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# Material Handling Systems for Physical Internet hubs

## Evaluation and readiness of present Material Handling Systems for the Physical Internet

**MASTER'S THESIS**

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## AFFIDAVIT

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# Danksagung

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# 1 Introduction

Logistics has become an increasingly complex field due to the rising needs of companies which are faced with increasing requirements of their customers. Services like Just-in-time manufacturing and e-commerce delivery within the next day are just two characteristics, which logistics has nowadays to deal with. Although the general function of logistics has not really changed (Objects are still moving from one place to another) the execution of logistics has changed a lot. Society's behaviour has been influenced by the changes in executing logistics, offering products to be accessible over lager territories and shorter amount of time (cf. [BMM14], p. 13). This logistics trend is one reason for the current unsustainable way physical objects are moved, handled, stored, realized, supplied and used throughout the world. Current logistics practices have become economically, environmentally and socially unsustainable. Symptoms for this unsustainability and their correlation with economical, environmental and societal facets are illustrated in Table 1-1.

Table 1-1: Unsustainability symptoms and their economical, environmental and societal facets ([MON11], p. 20)

| | 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 | ● | ● | ● |

To address this unsustainable logistics situation a concept, known by the term "Physical Internet", was proposed. A concept for logistics organisation that challenges these current unsustainable practices, which was first introduced by Professor Benoit Montreuil of Laval

University Quebec, Canada and then developed with Professor Russell D. Meller and Eric Ballot. The main idea is to use an open, shared and interconnected network for organizing the logistics activities rather than using dedicated and specialized networks (cf. [BMM14], p. 14).

As the Physical Internet is an almost entirely new way of organizing logistics, a vast amount of research fields are arising from this topic.

The task of this master thesis is to investigate processes, executed inside current logistics distribution facilities throughout the supply chain network, with a special focus on material handling systems. Therefore this thesis addresses the unsustainability symptoms 1, 2, 4, 5, 9 and 13, listed in Table 1-1. In order to make the handling of goods in future PI-hubs more efficient and sustainable, this master thesis is dealing with different research questions, which are described in chapter 1.2.

## 1.1 Motivation

Like many other industries, transportation and logistics is currently confronting great change, which brings both risks and opportunities. There are many ways the sector could develop to meet the upcoming challenges, influenced by new technologies, new market entrants, new customer expectations and new business models. Logistics enterprises are facing an era of unprecedented change as digitalisation takes hold and customer expectations evolve. As mentioned above, current logistics developments and trends like the e-commerce boom are driving the need for an overall change in logistics thinking. Chapter 2 will give more insight in the current logistics situation and the inevitable need for a change in executing logistics processes (cf. [TK16], p. 3-2).

During all these upcoming developments, it will be of great importance to not only focus on achieving economic goals but also realizing environmental and social aims. It is a tenuous situation, but one promising way to meet the upcoming challenges could be the Physical Internet. It takes up the grand challenge of making current logistics operations economically more efficient and sustainable as well as reducing the environmental and social burden at the same time. Especially the Physical Internet's intention to increase the economic performance and to reduce the environmental burden at the same time, was a big reason for the author of this master thesis to start working on this subject. The author's particular interest in this topic was to find out, to what extend the current technological developments can already satisfy the idea of the Physical Internet. As technological developments and breakthroughs are changing the way logistics companies are operating, it will be important to understand how to exploit a whole range of new technologies, from data analytics to automation solutions. Some of the industry's most labour-intensive processes are becoming fully or partially automated, from warehousing to last-mile delivery (cf. [TK16], p. 7-8).

## 1.2 Research questions

Upon the numerous research fields arising from the Physical Internet, this master thesis is focusing on material handling processes and their used systems within hubs. More precisely, this thesis aim is to evaluate the readiness of material handling processes of current hubs for a Physical Internet (PI). For achieving this aim, this master thesis is dealing with the investigation of the following research questions:

Research questions:

1. What are material handling processes for goods and their corresponding material handling systems within present hubs throughout the supply chain network?
2. What are PI-hub key elements and their characteristics in terms of material handling processes?
3. What are the technological gaps between the present situation of used material handling systems and the desired systems for realizing the Physical Internet?

## 1.3 Structure of the thesis

This work is structured in the following way as illustrated in Figure 1-1.

Chapter two contains the problem statement arising from the current logistics situation, global trends and environmental conditions. It also contains the terminology used for this thesis, an analysis of the research field, the definition of the investigation's system boundary and the establishment of correlating research goals.

The third chapter gives the main overview of the general framework of the research approach and also consists of a detailed description of the research design and methodology development. Framework conditions and assumptions for the chosen system boundary within which this work investigates the research questions are also outlined. In the end, chapter three closes with the data collection for the PI-Literature study.

Chapter four follows with the explanation of the conducted methods and approaches, as well as listing their results.

Chapter five deals with the comparison of the results received from chapter 4.3 and 4.4.1 and also contains a summary of theses main findings.

The overall conclusion of the conducted research as well as listing suggestions for further research takes place in chapter six.

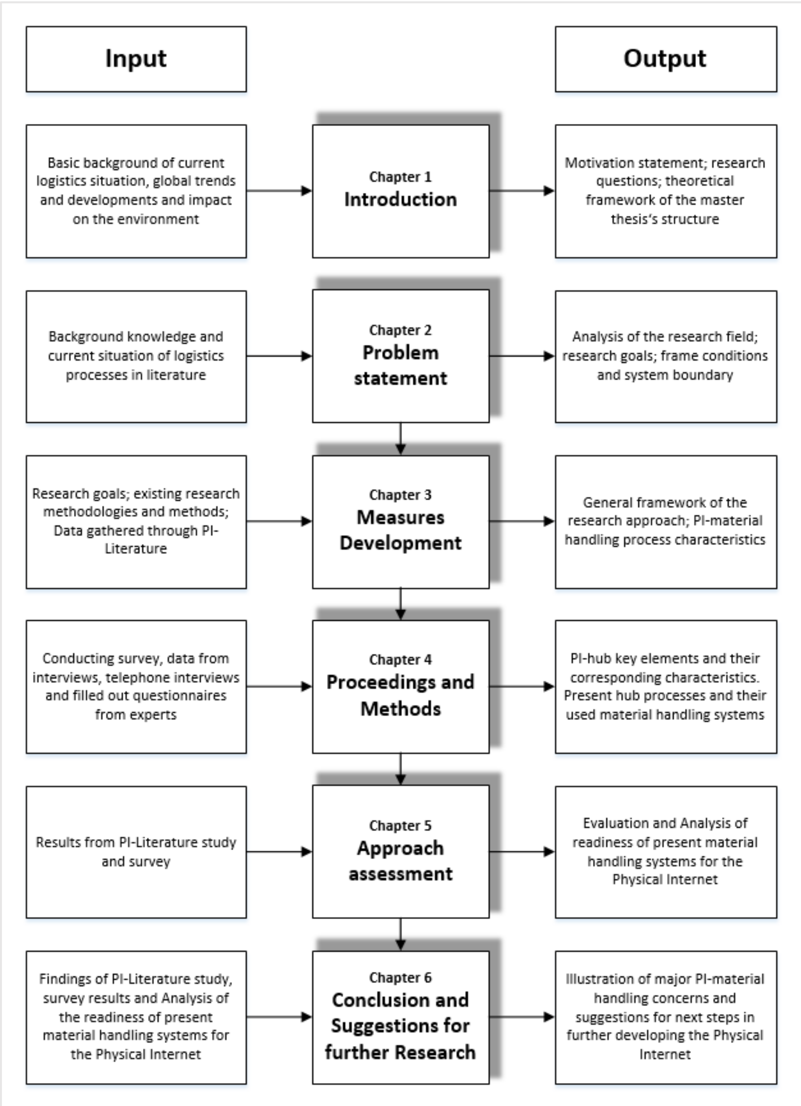



Figure 1-1: Structure of the thesis

# 2 Problem statement

At the beginning of the following chapter, the terminology used throughout this master thesis is listed and described. Afterwards, the current logistics situation is discussed to make the need for a change in logistics thinking more evident. Then, the system boundary and frame conditions chosen for the investigation of the research questions, declared in the previous chapter, will be outlined here. The last part of the problem statement consists the defined research goals which were created in coordination with the corresponding research questions and the defined system boundary.

## 2.1 Terminology

Several terminologies and their corresponding definitions will be listed here. For simplification reasons some existing definitions have been extended in the context of the thesis and also new definitions were set up to better meet the defined system boundary related situation of the investigation. First, existing definitions of the terms are listed, followed by explanations about how the terms are used within the context of this thesis. Some initial definitions were already suitable for this research and therefore no further explanations are needed.

**Automation technology**

Existing definition: The aim of automation technology is to automate plants or machines, so that they can be run independently and without the intervention of human operators. The better this goal is achieved, the higher is the level of automation (cf. [GLI17]).

Note: Even though there exist more specific subdivisons of the term automation like semi-automation and full-automation technology, a more general and simplified definition is used within the context of this master thesis. In this thesis terms like automated processes, automated systems or automated technlogies refer to the highest level of automation, so they can be run independently and without any intervention of human operators.

**Buffer storage**

Existing definition: The buffer storage system, also known as short-term storage, is a temporary storage location for goods. It is this interim storage that distinguishes it from final storage spaces. The goods are not given fixed storage spaces, but are merely “parked” until they are retrieved again for the next process stage. The main purpose of a buffer storage is to keep a steady replenishment of goods from storage, thereby ensuring that the production or order picking process continues without interruptions (cf. [INT17]).

Note: Within the context of this master thesis the term buffer storage describes a system with the purpose of “storing” goods/PI-containers for only a short period of time in between processes executed inside hubs. Hereby the purpose is to store goods/PI-containers for a certain period of time if the next process step is not ready or some constraints have to be fulfilled before, e.g. if the necessary means of transport in which the goods have to be loaded in, are not available yet.

**Conveyor**

Existing definition: A conveyor is a mechanical equipment used in handling that helps in material movement from one location to another. Conveyor systems facilitate quick and efficient transportation for a wide variety of materials (cf. [MBA17]).

Note: Within the context of this master thesis the term conveyor describes material handling systems with the purpose to simply transport goods from one place to another without any sortation function.

**Floor conveyor**

Existing definition: Floor conveyors are used as a means of transport for the horizontal transportation of goods. They are also known as industrial trucks or ground conveyors. They comprise a travel drive, lifting gear, load-handling attachment, lift drive, chassis, steering mechanism, brakes and operating elements. Floor conveyors are usually operated on level ground (cf. [ITE17]).

Note: Within the context of this master thesis the term floor conveyor describes material handling systems operating at ground level with the purpose to load and unload goods from and to means of transport, arriving and departing from hubs. They represent the first and last link (element) of material handling systems within the investigation’s system boundary.

**Hub**

Existing definition: Logistics centre charged with transferring freight from one logistics service to another. This can also concern different means of transport ([BMM14], p. 192).

Note: Within the context of this master thesis the term hub is used as a collective term for all logistics facilities, concerned with the distribution of goods like distribution centres, consolidation centres, terminals, depots, hubs, etc.

**Identification system**

Existing definition: Item identification is the most important element of the codification system because it establishes a unique identification for every item of supply. The identification consists of the minimum data required to establish clearly the essential characteristics of the item, i.e., those characteristics that give it a unique character and differentiate it from all others (cf. [NCS17]).

Note: Within the context of this master thesis the term identification system describes a system with the purpose to identify goods during material handling processes executed inside hubs. This system consists out of tags and reading devices. Tags are placed on goods and contain essential information about the corresponding item. Reading and recording devices are used to capture this information and update it, if necessary.

**Management and Planning system**

In logistics exist different systems and applications for the execution of management/planning tasks like a TMS (Transport Management System), WMS (Warehouse Management System), etc. Therefore a more general definition was used within the context of this research.

Note: Within the context of this master thesis the term management and planning system is used as a collective term for activities associated with logistics management. This includes management for e.g. warehousing, materials handling or choosing the most effective routes for transportation (cf. [SEA17a]). More generally it describes a system with the purpose to execute managerial and planning tasks concerned with processes executed mainly inside hubs.

**Physical Internet**

Existing definition: An open global logistics system founded on physical, digital, and operational interconnectivity with encapsulation, interfaces and protocols developed for increased efficiency and sustainability ([BMM14], p. 194).

**PI**

Acronym for Physical Internet ([BMM14], p. 194).

**PI-composite**

Note: Within the context of this master thesis, a PI-composite is a unit load composed out of interlocked PI-containers.

**PI-container**

Existing definition: Modular box in which products are packed to be transported. Characteristics and requirements of this box are outlined in (cf. [LEJ15]):

- Unique international identification for traceability
- Physical protection of the content
- Standardized size
- Standardized mechanical strength which enables them to be handled and stacked.
- The possibility of handling and locking between containers using a standardized system, a suitable development of the twist-lock.

**PI-hub**

Existing definition: A node in the Physical Internet where PI-containers switch from one logistics service to another: gateway between two logistics networks, change of mode of transport, change of vehicle, coupling/decoupling, etc. ([BMM14], p. 192).

Note: Within the context of this master thesis the term PI-hub is used as a collective term for all logistics facilities, concerned with the distribution of PI-containers and PI-composites in a future PI.

**PI-nodes**

Existing definition: The PI-nodes of the Physical Internet are locations expressly designed to perform operations on PI-containers such as receiving, testing, moving, routing, handling, placing, storing, picking, monitoring, labeling, paneling, assembling, disassembling, folding, snapping, unsnapping, composing, decomposing and shipping PI-containers ([MMB10], p. 10).

