presented in Table 6-1.

Table 6-1: Compilation of evaluation results

	Evaluation MHE questionnaires	Evaluation MHE research
Unit load formation	*Poor*	*Fair*
Transportation (moving goods)	*Poor*	*Fair*
Storing	*Poor*	*Fair*
Loading/Unloading	*Poor*	*Fair*
Sorting	*Poor*	*Poor*
Conveying	*Poor*	*Fair*

Despite this, the key element around which the PI Systems will be developed is the PI Container.

PI Containers represent the cornerstone of the PI as the material handling systems will be designed to exclusively move, handle, store, transport, load PI Containers. These new systems will include features that will facilitate the use of PI Containers, unlike the present systems do. Checking the results of the readiness presented in Chapter 5.1 shows that the rating for the comparison between the material handling systems in consulted hubs and the PI Hubs is in general low, a reason for this level, could be that the present equipment is designed to handle current unit loads which are usually in form of pallets. Major changes would have to be applied to the mentioned systems in order to make them able to handle PI Containers.

As Figure 6-1 shows, it won't be possible to develop PI Containers without developing suitable material handling equipment and vice versa, it has no sense to design new systems without taking in consideration the PI Containers main features. PI requirements play an important role in the design and development of both of them, but PI requirements might be modified by the technological advances, which means, the whole PI will be experimenting an unpredictable status.

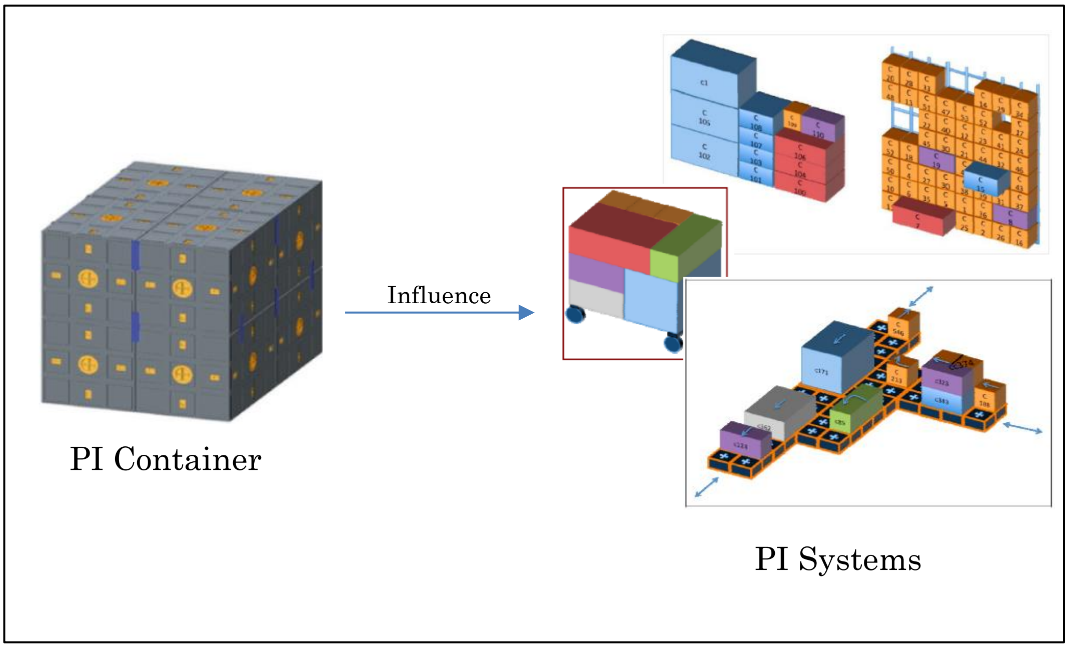

Figure 6-1: Influence of PI Container in the PI Systems

The investigation about present material handling equipment exposed in Chapter 4.4 has shown that the technology is developing in the direction of the PI, by using smart containers which share many of the main characteristics of PI Containers, a grid of stacking bins which are picked up by a robot, omnidirectional conveyors that are able to move goods in any direction, the use of self-driven vehicles which represents a higher level of automation. Therefore, the focus of further research should be on keeping the development of these systems, and what is more important, stablishing a common and uniform definition of PI Container and its main characteristics, because this is the starting point for developing PI material handling systems, once the PI Container is set up, it would much easier to develop PI Movers, PI Stores, PI Composers etc.

A crucial part of this thesis was to find out which material handling equipment are present in the current hubs, apart from the existing technology exposed in the additional investigation. The results are shown in Chapter 4.1, showing that belt conveyors and forklifts are the most popular devices for moving, loading/unloading goods or pallets, boxes and bags the most popular for unit load formation. The present hubs also don't have a specific area for storing goods or buffers, they mainly placed them in the floor of the facility. The level of automation in general, was very low in the consulted facilities, only one of them presented a higher automation, and the facilities don't sense the need for investing in this, since the work is done efficiently, this only represents a big waste of money for them.