**Sorter**

Existing definition: In logistics, a sorter is a system which performs sortation of products according to their destination. A common type of sorter is a conveyor-based system. While they may be based on other conveyor systems, usually sorters are unique types of conveyors (cf. [WIK17]).

Note: Within the context of this master thesis the term sorter describes material handling systems which transport goods from one place to another with the main purpose to sort them according to specific constraints.

**Store**

Existing definition: A store is a node within a logistics system in which goods are temporarily stored. Different types of stores can be distinguished, depending on the particular main function of the store (cf. [WIR17]).

Note: Within the context of this master thesis the term store describes a system with the purpose of storing goods temporarily, also over longer periods of time executed in between processes executed within hubs.

**Transport Management System**

Existing definition: A Transport Management System (TMS) is used in intralogistics to enable a smooth Supply Chain Management. A TMS executes four core processes of a transport management (cf. [LOG17]):

1. Planning and decision-making
2. Transport
3. Post-editing
4. Reporting

**Unit load Composer/Decomposer**

Note: Within the context of this master thesis the term composer/decomposer describes material handling systems with the purpose to assemble unit loads out of single goods/PI-containers and to disassemble unit loads into single goods/PI-containers.

**Unit load formation equipment (ULFE)**

Existing definition: Unit load formation equipment is used to restrict goods so that they maintain their integrity when handled a single load during transport and for storage ([KAY12], p. 10).

**Unit load**

Existing definition: Packages/goods loaded on a pallet, in crate or any other ULFE that enables them to be handled at one time as a unit (cf. [GLN17]).

**Warehouse-Management-System (WMS)**

Existing definition: The WMS is an essential software application for the control of the internal inventory management inside enclosed plants (distribution centres or manufacturing plants). A WMS enables centralized management of tasks such as tracking inventory levels and stock locations. WMS may be standalone applications or part of an Enterprise Resource Planning (ERP) system (cf. [SEA17b]).

## 2.2 Current Logistics Situation

To achieve a sufficient transparency and understanding of the problem case which this master thesis is trying to address, this part of the chapter will display the development as well as the current situation in today's supply chains, especially from a logistics point of view.

Current logistics systems are achieving remarkable performance throughout developed countries, offering an outstanding level of service which was never before attained. For instance it is possible to have a parcel delivered across all 50 states of the U.S. within hours (cf. [FED17]), to deliver parts to an automotive plant in the exact order in which they are needed on the production line within a two-hour time window or to simply ship clothes from Asia for a few cents per item. As illustrated in Table 2-1, the number of different service options is huge and modern consumers are making use of this options on a large scale. They already have become dependent on them (cf. [BMM14], p. 19).

Table 2-1: Domestic services offered to UK customers by major parcel carriers ([APP16], p. 11).

| Services | Same day | Next day | By 7/8am | By 9am | By 10am | By 12pm | Next day PM | 2 days | 3 days | Saturday | Sunday |
|---|---|---|---|---|---|---|---|---|---|---|---|
| APC Overnight | X | Yes | Yes | Yes | Yes | Yes | Yes | X | X | Yes | X |
| DHL Express UK | X | Yes | X | Yes | X | Yes | Yes | Yes | Yes | Yes | X |
| DPD | X | Yes | X | Yes | X | Yes | Yes | Yes | X | Yes | Yes |
| DX Group | X | Yes | X | Yes | X | Yes | Yes | X | X | X | X |
| Fed Ex UK | X | Yes | X | Yes | Yes | Yes | Yes | Yes | Yes | Yes | X |
| Interlink Express | X | Yes | X | X | Yes | Yes | Yes | Yes | X | Yes | Yes |
| Parcelforce | Yes | Yes | X | Yes | Yes | Yes | Yes | Yes | X | Yes | Yes |
| TNT UK Ltd | Yes | Yes | X | Yes | Yes | Yes | Yes | X | X | Yes | X |
| Tufnells | X | Yes | X | X | Yes | Yes | Yes | X | Yes | Yes | X |
| UK Mail | Yes | Yes | X | Yes | Yes | Yes | Yes | Yes | Yes | Yes | X |
| UPS | X | Yes | X | Yes | Yes | Yes | X | Yes | Yes | Yes | X |
| Yodel | X | Yes | X | X | Yes | Yes | X | Yes | Yes | Yes | X |

The reason for the current state of logistics is due to the combination of different factors like technological innovations in the field of transportation, major commercial agreements, increasing globalization and the abundance of natural resources (cf. [BMM14], p.19). From the technological point of view, logistics processes have become so effective, that fragmentations of production processes and international production networks are no longer a phenomenon. Production strategies like outsourcing and offshoring have become a standard in manufacturing industry, allowing production operations to be distributed around the whole world resulting in higher profits due to access to lower labour costs, lower energy prices etc. (cf. [AND09], p. 7).

All these improvements in logistics and their resulting advantages for all the elements in a modern supply chain have also a shady side. The present situation shows a high dependency of the production industry on logistics which implies a certain vulnerability if conditions that led to this development were about to change. For instance, a significant increase in the price for fuel or implementation of taxes on emission by law would increase transport costs. Another more present and severe problem, is the high environmental unsustainability of the current state of logistics processes, especially the rates of greenhouse gas emissions and the pace of resource consumption are in a contradiction with the objectives of a sustainable development (cf. [BMM14], p. 19-20). A worldwide increase in volume of merchandise exports and imports, displayed in Figure 2-1, is contributing to this effect and puts logistics under great pressure.

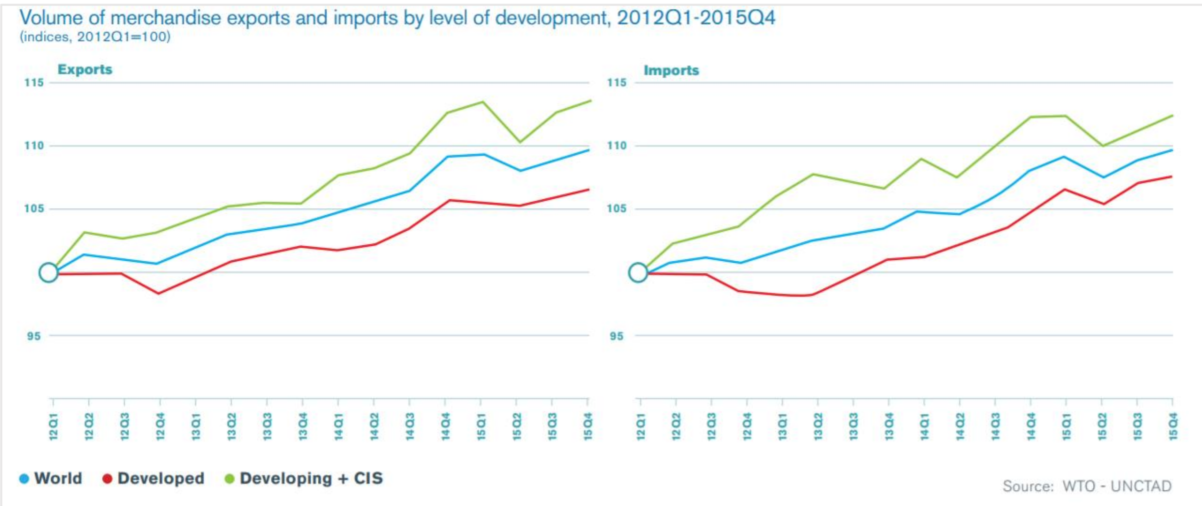



Figure 2-1: Volume of merchandise exports and imports ([WTO17], p.20).

The e-commerce boom illustrated in Figure 2-2 is also contributing to this unfavourable trend caused by an increase in shipments resulting in additional greenhouse gas emissions.

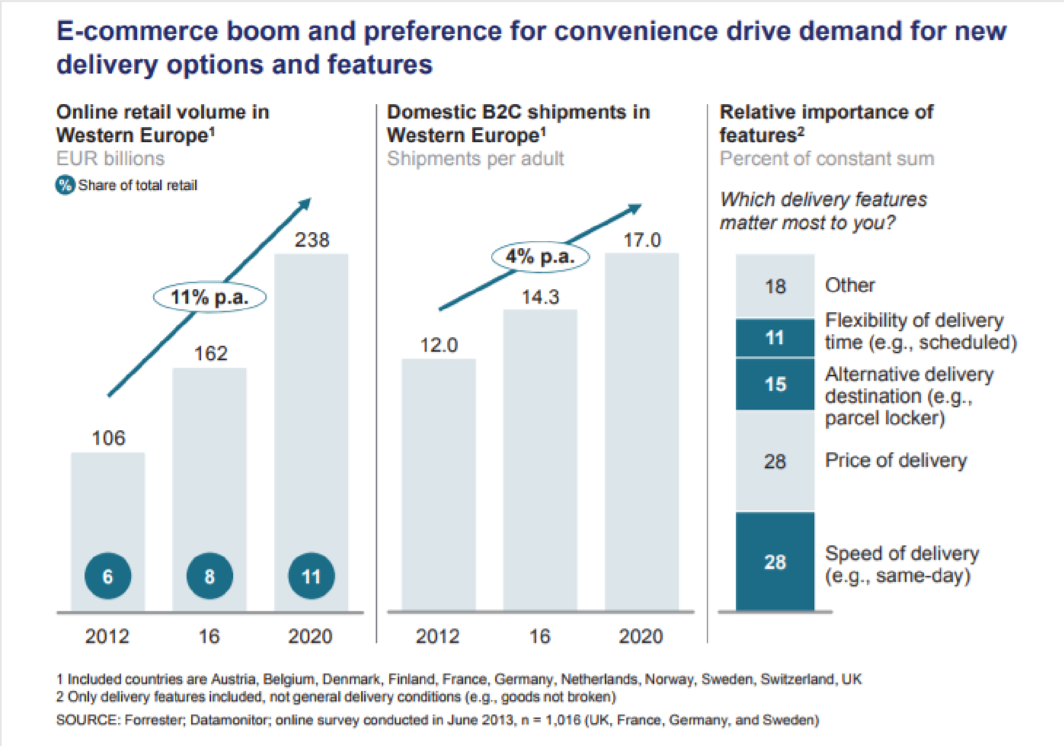



Figure 2-2: e-commerce boom and trends [MCK17].

Another trend which is in a close relation with the e-commerce boom, is urbanization.
There currently exist more than 800 cities with a population greater than one million. Urbanization is an ongoing trend, with 55 percent of the world's population expected to be living in cities by 2050 (up from 51 percent today) (cf. [OLI17], p. 1).
Regarding the presented statistics and forecasts, the increase in population inevitable will lead to an increase in deliveries, causing more greenhouse gas emissions. Of course these effects are depending on certain circumstances and developments like green vehicles, distribution scenarios, business models, regulations by municipalities and so on.

Even though logistics systems are achieving remarkable performance in many sectors, it is important to make clear that the current state of overall logistics efficiency is not ideal. In particular, freight transportation, the backbone of a logistics network, is not optimized and is characterized by overall, system inefficiencies – even at the same time that a great amount of effort is directed towards optimization of an individual organization's logistics network (cf. [BMM14], p. 13).

In response to the state and development of current logistics systems, a new organizational model for logistics has been proposed by Benoit Montreuil, Eric Ballot and Russell D. Meller. This new organization is based on universal interconnection of logistics services, that means to create a logistics "inter-network" which is called a Physical Internet (cf. [BMM14], p. 29).

The central idea of the Physical Internet is to achieve an interconnection of logistics networks, which leads to a network of logistics networks. A more precise definition is given by Benoit Montreuil, Eric Ballot and Russell D. Meller ([BMM14], p. 30):

*"The Physical Internet 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 Physical Internet's fundamental idea arises from the Digital Internet, especially its way of creating an interconnection of IT networks by standardizing the connections, using an addressing system and an intermediate protocol layer (TCP/IP) (cf. [BMM14], p. 29). A definition of the Digital Internet can be found in ([MON11], p. 27):

*"The Digital Internet is about the interconnection between networks in a way transparent for the user, so allowing the transmission of formatted data packets in a standard way permitting them to transit through heterogeneous equipment respecting the TCP/IP protocol."*

Although the parallels between the Digital and the Physical Internet are significant, they are not absolute and information transfer protocols cannot be directly transposed to goods transfer. In the end, the Physical Internet tries to keep the fundamental principle of the Digital Internet, especially interconnection, and to explore its potential for logistics operations (cf. [BMM14], p. 30).

Main components and requirements, essential for realizing the Physical Internet are (cf. [BMM14], p. 38-43):

- A range of standardized containers,
- suitable handling tools,
- an open and secure information infrastructure,
- new economic models,
- a suitable regulatory and legal framework as well as
- new operational processes.

These main components and requirements result in a few key points that differentiates current logistics and the Physical Internet, illustrated in Table 2-2.

Table 2-2: Key points in differentiating between current logistics and the Physical Internet ([BMM14], p. 32).

| Function | Current logistics | Physical Internet |
|---|---|---|
| Shipping | Goods | Containers |
| Network | Specific services | Network of open and shared networks |
| Trip | Logistics service | Dynamic routing |
| Information system | Proprietary | Internet of Things<br>Platform of services on the Cloud |
| Standard | Proliferation of standards | Market movement to agreement on interfaces, identification and protocols |
| Storage | Time-intensive (centralized) | Deployment logic |
| Capacity management | Private | Market-based |

## 2.3 System boundary - hub

The first step for a better identification of the problem characteristics is, to clearly define the system boundary of the investigation.

As mentioned in chapter 1.2, the research is focusing on the material handling processes within hubs throughout the supply chain network. Like present distribution centres today, also PI-hubs will be located in different stages of the supply chain network, so they will be both in overland and suburban regions as well as in cities. Therefore a more general view was selected to take different types of distribution centres within the supply chain network into consideration.

As there exist different distribution strategies, the system boundary will be outlined on the basis of the following distribution chain example given in Figure 2-3. It displays different stages of a supply chain network with their different types of distribution centres.

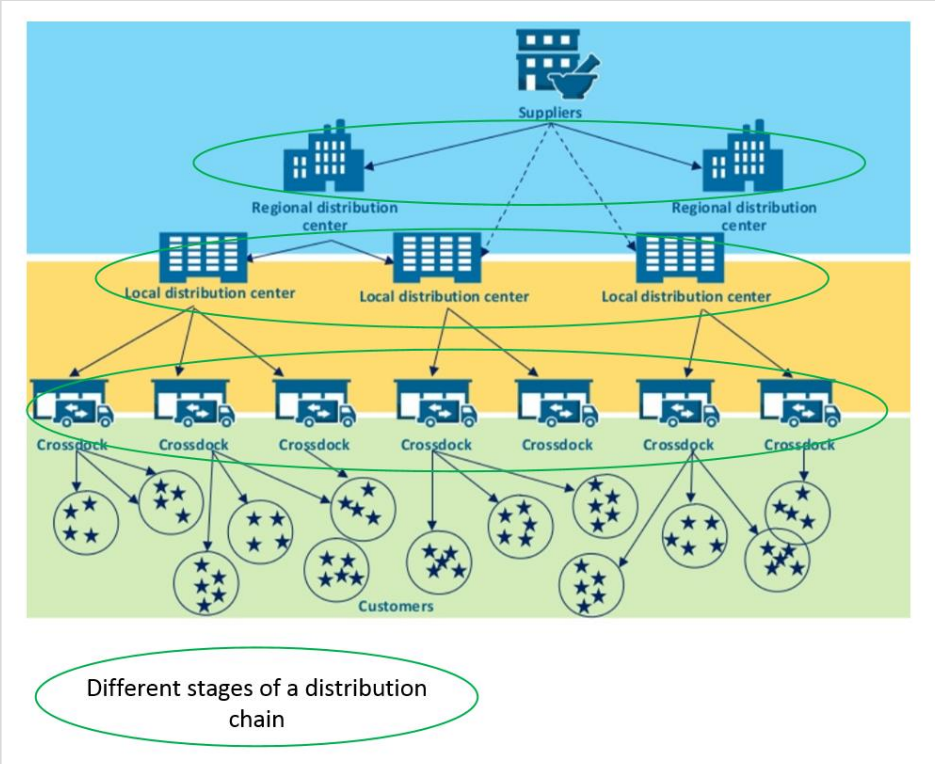



Figure 2-3: Goods distribution scheme (cf. [SLI17], p.16).

As described in chapter 2.1, a collective term called "hub" was chosen, to address all kind of distribution centres (Regional distribution centres, local distribution centres, crossdocks etc.), implying that the main material handling processes within these facilities are generally the same. The chosen system boundary "hub" is illustrated in Figure 2-4.

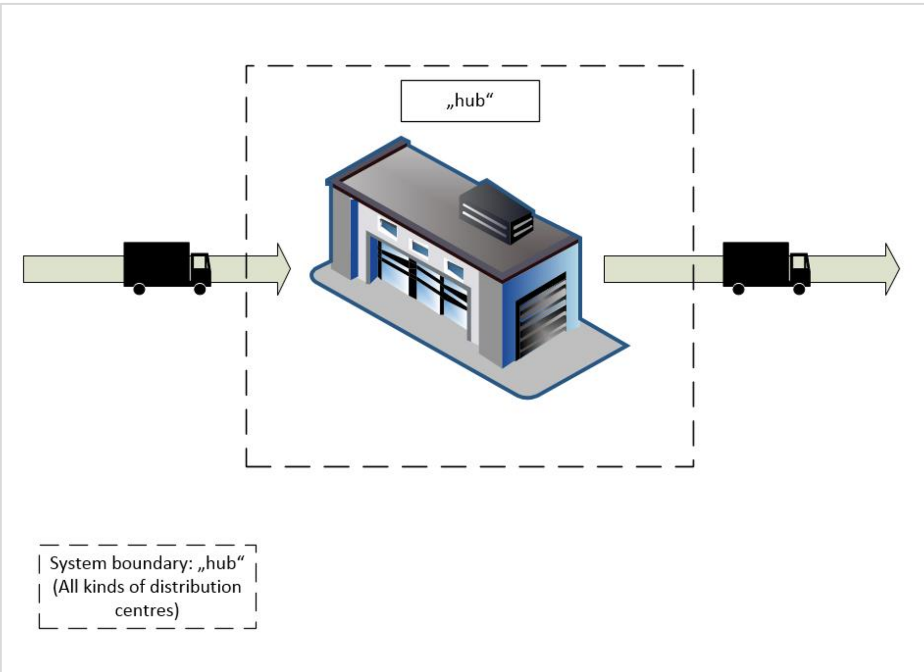



Figure 2-4: System boundary „hub".

## 2.4 Research goals

In order to meet the research questions described in chapter 1.2, the following research goals are defined as:

1. To identify which material handling processes and systems are used for handling and moving goods throughout hubs within the supply chain network.
2. To identify key-characteristics for the PI-hubs arising from the key elements of the Physical Internet.
3. To identify technological gaps between current material handling systems and future PI-systems.

# 3 Measures development – approaches

In this chapter, the measures development is described, starting with a more precise definition of the investigation's framework conditions and assumptions, which were already briefly outlined in chapter 2.3. Afterwards the choice of the conducted research methods is discussed.

## 3.1 Framework conditions and assumptions

Several assumptions, simplifications as well as framework conditions have been set up for defining the investigation's system boundary, described in chapter 2.3, more precisely.

The hub's area dedicated for the **receiving of goods** was selected to be the **starting point** of the investigation which defines the initial position of the investigation as follows:

External means of transport

- have arrived at the hub's area dedicated for receiving goods,
- are loaded with goods,
- are docked at the hub and
- are ready for unloading.

The hub's area dedicated for the **outgoing of goods** was selected to be the **end point** of the investigation which defines the final position of the investigation as follows:

External means of transport

- are loaded with goods,
- are docked at the hub and
- are ready for departing to the next destination within the supply chain network.

Defining the starting and the end point already specifies the investigation's system boundary more clearly, but as the research questions are aiming to identify processes and their corresponding material handling systems within hubs, knowledge about fundamental processes within a distribution centre was needed. For addressing these fundamental processes, the Distribution Centre Reference Model (DCRM) was selected.

The general processes within a distribution centre, defined by the DCRM are illustrated in Figure 3-1 based on (cf. [AAB06], p.94-96):

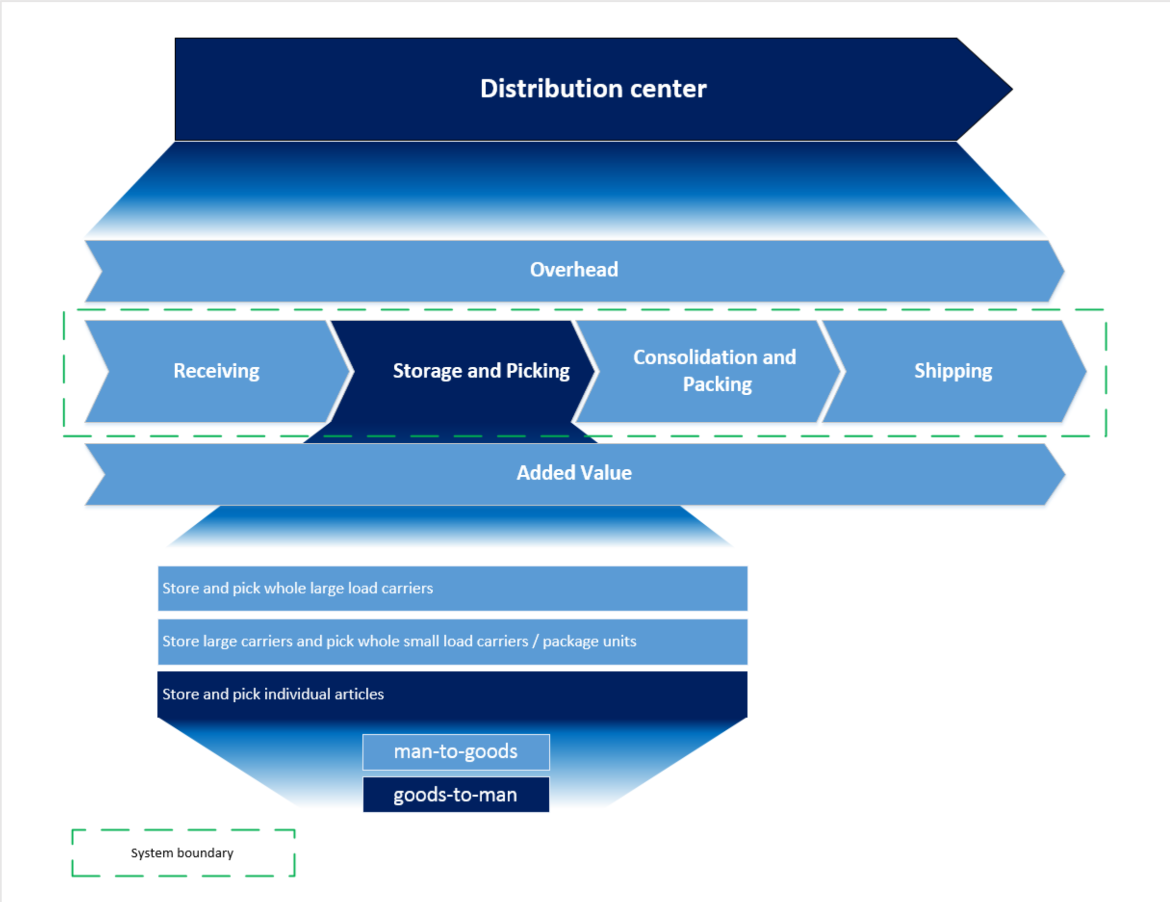



Figure 3-1: General processes of the DCRM and system boundary of the research (cf. [WAR17]; [WIS17], p. 10, 23).

### 3.1.1 DCRM – Main Processes

As described above, the DCRM worked as the system boundary of the research. The process level of the DCRM structures a distribution centre into a logical connected sequence of tasks. There exist six general processes that can be identified in a distribution centre as illustrated in Figure 3-1 (cf. [WIS17], p. 11, 12):

1. Receiving
2. Storage and Picking
3. Consolidation and Packing
4. Shipping
5. Added Value
6. Overhead

In this master thesis, only the first four processes are investigated because they are the most interesting processes regarding the research questions in chapter 1.2. For the investigation in this thesis, the processes “Receiving”, “Storage and Picking”, “Consolidation and Packing” and

"Shipping" are therefore declared as "main processes" of a distribution centre illustrated in Figure 3-2. It is important to also mention, that not every distribution centre must have all of the listed processes. For example a cross docking centre should ideally only consist out of the processes receiving and shipping (cf. [WIS17], p. 12).

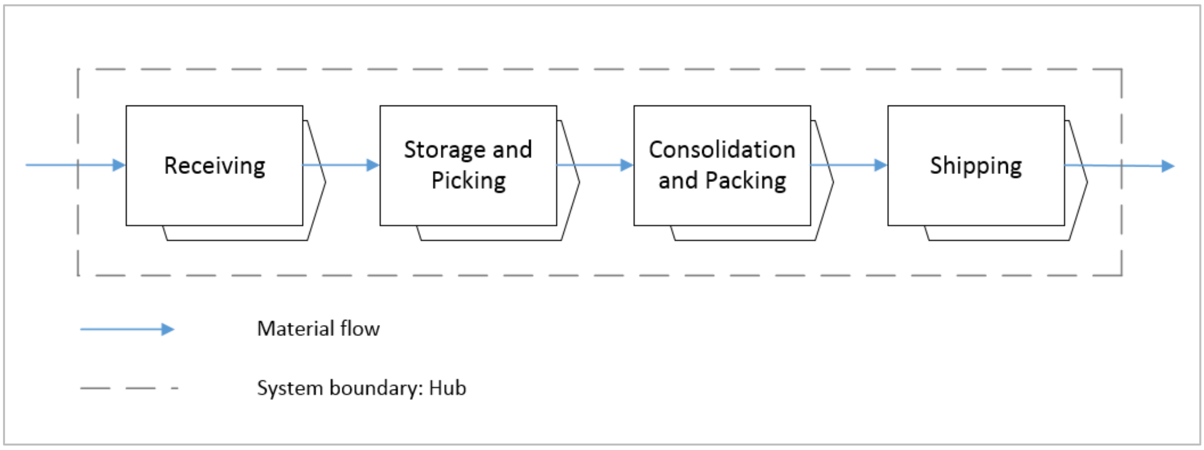



Figure 3-2: DCRM - main processes

#### 3.1.1.1 DCRM - Receiving

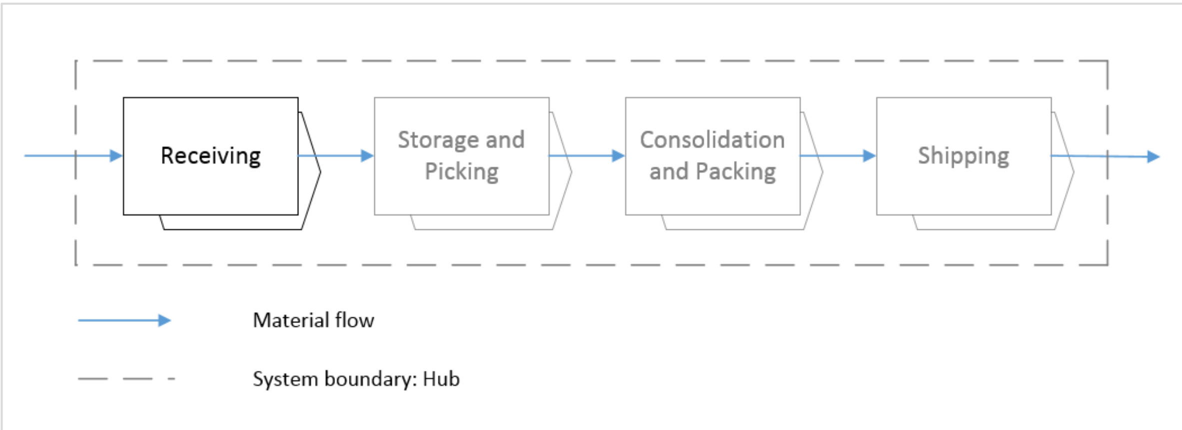



Figure 3-3: DCRM-Receiving

The first process in a distribution centre material flow is the receiving, which represents the interface to the surrounding. This process contains tasks, necessary for the receiving of goods. The first process associated with the receiving is the unloading of external means of transport like trucks, trailer trucks or transporters. Following essential tasks after or during the unloading is the identification of goods and their assignment to the receipt of goods puffer, where the goods are waiting for the subsequent quality control. In case of defective goods, packaging or unit load formation equipment (ULFE), necessary rework is executed (e.g. exchanging carriers). The process receiving ends with the approval for further processing and placing the goods at the disposal (cf. [WIS17], p. 12, 13).