The scope of the present work was also to highlight the technological gaps between present material handling equipment and PI Systems. This was covered in

Chapter 5, various KPIs helped to address the main gaps between the present and the PI systems. As it was mentioned before, the level of the readiness was rated as low, because it is not feasible to import the majority of the equipment into the PI, major changes would have to be implemented in order to make the present equipment fulfill the requirements of PI and its systems, as instance, the conveyors will not use rollers or belts which is an advantage for the environment and they will only handle and move PI Containers, the majority of the PI Systems won't be able to move, handle or use the current freight since they are exclusively designed for the PI. Another example is the equipment for storing goods, it is not very clear how PI Stores will be, but it is possible to affirm that they will be very different from the present ones, since there is no specific area for this purpose in the present facilities.

Implementing the PI will change completely the logistics as it is known now. Great innovations will come together with the PI expansion but this development is also affected by the difficulty of some companies to change the current processes for new ones, they summarize their way of thinking in "why to change something that works and it is profitable?". This is an important concern because it means it will be even more complicated the transition to PI, it is rough task to change a fully implemented logistics model for a totally different one.

As a final conclusion, it is possible to affirm that logistics is slowly developing in the direction of PI, adopting some of its features, but there are still many points to discuss and investigate regarding material handling equipment in the PI.

7 Bibliography

[ABR19] **ABR**: URL. *https://www.abr.com/what-is-rfid-how-does-rfid-work/* - Accessed: 06.02.2019

[AMP19] **Ampkgp**: URL. *https://www.ampkgp.com/palletizer.php - Accessed: 12.04.2019*

[BAST19] **Bastiansolutions**: URL. *https://www.bastiansolutions.com/solutions/service/industrial-robotics/industrial-robotic-solutions/robotic-palletizing/robotic-case-palletizer/* - Accessed: 12.04.2019

[BMM14] **Ballot, Eric; Montreuil, Benoit; Meller, Russell D.**: *The Physical Internet: The Network of Logistics Networks.* Paris, France, 2014.

[BMT12] **Ballot, Eric; Montreuil, Benoit; Thivierge, Collin**: *Functional design of Physical Internet facilities: A road-rail hub.* France, 2012

[CELL19] **Celluveyor**: URL. *http://www.celluveyor.com/en/* - Accessed: 13.04.2019

[CMA19] **CMA-CGM**: URL. *https://www.cma-cgm.com/services/smart-containers* - Accessed: 13.04.2019

[CON19] **Conveyor networks**: URL *https://conveyornetworks.co.uk/sorting/* - Accessed: 04.05.2019

[DES98] **Descomble, Martyn**: *The good research guide.* US, McGrawhill, 1998, ISBN-13: 978 0 335 24139 2

[EEA19] **EEA**: URL. *https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-11* - Accessed: 10.01.2019

[EQU19] **Equinox**: URL *https://equinoxmhe.com/sorters/slide-tray-sorter/* - Accessed: 05.05.2019

[GLO19a] **Globalspec**: URL. *https://www.globalspec.com/learnmore/industrial_engineering _software/tracking_software/logistics_software* - Accessed: 06.02.2019

[GLO19b] **Global industrial:** URL *https://www.globalindustrial.com/warehouseStorage* - Accessed: 06.05.2019

[HK14] **Heutger, Matthias; Kückelhaus, Markus:** *SELF-DRIVING VEHICLES IN LOGISTICS. A DHL perspective on implications and use cases for the logistics industry.* Germany, 2014

[IND19] **Indiamart:** URL. *https://www.indiamart.com/proddetail/flexible-conveyors-10994811233.html* - Accessed: 13.04.2019

[INT19] **Intralogistics:** URL. *https://intralogistics.tips/buffer-storage-intralogistics-solution-guaranteeing-replenishment/* - Accessed: 06.02.2019

[ITA19] **Itainnova:** URL. *http://web.itainnova.es/elogistica/lineas-de-trabajo/sistemas-de-identificacion-logistica/* - Accessed: 06.02.2019

[IXT19] **Ixtenso:** URL. *https://ixtenso.com/logistics/robots-automated-processes-are-the-future-of-warehouse-logistics.html* - Accessed: 13.04.2019

[KAY12] **Kay, Michael G.:** *Material Handling Equipment.* Fitts Dept. of Industrial and Systems Engineering. North Carolina state University, US, 2012

[LOG19a] **Logistica y abastecimiento:** URL. *https://logisticayabastecimiento.jimdo.com/almacenamiento/* - Accessed: 12.02.2019