#### 3.1.1.2 DCRM – Storage and Picking

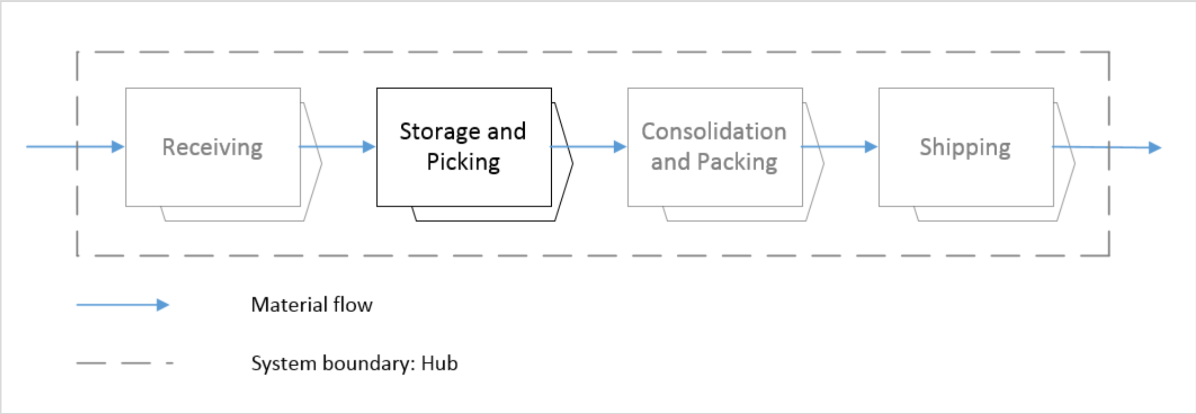



Figure 3-4: DCRM-Storage and Picking

The two central process steps of a distribution centre, storage and picking, are summarized in the DCRM into one single process because one causes the other. The process starts with the transport of goods from the disposal area of the previous main process (receiving) to the storage and picking area. The process storage and picking contains the placement of goods into the store, the storage, the picking of goods out of the store and the removal of ULFE and packaging. The process storage and picking ends with placing the goods at the disposal for further processing.

#### 3.1.1.3 DCRM – Consolidation and Packing

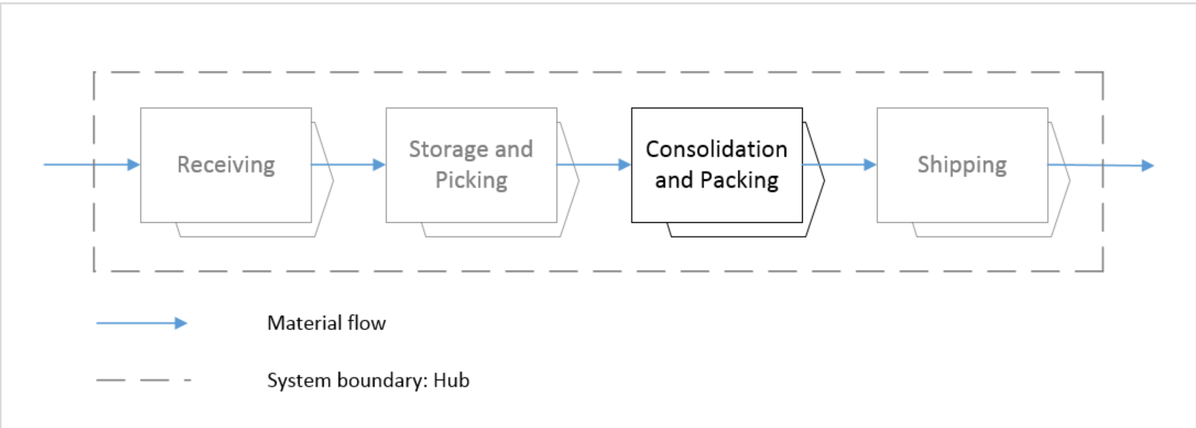



Figure 3-5: DCRM-Consolidation and Packing

Due to their close connection, the process steps consolidation and packing are also summarized in the DCRM into one single process. The process starts with the transport of goods from the disposal area of the previous main process (storage and picking) to the consolidation and packing area. The next step is the consolidation of goods and the following composition into a packaging unit. The consolidation of goods can be executed during transport directly in the buffers of the packaging stations or by running through a distinct consolidation area, e.g. a sorter. In addition, goods are identified, packed and labelled for shipment. There also exist multi-level models of the consolidation and packing process. This is the case if there exist separate areas for packaging, e.g. one area where goods are first packed in parcels and another area where these parcel are packed on pallets in the end. The process consolidation and packing ends with placing the goods at the disposal for further processing (cf. [WIS17], p. 13, 14).

#### 3.1.1.4 DCRM – Shipping

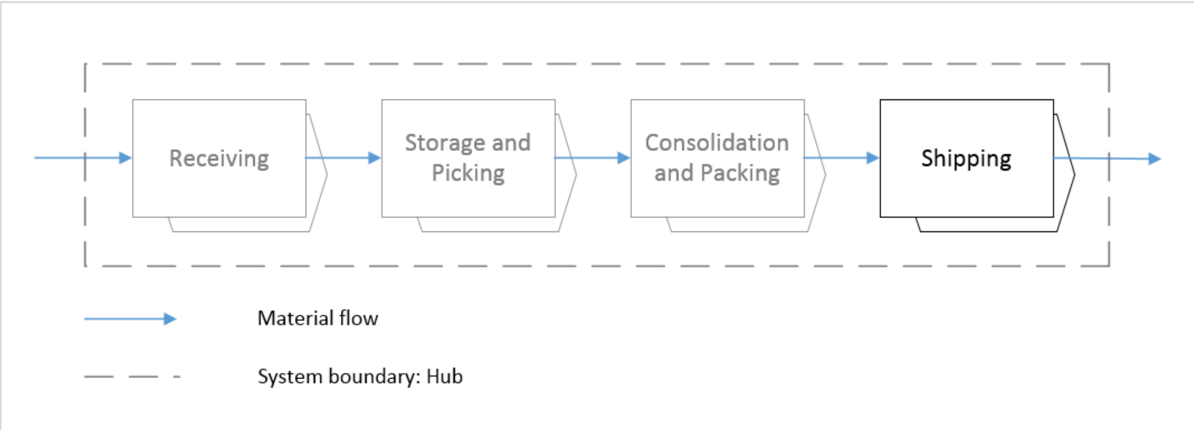



Figure 3-6: DCRM-Shipping

The last process in a distribution centre's material flow is the shipping. The process starts with the transportation of goods from the disposal area of the previous main process (consolidation and packing) to the shipping area. Following essential processes are the sortation of goods for the subsequent loading, identification of goods and their loading into the external means of transport like trucks, trailer trucks or transporters. The process shipping ends when the loading process is fulfilled (cf. [WIS17], p. 15).

## 3.2 Development of the research strategy

The choice of the research strategy was made by the help of the research 'onion' (cf. [SLT09], p. 108).

Figure 3-7 clearly illustrates the stages that must be covered when developing a research strategy, starting with the selection of the underlying research philosophy and ending with the selection of proper data collection and analysis methods.

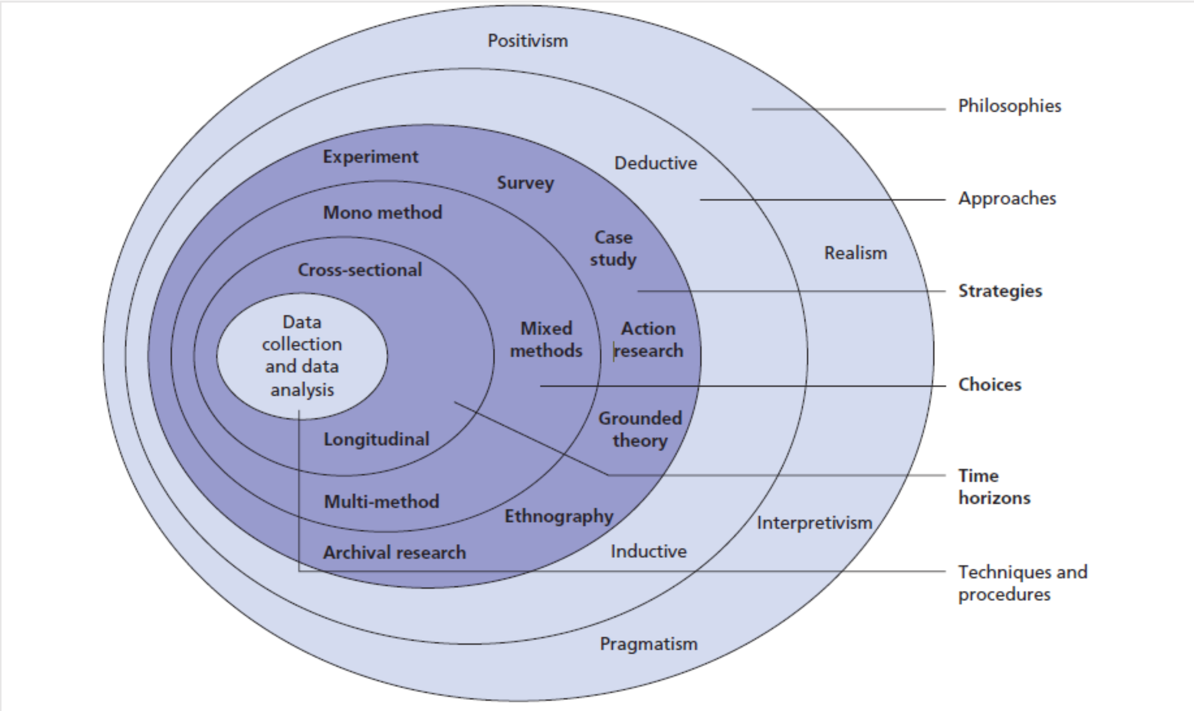



Figure 3-7: The research „onion"([SLT09], p. 108).

The applied research philosophy is strongly related to the type of research questions, seeking to be answered. Some philosophy fits better to a certain research issue than another but of course, the practical reality is that a particular research question rarely falls into only one philosophical domain as suggested in the "onion" (cf. [SLT09], p. 109).

The philosophy of positivism, symbol for the philosophical stance of the natural scientist, was chosen as a tenor for this research.

Positivism ([SLT09], p. 598):

*"The epistemological position that advocates working with an observable social reality. The emphasis is on highly structured methodology to facilitate replication, and the end product can be law-like generalisations similar to those produced by the physical and natural scientists."*

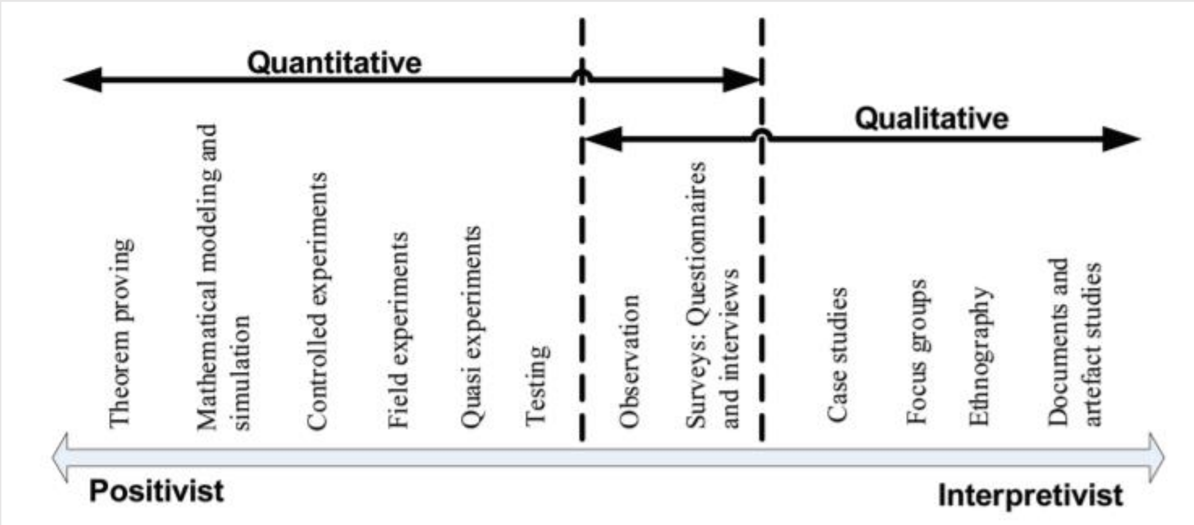



Figure 3-8: Research methods and strategies ([MGS12], p. 225)

By the nature of the research questions cited in chapter two and the general open way of converging to the object of research, this study can be classified as qualitative. The aim was to approach to the object of research with a great openness and to keep room for adaptivity during the research in order to increase the possibility of potential findings (cf. [STU17]). Nevertheless, following the classification of research methods given by Krishnan Nallaperumal (cf. [NAL14], p. 8), this research should be identified as quantitative, because it is mainly based on analysis of numbers and the study is conducted by using the deductive approach seen in Figure 3-9 (cf. [SLT09]).

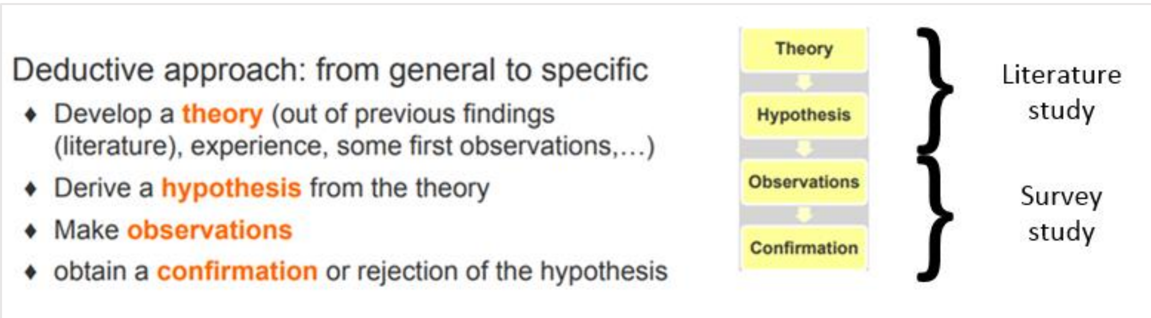



Figure 3-9: Deductive approach based on (cf. [KNU17]).

All above-mentioned points, made it reasonable to use multiple methods for conducting this research, ensuring to address the most important issues of the study. Multiple research methods can be subdivided into two further methods, the “Mixed-method research” and the “Mixed-model research”. This study can most likely be described as a “Mixed model research” as it combines quantitative and qualitative data collection techniques and analysis procedures as well as combining quantitative and qualitative approaches at other phases of the research. This means having quantitative data which can be converted into narrative that can be further analysed qualitatively. (cf. [SLT09], p. 143)

The classification in terms of research design is related to the time horizon in which the investigation takes place. The survey part takes a “snapshot” at a particular time and thus can be declared as a cross-sectional study ([SLT09], p. 155). The part of the literature study is hard to classify, as it also illustrates a snapshot taken in present, but this time for a future scenario, the Physical Internet.

As one object of the research is to accurately portray the current situation of processes executed within hubs, the research is considered to be descriptive in the first place.

*“The descriptive research approach is a basic research method that examines the situation, as it exists in its current state. Descriptive research involves identification of attributes of a particular phenomenon based on an observational basis, or the exploration of correlation between two or more phenomena* ([WIL07], p. 66)*.”*

The descriptive research methodology enables a well-founded gathering of facts and is used within this thesis as a precursor to further explanations and establishing relationships between variables. As both descriptive and explanatory means are used, it is considered to be a descripto-explanatory study (cf. [SLT09]).

Questionnaires and interviews tend to be used for descriptive and explanatory research, thus have been selected as data collection techniques within this thesis for the investigation of the situation of processes inside current hubs (cf. [SLT09], p. 362).

In the following Table 3-1 all selected methods for answering the research questions are illustrated.

Table 3-1: Selected research methods and their corresponding research questions.

| Research Question | Research method |
|---|---|
| 1. What are material handling processes for goods and their corresponding material handling systems within present hubs throughout the supply chain network? | Survey: **Questionnaires** and **interviews** |
| 2. What are PI-hub key elements and their characteristics in terms of material handling processes? | **Desk research**, **academic literature**, **secondary data** |
| 3. What are the technological gaps between the present situation of used material handling systems and the desired systems for realizing the Physical Internet? | **Variance-comparison** between the **present hubs** and the **future PI-hubs** based on results from research question 1 and 2. |

### 3.2.1 Type of questionnaire

After the selection of the research methods in chapter 2 for answering the research questions in chapter 1.2, further decisions about the used type of questionnaire had to be made. As illustrated in Figure 3-10, there exist different types of questionnaires, all possible for conducting a research. In this work, the design of the used questionnaire is considered to be self-administered as well as interviewer-administered. On the one hand, it is declared to be self-administered because after spreading the questionnaires electronically to various recipients via using the Internet (Internet-mediated questionnaire), the questionnaires were completed by the different respondents. On the other hand, it is also declared to be interviewer-administered as some responses were also recorded during an interview on the basis of each respondent's answers. In this very case the interviews were realized by using the telephone, thus classified as telephone questionnaires (cf. [SLT09], p. 362-363).

Both proceedings were using the same questions as prepared for the Internet-mediated questionnaire.

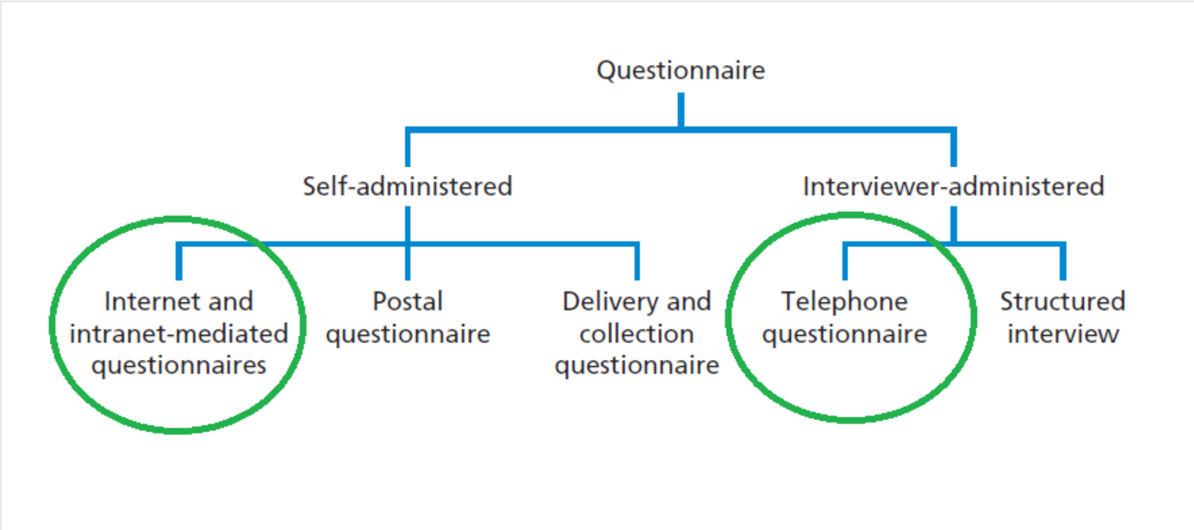



Figure 3-10: Types of questionnaires (cf. [SLT09], p. 394).

Internet-mediated and interviewer-administered questionnaires have been selected to improve the reliability of data, as both types are administered in conjunction with email, which offers greater control because most users read and respond to their own mail at their personal computer or may forward it to a colleague who has proper knowledge about the topic. In particular, interviewer-administered questionnaires enable to ensure that the respondent is whom you want, reducing the probability of gathering contaminated data from respondents with insufficient knowledge (cf. [SLT09], p. 363).

## 3.3 Process modelling

In addition to the methods illustrated in Table 3-1, used for answering the research questions, process modelling was used to clearly visualize the sequence of processes executed within hubs. After receiving the results from research questions 1 and 2, Event-driven Process Chains (EPC) have been selected to clearly illustrate the workflow of the executed processes within hubs/PI-hubs and to assign used material handling systems to their corresponding processes.

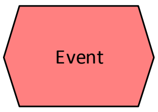
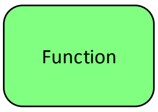
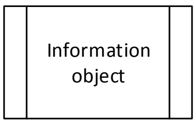
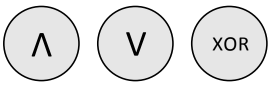
### 3.3.1 Event - driven Process Chains

In many companies, Event-driven Process Chains are used for modelling, analysing and redesigning business processes. The EPC provides extensive means for modelling different aspects of a business process and is mainly used for (cf. [LA98], p. 4):

- Business process re-engineering
- Definition and control of workflows
- Configuration of standard software
- Software development
- Simulation
- Activity based costing
- Quality-related documentation of processes according to the requirements of ISO 900

The main elements of an EPC are functions and events. Functions are always triggered by events and functions produce events. Therefore a process is described by a sequence of alternating events and functions. Also alternative or parallel paths can be modelled by using logical operators, such as AND, OR, XOR or more complex expressions. Such operators can be used to split control flows and to join them again (cf. [LA98], p. 4). The EPC elements used in chapter 4.7 are illustrated in Table 3-2.

Table 3-2: EPC-elements (cf. [LA98], p. 4, 5; [BCK15], p. 40).

| Elements | Description |
|---|---|
|   | An event describes the occurrence of an operational status, which triggers a function or which can be a function's result. |
|   | The function describes what is done after an event. |
|   | The organisational unit shows, which person executes a specific function. |
|   | The information object illustrates the data, necessary for the execution of functions. |
|   | The three logical operators enable to create branches between events and functions and vice versa.<br>∧ = AND<br>∨ = OR<br>XOR = exclusive OR |

Note: Within the context of this master thesis, not only humans can act as the element "Organisational unit", but also machineries.

## 3.4 Data collection - PI-Literature study

For answering the second research question defined in chapter 1.2, a PI-Literature study was conducted. In the following chapter the key elements of PI-nodes, especially their requirements and characteristics for realizing the Physical Internet will be investigated. As the PI-nodes of the Physical Internet are locations expressly designed to perform operations on PI-containers such as receiving, testing, moving, routing, handling, placing, storing, picking, monitoring, labeling, paneling, assembling, disassembling, folding, snapping, unsnapping, composing, decomposing and shipping PI-containers (cf. [MMB10], p. 10), literature on these PI-nodes have been selected for the derivation of PI-hub key elements and their corresponding characteristics.

This is achieved by analysing the single main processes executed inside a PI-node with respect to the investigation's system boundary defined in chapter 2.3, beginning at the receiving area and ending at the shipping area as illustrated in the DCRM outlined in chapter 3.1.1. As it is difficult to focus on all of the main and sub processes defined in the DCRM to the same extent, the following processes are chosen to be further investigated:

1. Loading and unloading external means of transport
2. Composing and decomposing
3. Sorting and conveying
4. Goods identification and management
5. Storing and buffering
6. Dispatching external means of transport (not part of the DCRM)

### 3.4.1 Loading and Unloading

Unloading processes of PI-containers are strongly connected with PI-movers. It is all about moving PI-containers from one place to another in the most general way including the three main types: PI-transporters, PI-conveyors and PI-handlers (cf. [MMB10], p. 7). As this thesis is focusing on processes inside PI-facilities, mostly PI-vehicles for indoor movements of PI-containers will be discussed here. It is well known, that pallets are the most common choice in terms of unit load formation equipment. As a result the most typical kind of vehicle for moving unit loads is a conventional lift truck. Because of the sustainability issue of the Physical Internet already mentioned in the previous chapters, palletless packaging and transportation is intended to be achieved by modular PI-containers that are stackable, inter-lockable and designed for a handling without pallets (or any other unit load formation equipment). Therefore such PI-containers should have the means to attach themselves to a PI-mover without having to be placed on a platform (cf. [MMB10], p. 7).

A potential forklift concept, capable of lifting PI-containers without the traditional forks could look like the simple illustration in Figure 3-11.

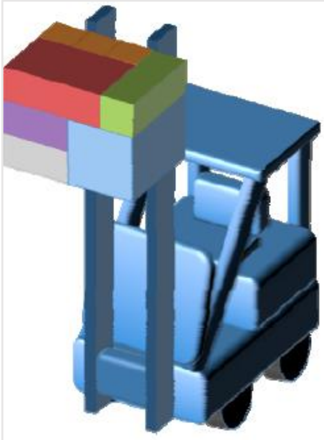


Figure 3-11: PI-lift-truck lifting a PI-composite composed out of several single PI-containers ([MMB10], p. 8).

Transportation of PI-containers as well as whole composites of PI-containers from origin to destination within a PI-facility autonomously, is also considered to be part of PI-facility processes to realize the Physical Internet. A simple PI-mover could look like illustrated in figure X, with four wheels that could be motorized and smart-sensor enabled so as to allow its autonomous travel (cf. [MMB10], p. 8).