[LOG19b] **Logeq:** URL *http://logeq.eu/en/product/rolltainer-sloping-floor/* -Accessed: 07.05.2019

[MAT19] **Material handling:** URL *https://www.materialhandling247.com/product/pocket_sorter_order_fulfillment_technology/Knapp* -Accessed: 05.05.2019

[MHI19a] **Mhi:** URL. *http://www.mhi.org/solutions-community/solutions-guide/conveyor* - Accessed: 15.02.2019

[MHI19b] **Mhi:** URL. *http://www.mhi.org/fundamentals/conveyors* - Accessed: 15.02.2019

[MMB10] **Montreuil, Benoit; Meller, Russell D.; Ballot, Eric:** *Towards a Physical Internet: The Impact on Logistics Facilities and Material Handling Systems Design and Innovation.* Milwaukee, US, 2010.

[MON11] **Montreuil, Benoit:** *Toward a Physical Internet: meeting the global logistics sustainability grand challenge,* Springer-Verlag, 2011

[OXF19] **Oxford dictionaries:** URL *https://en.oxforddictionaries.com/definition/key_performance_indicator* - Accessed: 24-04-2019

[PAC19] **Pacline:** URL *https://www.pacline.com/solutions/* -Accessed: 04.05.2019

[QUE19] **Questionpro**: URL. *https://www.questionpro.com/blog/rating-scale/* - Accessed: 23.03.2019

[RES19] **Research Methodology:** URL. *https://research-methodology.net/research-methodology/research-approach/deductive-approach-2/* - Accessed: 21.03.2019

[SDI19] **Sdi systems:** URL *https://sdi.systems/pop-up-sorters/* -Accessed: 03.05.2019

[SEA19] **Searchep:** URL. *https://searcherp.techtarget.com/definition/warehouse-management-system-WMS* -Accessed: 17.02.2019

[SLT09] **Saunders, Mark; Lewis, Philip; Thornhill, Adrian:** *Research methods for business students.* United Kingdom, Pearson Education, 2009, ISBN: 978-0-273-71686-0

[SMA13] **S. Sreejesh; Mohapatra, Sanjay; Anusree, M. R:** *Business research methods, an applied orientation.* US, Springer, 2013, ISBN 978-3-319-00538-6

[SMR19] **Smart containers:** URL. *https://smartcontainers.ch/en/index.html* - Accessed: 13.04.2019

[SOL19] **Solidswiki:** URL *http://www.solidswiki.com/index.php?title=Overhead_Conveyors* - Accessed: 04.05.2019

[SSI19] **SSI-Schaefer:** URL *https://www.ssi-schaefer.com/en-at/products/order-picking/automated-order-picking/3d-matrix-solution--14640* - Accessed: 04.05.2019

[STA19] **Statista:** URL. *https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/* - Accessed: 22.01.2019

[SUR19] **Survio**: URL. *https://www.survio.com/en/blog/quantitative-research-1-introduction* - Accessed: 27.03.2019

[TK16] **Tipping, Andrew; Kauschke, Peter**: *Shifting patterns - The future of logistics industry.* Germany, 2016

[VIS19] **Visio**: URL. *https://www.visual-paradigm.com/VPGallery/bpmodeling/epc.html* - Accessed: 25.03.2019

[WAR19] **Warehouse excellence**: URL. *http://en.warehouse-excellence.de/homepage/dcrm/* - Accessed: 02.04.2019

[WEB19] **WEB70**: *http://web70.ttr.web.tr/en/our-solutions/sortation-systems/pusher-or-puller-sorter* - Accessed: 05.05.2019

[WEC19] **Wecon systems**: URL. *https://weconsystems.com/services/flexible-conveyors/* - Accessed: 13.04.2019

[WIK19a] **Wikipedia**: URL. *https://en.wikipedia.org/wiki/Sorter_(logistics)* – Accessed: 15.02.2019

[WIK19b] **Wikilogistics**: URL *https://www.wikilogistics.ch/begriffe_az_1de.php?begriff_url=Rollcontainer* -Accessed: 06.05.2019

[WIS09] **Wisser, Jens**: *Der Prozess Lagern unf Kommissionieren im Rahmen des Distribution Center Reference Model (DCRM).* Germany, Universitätsverlag Karlsruhe, 2009, ISBN: 978-3-86644-372-3

[WUA19] **Wu ac**: URL. *https://www.wu.ac.at/erp/webtrainer/epc-webtrainer/theory/* - Accessed: 25.03.2019

[WYN19] **Wynright**: URL *https://www.wynright.com/products/by-system/shipping-systems/robotic-truck-loading/#loading* - Accessed: 03.05.2019

8 Listings

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