Figure 3-12: Example of a PI-mover used for moving a PI-Composite ([MMB10], p. 8).

From this, it can be derived that PI-movers with adequate system design suitable for handling PI-containers will be needed for future. Either manual or automated moving of PI-containers, the desired system of PI-movers will have to be designed with a kind of snapping device, which allows the attachment with PI-containers and PI-composites (cf. [MMB10], p. 8).

### 3.4.2 Composing/Decomposing

PI-composers are used for constructing PI-composites from specified sets of PI-containers, usually according to a 3D layout specified by the end customer or for the purpose of making the Physical Internet more efficient and/or for decomposing PI-composites into a number of PI-containers that may be either smaller PI-composites or single PI-containers, according to client specifications. This composition and decomposition of composite PI-containers should be realized by an interlocking mechanism, which enables to unsnap PI-composites into smaller PI-containers as well as to snap them together (cf. [MMB10], p. 17).

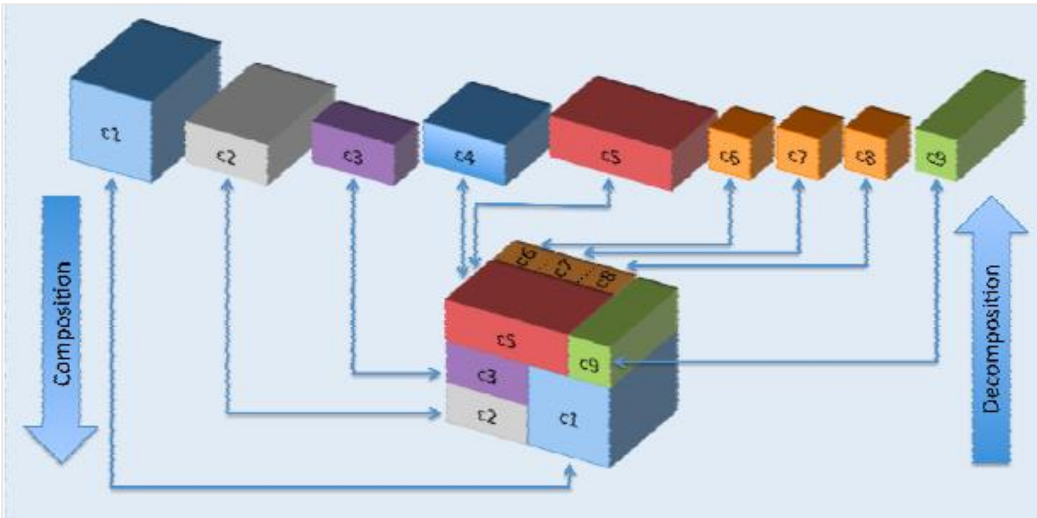



Figure 3-13: Conceptual illustration of a PI-composer's functionality ([MMB10], p. 17).

In Figure 3-13 a conceptual illustration of a PI-composer's functionality is shown. Several PI-containers varying in size are interlocked to compose a PI-composite (cf. [MMB10], p. 17).

Even though the modularity of PI-containers contributes a lot to build compact PI-composites out of PI-container sets, it will not always be possible to reach a perfect fit as in Figure 3-13. In such cases, either the holes may be left as such when the structural integrity of the PI-composite is not affected or empty PI-container-structures may be used to fill the holes if the overall structure would suffer from leaving the holes empty (cf. [MMB10], p. 18).

It is anticipated that PI-composers will be designed for composing and decomposing composite PI-containers at high velocity. For example, it will be normal that a PI-composer is able to compose in a few minutes (or less) a 1.2x1.2x6 cubic-meter PI-composite from twenty smaller PI-containers. PI-composers are prime candidates for automation, notably integrating PI-conveyors and PI-sorters. They play a role similar to current palletizers and depalletizers, but with standard easy-to-interlock modular PI-containers rather than different arbitrarily sized objects that are not necessarily easy to handle. Overall, PI-composers perform fragmentation and defragmentation operations on PI-composites, without ever opening a unitary PI-container (cf. [MMB10], p. 18).

## 3.4.3 Sorting and Conveying

### 3.4.3.1 PI-Conveyors

In addition to PI-movers and PI-vehicles, PI-conveyors will also play an important role for PI-facility processes and in realizing the Physical Internet. PI-conveyors are conveyors specialized in the continuous flowing of PI-containers along determined paths without using PI-vehicles and PI-carriers. Contemporary conveyors like belts and rollers, with their underlying mechanics, represent a significant part of the overall cost and therefore contribute to the physical footprint of the conveyor. As PI-conveyors will be explicitly designed for PI-containers, they may will differ from present conveyor techniques, even though it is not sure yet, whether upcoming PI-conveyors will apply conventional mechanics used in present systems or entirely new PI-conveyor mechanics (cf. [MMB10], p. 8-9).

Various conveying solution concepts for PI-conveyors can be found. One concept often mentioned has the structure of grid, which can be seen in Figure 3-14.

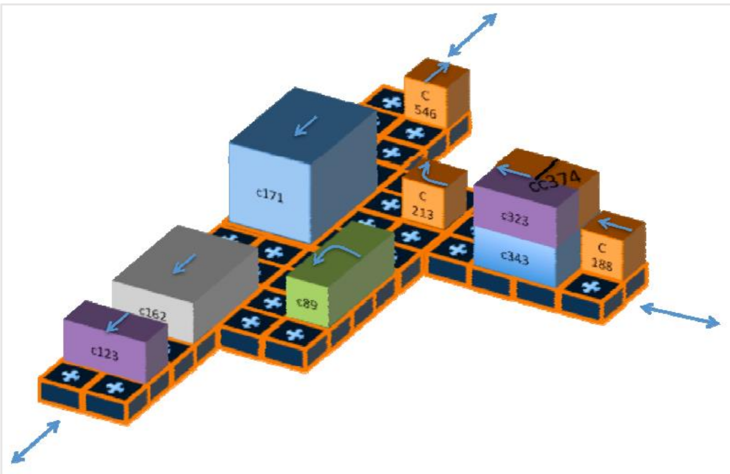



Figure 3-14: PI-conveyor grid composed out of single, flexible PI-cells ([MMB10], p. 9).

From that very simple illustrative concept can be concluded, that some additional key requirements for the concept arise, especially in terms of how PI-containers are attached to the

PI-conveyor and in which way they will be moved. To exploit the whole potential of such a PI-conveyor platform built out of single PI-cells, the movement of PI-containers placed on these PI-cells should be possible in at least the four cardinal directions on each of the PI-cells (cf. [MMB10], p. 9).

#### 3.4.3.2 PI-Sorters

A PI-sorter may incorporate a network of PI-conveyors and/or other embedded PI-sorters to achieve its task. A PI-sorter is receiving PI-containers from one or multiple entry points, has to sort them so as to ship each of them from a specified exit point, potentially in a specified order. The PI-sorters are typically embedded within more complex PI-nodes (cf. [MMB10], p. 16).

A PI-sorter built in matrix form with 12 rows and 16 columns is illustrated in Figure 3-15.

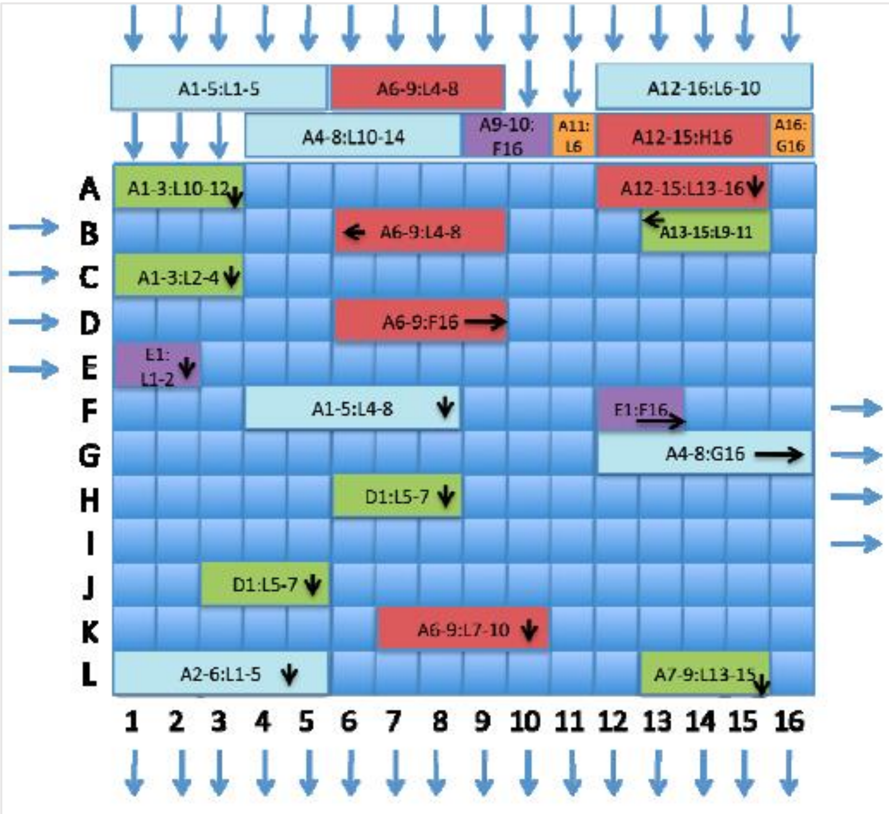



Figure 3-15: Matrix-style PI-sorter ([MMB10], p. 16).

### 3.4.4 Identification and Management System

#### 3.4.4.1 Identification System

Physical Internet PI-containers should be equipped with a unique physical number and means to automatically capturing information via a smart tag and then resorting to other technologies derived from the Internet of Things as they become available. It is necessary to equip PI-containers with these tags to allow their identification and routing through the networks. This tag also enables faultless traceability of the PI-containers within the Physical Internet, an important condition to its efficient and secure operation. Several types of information can be contained in the tag, enabling PI-container identification, integrity, delivery and security (cf. [BMM14], p. 69).

The tag only provides its information to the authorized parties via the management of access rights to the container's context. With regard to the data concerning the products, it should be stored by the corresponding stakeholders who have to manage its access (cf. [BMM14], p. 69).

Among various contemporary existing data acquisition means, RFID technology is currently perceived to be suitable for building PI-container tags. With the Internet of Things, also other structuring and protection technologies are emerging, fields which are currently the subject of heavy R&D investments. The unique identification of the PI-container can also be coupled with an Ipv6 Internet address to ensure not only identification, but also communication (cf. [BMM14], p. 70).

Examples of relevant information about a PI-container include ([BMM14], p. 70):

- Identifier of the customer that uses it;
- Identifier of the owner;
- Identifier of the logistics service provider (or its software agent) responsible for it;
- Dimensions and maximum weight;
- Structural load capacity (internal and stacked);
- Functionalities (handling, storage, etc.);
- Identifier of the service contract(s) in force;
- Status of the container on the tag or in immediate proximity (signal, fault identifier, seal integrity);
- Status of the container on the tag or in immediate proximity (signal and over-limit warning: time, temperature, vibration, humidity, etc.);
- Secure access for the approved agents: customs, health, etc.;
- Geolocation

The protection of the content of the PI-containers by an encryption/decryption key and its controlled access will be increasingly important as well, but is not discussed within this thesis.

#### 3.4.4.2 Management System

In addition to the physical structure of the Physical Internet networks, the other component that plays a fundamental role in the development of services in an interconnected network is to structure these services in layers according to standardized protocols. These protocols are a set of professional rules, which have to be observed by each of the stakeholders of the network (truck driver, handler, facilities, software agent, service provider, etc.). Herein arises another relation between the Digital and the Physical Internet. According to the Open System Interconnection (OSI) reference model adopted by the International Standardization Organization (ISO) the IT network services have been structured into seven layers (cf. [BMM14], p. 71).

In (Ballot, Montreuil, & D. Meller, The Physical Internet - The Network of Logistics Networks, 2014), Ballot, Montreuil and D. Meller recommended to use this OSI reference model as a conceptual basis for the Physical Internet by introducing the Open Logistics Interconnection (OLI) reference model. The OLI model illustrated in Figure 3-16 is an abstract description aiding the protocols design for logistics flow networks, including activities such as procurement, handling, realization, storage and transportation (cf. [BMM14], p. 71).

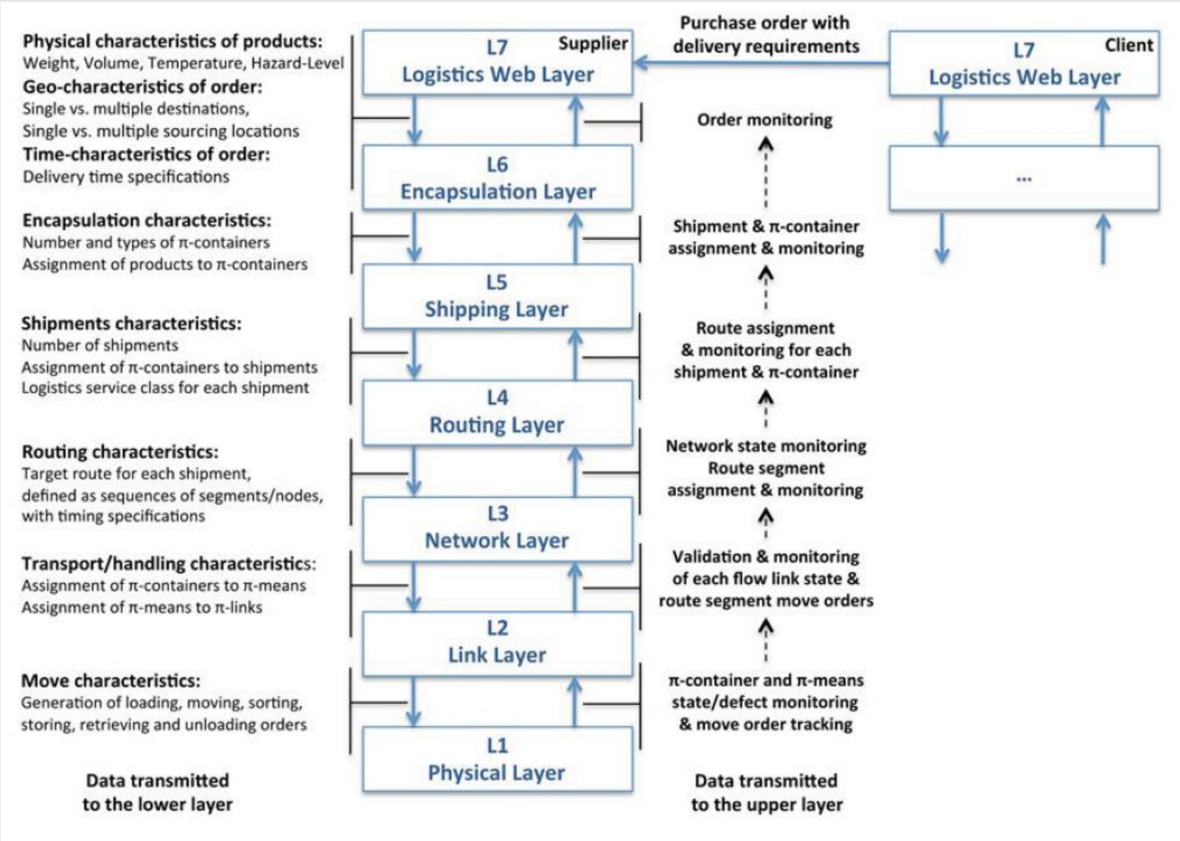



Figure 3-16: OLI model ([BMM14], p. 76).

These structuring components of the Physical Internet enable the examination PI-hubs. The service layers are implemented at each user of the Physical Internet, thus among all PI-nodes to ensure the PI-Containers are routed and monitored (cf. [BMM14], p. 74,76).

The initial approach of this OLI reference model does not include the possibilities offered by the infrastructure, which could also contribute to an increase in performance. This would mean adding physical layers ranging from container support features (communicative handling equipment or vehicles) to the infrastructure itself (smart or automated road, smart sorting and storage infrastructure) to achieve a better representation of status which makes it possible to control traffic, choose itineraries, etc. These layers should additionally provide services to and receive services from several non-physical layers such as those of the network and routing layers, to find a balance between their use and the performance of the services that use them. This means that for example a hub, according to its level of saturation, or a road, according to the traffic condition, could communicate its status which in the end enables to update the processing or arrival time according to the vehicle used. In this way the Physical Internet's logistic network would be able to exploit for anticipation, regulation and control purposes the high speed of the information compared with the much lower speed of logistics operations (cf. [BMM14], p. 74-75).

This results in certain requirements for the information structure. By now, logistics information systems have been built on the physical network they control, resulting in specialized and centralized systems. The Physical Internet stands for a decentralized view. The idea is to capture information locally from the PI-containers themselves or via the network equipment (handling equipment, means of transport, storage slots, etc.) and to make the information available on the Digital Internet which enables the stakeholders to use it in a secure context. This way of information flow shall be enabled by using the Internet of Things (cf. [BMM14], p. 35).

Herein, the capturing and publication of logistics performance information is just the first link in the information chain that leads to logistics decision making processes. The vision is, that providing the information to the different stakeholders should enable the creation of several types of applications within the cloud that will enable not only new flow control logic to exploit an overview network that is both more global and more precise as it is individualized, but also network management applications to exploit the perfect knowledge of its operations. This means that shipping a container from one hub to another is a logistic decision which is made according to the conditions of a given distribution network. At the same time, this represents the performance of that part of the Physical Internet network at the precise moment this operation takes place (cf. [BMM14], p. 35-36).

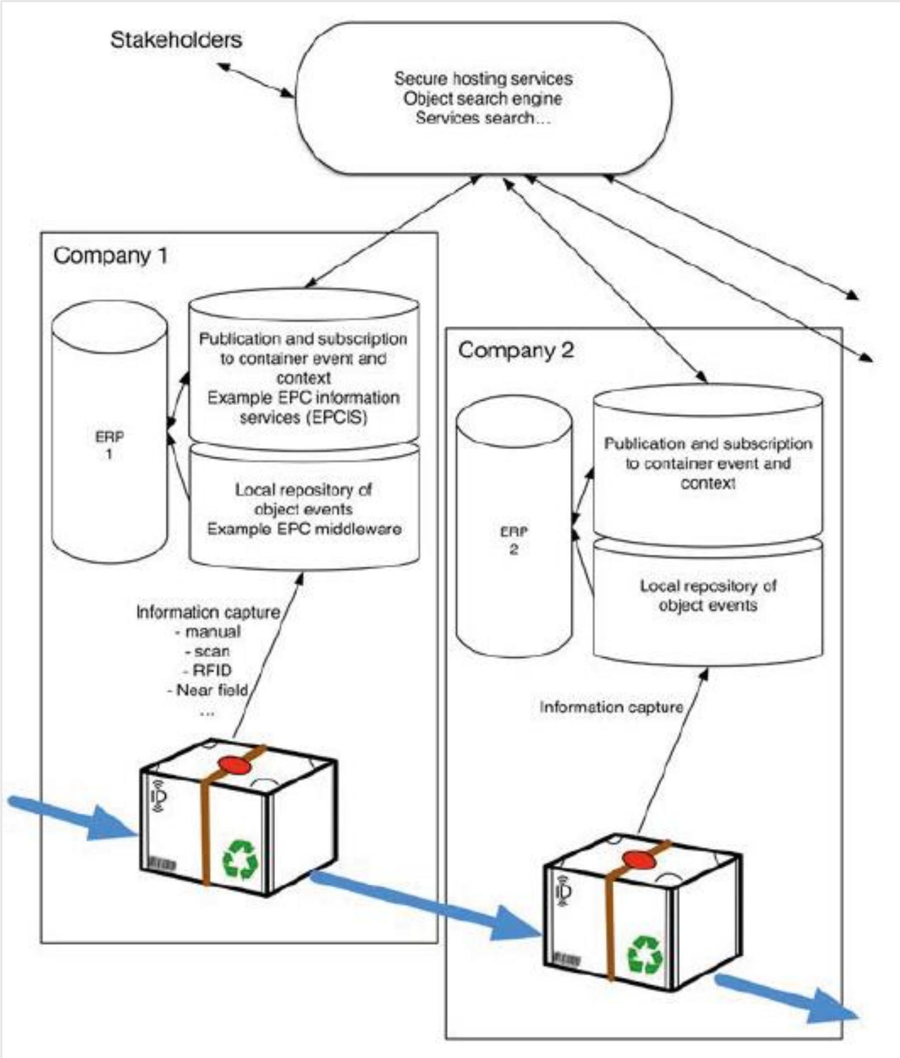



Figure 3-17: Information architecture for monitoring containers in the Physical Internet – All communication is conducted by using the Digital Internet, some applications can be in the cloud ([BMM14], p. 41).

### 3.4.5 Storing and Buffering

Current logistics networks are specific to each customer and therefore need to be centralized to be efficient. Such a centralization of logistics networks impacts the level of inventory that is necessary by considering economical shipping volumes as well as those for buffer inventory to compensate for the variability in demand(cf. [BMM14], p. 37).

To reduce lead-times for products consumed regularly, it may be of interest to locate products near to the customers.

A PI-store has the mission to enable the storage of PI-containers for clients during a certain target time window, which can be very precise or more probabilistic, shorter or longer term, depending on current circumstances. Imagine that PI-hubs, as well as other PI-nodes in the network, are in addition to their other functions, equipped with storage capacities, opens the possibility of storing inventory in a high number of locations. When a customer demand arrives, the inventory position within the logistics network is examined to select that which will best satisfy it and perform the adjustments to cover future demand (cf. [BMM14], p. 37).

A completely new prospect for inventory management and the supply chain arises from the possibility of setting up a decentralized storage in the network, even though theoretical and actual gains according to the sectors and stakeholders remain to be assessed, not only from the inventory point of view, but also from the point of view of transport (cf. [BMM14], p. 37).

In a more particular case described in (cf. [BMT13]), the purpose and the basic idea of a road-rail PI-hub is discussed and it becomes clear that the rail process as such is subject to some degree of uncertainty such as delays, though it is expected to be limited.

The aim of such a road-rail PI-hub is to transfer PI-containers from trains from one line to trains from another line or from and to trucks in an efficient and sustainable way. Therefore the basic idea of a road-rail PI-hub is (cf. [BMT13], p. 4):

1. To never dismantle trains to avoid very strict safety constraints
2. To enable a real network with many destinations available with short lead-times
3. To smoothly interconnect with truck-services

In this very case and because train services are not flexible, they set the pace for all operations. Whenever the hub is not able to deal with the forecasted volumes, PI-protocols have to switch extra volumes to road transit centres or the opposite. One big source of variation the PI-hub will be faced with, is the number of PI-containers to unload and load and their type from and to each train. Some uncertainty is also expected at the truck side so the sorting operations will have to deal with these variations (cf. [BMT13], p. 4, 7).

From this, it can be concluded that some dedicated areas for storing and buffering containers will be needed inside the PI-hub facilities to keep a certain level of flexibility to compensate uncertainty.

PI-stores will further differ from contemporary warehouses and storage systems in two major points. First, they will be explicitly designed for PI-containers: They will be able to stack PI-containers, interlock them, snap them to a rack and so on. Second, they will not deal with products as stock-keeping units (SKU's), but rather focus on PI-containers, which are all individually contracted, tracked and managed to ensure service quality and reliability (cf. [MMB10], p. 18).

The simple illustrative concept in Figure 3-18 shows the stacking and snapping functionalities of a potential PI-store, enabled by the fact that it only deals with modular PI-containers that are designed for handling and storage.

In the left illustration of Figure 3-18, a PI-store designed for stacking is presented. From a functional point of view, stacking is identical to what is being done across the world in cargo container ports, with the added flexibility provided by the dimensional modularity and structural strength of PI-containers.

Even though PI-containers could be stored in conventional racks, due to their modular dimensionality, there is a need to develop new kinds of PI-store technologies to exploit the powerful functional characteristics of PI-containers and the dynamics of the Physical Internet.

The illustration on the right side of Figure 3-18, depicts one innovative example of a PI-store designed with snapping features. This PI-store exploits fixtures embedded in the PI-containers in order to attach them to a grid, without having to deposit the PI-containers on a flat surface as in conventional rack based storages. In this way, platforms used in present storage slots of any rack today will lose their purpose.

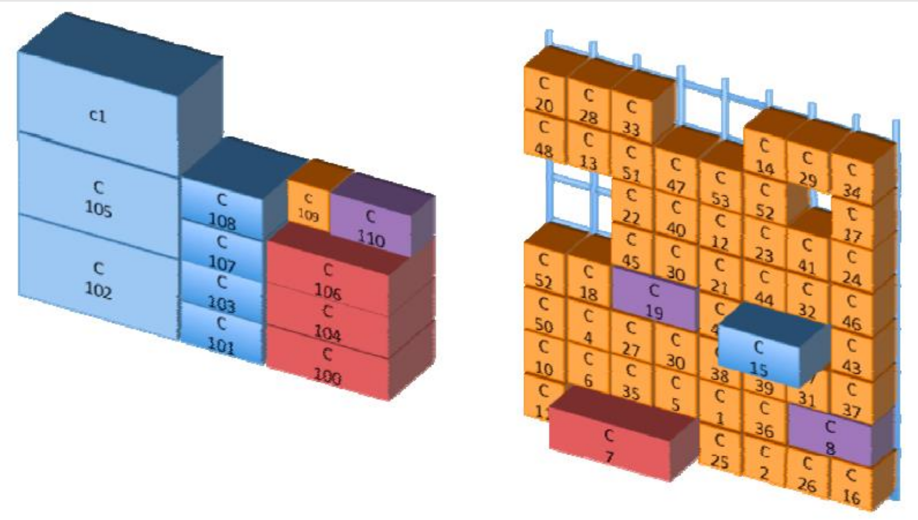



Figure 3-18: Stacking and snapping functionalities of a PI-store ([MMB10], p. 19).

## 3.4.6 External means of transport between PI-hubs

As already mentioned before, one major aspect of the Physical Internet concept is sustainability. The aim to increase the sustainability level of present logistics, which ranges over the whole structure of the supply chain, thus also affects the means of transport, responsible for moving PI-containers from origin to a certain destination. Even though this thesis generally investigates only processes executed inside PI-hubs, some information concerning transportation outside these facilities are displayed here.

In this context, taking advantage of green vehicles which can be powered by alternative fuels and advanced vehicle technologies including hybrid electric vehicles, battery electric vehicles etc. will be inevitable for realizing the Physical Internet.
For generating a fully efficient and sustainable PI-network, not only the use of various road based vehicles arriving and departing from PI-hubs and other PI-facilities will be important, but also setting up larger PI-sites capable of handling multimodal transport like a road-rail hub (cf. [BMT13]).
Even though a strict differentiation upon the single PI-facilities in terms of scope and tasks has been declared in (cf. [MMB10], p. 10-21), there will also arise the need of some larger PI-facilities designed for handling not only PI-containers or PI-carriers like e.g. PI-transits, but serving both types of loads. This includes dismantling of PI-carriers into PI-unit loads and further into PI-containers as well as all other necessary operations needed within such a PI-facility.

In (cf. [MMB10]), such a kind of PI-facility termed PI-hub should fulfill these requirements, even though their aim is to rather enable unimodal PI-container crossdocking operations than handling both PI-carriers and PI-containers (cf. [MMB10], p. 14).
The mission of PI-hubs will be to enable fast, efficient and reliable multimodal transportation, by allowing ease of transfer of PI-containers between combinations of road, rail, water and air transportation (cf. [MMB10], p. 14).

# 4 Proceedings and Methods

In the following chapter, the chosen research methods from chapter 3 are executed. As the literature study for the deduction of PI-hub key elements and their corresponding characteristics was already executed in chapter 3.4, this chapter comprises the creation of the questionnaire design, used for data collection of the current hubs, followed by the presentation of results of this data collection. For the purpose of completeness, the main results of the literature study in chapter 3.4 are summarized and also presented in this chapter. Based on the findings about current hubs in chapter 4.4.1 and future PI-hubs in chapter 3.4, two extended Event-driven Process Chains for material-handling processes inside a present hub and a future PI-hub were created and are illustrated in the end. The variance comparison between present hub system characteristics and the derived PI-key element characteristics is executed later in chapter 5.

## 4.1 Application of Research methods – Questionnaire approach

Prior to the explanation of the questionnaire approach, a short overview of the research steps is given and illustrated in Figure 4-1.

Firstly, an overview of the system boundary related main material handling processes of present hubs as well as future PI-hubs was obtained by gathering and analysing related literature according to the objectives of the desired research questions and system boundaries.

Secondly, a survey strategy using questionnaires and interviews was chosen to identify the material handling processes (and their corresponding systems) executed in current hubs (cf. [SLT09], p. 145). Despite the immense amount of material handling technologies available nowadays, this analysis of the current situation is providing a clear picture of which systems are truly in use. Findings are of course dependent on the different types of hubs (e.g. small crossdocking facilities or big distribution centres), from which information was provided in the end. Therefore it's important to point out that all results of the survey refer to the investigated hubs and are no generalization for other kinds of distribution centres.

Parallel to the formulation of questions for the questionnaire, a detailed PI-literature study was selected to identify PI-key elements and their corresponding characteristics in respect to the system boundary of the investigation (executed in chapter 3.4). The creation of the questionnaire's questions was influenced by the PI-literature study, which will be explained more detailed in chapter 4.2. Building upon the findings from the questionnaires, interviews and the PI-literature study, extended Event-driven Process Chains (EPC) were created for both a present hub as well as a future PI-hub. In the end the gaps between the actual situation and the target PI-situation were highlighted in chapter 5, based on the results from chapter 4.3 and 4.4.1.

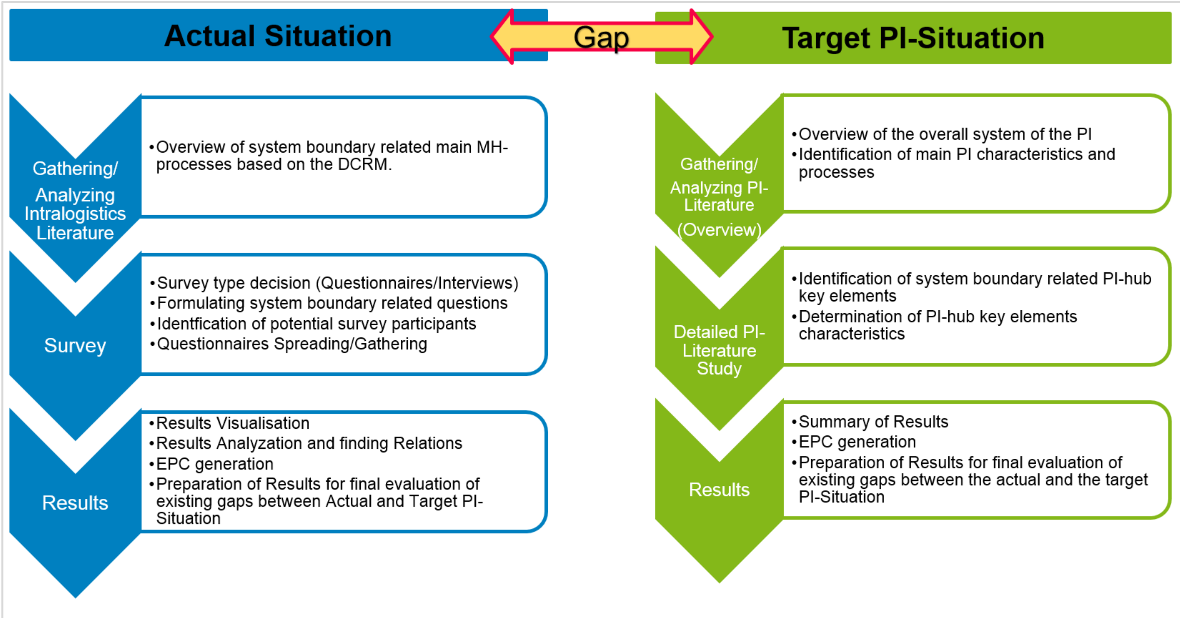



Figure 4-1: Research steps

## 4.2 Data collection - Questionnaires and Interviews

In this chapter, the development of the questionnaire design is explained, which describes the way of creating proper questions. Additional information about the distribution of the questionnaire is also outlined in this chapter.

### 4.2.1 Design of questions

Questionnaires mostly offer only one chance to collect data, as it is often difficult to identify the real respondent or to return to collect additional information. To answer the research questions in a desired way, the questions asked in the questionnaire have to be defined precisely prior to data collection. It is very important to select the appropriate characteristics to answer the research questions and to address objectives (cf. [SLT09], p. 366-367).

Five major steps have been applied to generate a proper questionnaire, following the guidelines by (cf. [SLT09], p. 366ff.):

1. Review of literature related to the research topic.
2. Discussion of ideas with colleagues, thesis supervisor, interested parties.
3. First formulation of questions.
4. Further development of questions in consultation with the thesis supervisor.
5. Pilot testing of the designed questions with colleagues to create a questionnaire with higher validity.
6. Refinement of questions so that respondents will have no problems in answering the questions and there will be no problem in recording data.

Four types of questions have been used within the questionnaire:

- Quantity questions, to which the response is a number giving the amount
- Category questions, where only one response can be selected from a given set of categories
- List questions, where a respondent can choose from a list of items
- Open questions

Most questions have been extended with an option to add individual information/answers when e.g. none of the possible listed answers were appropriate or if a potential answer was simply missing.

### 4.2.2 Formulation of questions

The main part of the formulation of the 18 questions was based on research related literature in coordination with the declared system boundary in chapter 2 and 3. The main processes of the DCRM illustrated in Figure 3-2 worked as a guideline for the creation of the questions. The main processes “receiving”, “storage and picking”, “consolidation and packing”, “shipping” and their underlying material handling processes were analysed in appropriate literature and are explained in chapter 3.1.1. This basic knowledge about processes and their sequence of execution in current distribution facilities was used as a guideline to create the main part of the questionnaire. Herein it’s important to mention, that the process of developing proper survey questions was not only influenced by current processes defined by the DCRM, but also by analysing PI-literature and the determined PI-characteristics. Therefore the analysing of both current theory concerning present hub processes and PI-hub processes were affecting each other, because it was important to create a common level for comparison in the end (for answering the research question number 3). This means that the formulation of the questions for the questionnaire was made by using the DCRM processes as a guideline but in correlation with the determined PI-characteristics. This enabled a more precise and effective formulation of questions and increased the possibility of a suitable comparison of results of both present hubs and PI-hubs.

The sequence of the asked questions was set in accordance to the sequence of the main processes in the DCRM. In addition to the main part of the questionnaire, also a few questions were set up, for a better identification and characterization of the investigated hubs. These questions were selected to be asked first in the questionnaire.

### 4.2.3 Distribution of the questionnaire

The next task after developing a proper questionnaire was, to identify relevant contacts among the huge amount of potential firms and initiatives which could be capable of contributing to this research by answering the designed questionnaire. For reasons of secrecy all firms, initiatives and other contacts which have provided information for this thesis, won't be disclosed here. Nevertheless, Figure 4-2 should give an overview of the process of getting hold of information.

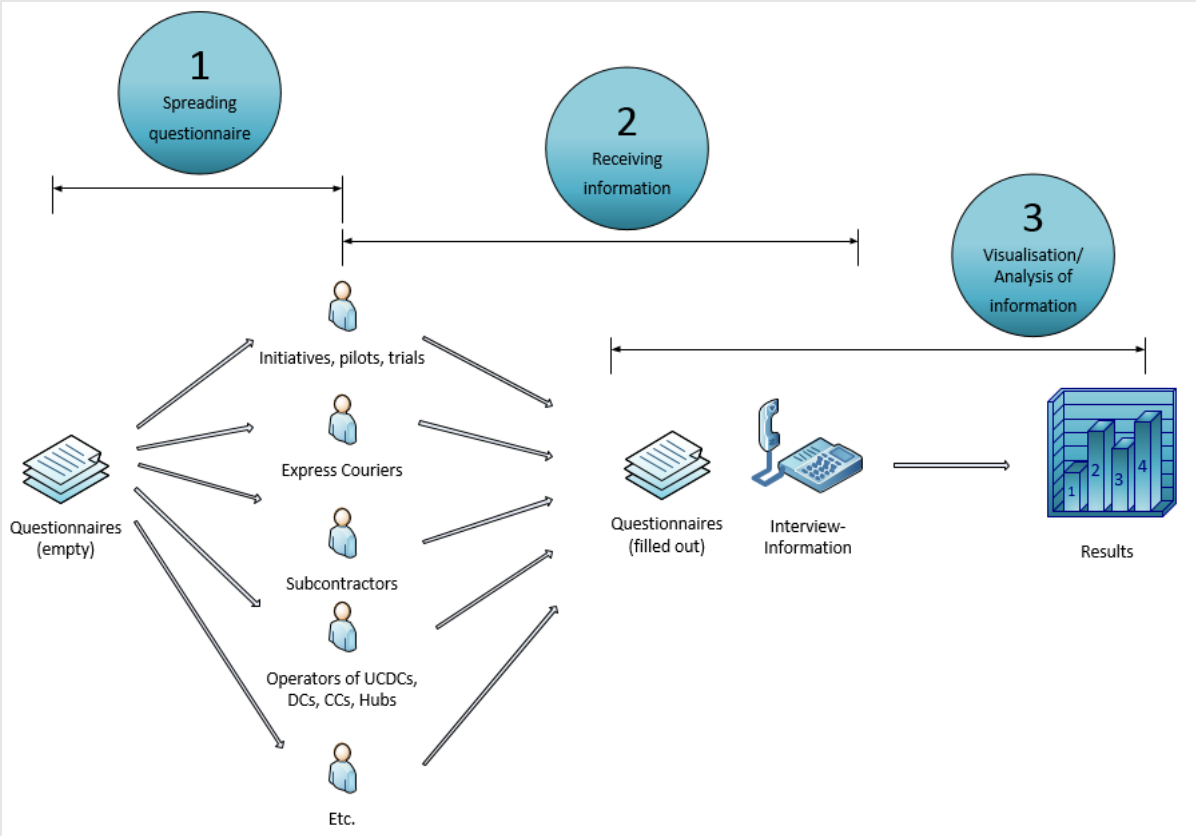



Figure 4-2: Information gathering approach by using questionnaires and interviews.

As seen in Figure 4-2, many different types of channels have been selected to get in touch with a broad spectrum of potential contacts and to increase the probability of receiving adaptive responses.

Selected contacts have been:

- Private sector companies,
- Cross-country initiatives in logistics and mobility sectors,
- Distribution service companies operating in urban areas,
- European sustainability programs, urban delivery service projects and trials,
- Cooperative initiatives in the field of multimodality, urban electro mobility, autonomous driving, car sharing, logistics in urban areas,
- Urban delivery service projects,
- Operators of UCCs, DCs, Terminals, Micro terminals, Depots, hubs,
- Express couriers,
- Express courier subcontractors,

- Logistics service providers,
- Logistics consultancies

All in all, 78 person have been contacted, from which 45 contact person have been reached and replied. Due to several reasons (e.g. some were not allowed to provide confidential data, others were simply the wrong contact person in terms of knowhow, etc.) only 6 out of the 45 responses led to a successful gathering of information through either filled out questionnaires or telephone interviews (positive response rate of only 4,68%). Four contact person provided information on one facility each and the remaining two were able to provide information on even three facilities within their companies, leading to an overall information on 10 facilities.

## 4.3 Characteristics of PI-hub key elements

In the following chapter, the PI-literature study executed in chapter 3.4 was used to derive PI-hub key element characteristics for the corresponding PI-hub key elements identified in chapter 3.4. The following Table 4-1 illustrates the PI-hub key elements with their corresponding characteristics.

Table 4-1: PI-hub key elements and corresponding characteristics

| PI-hub key elements | PI-hub key elements characteristics |
|---|---|
| PI-mover | • Snapping device/interface (allows attachment with PI-containers and PI-composites)<br>• Manual or automated moving of PI-containers and PI-composites<br>• ULFE(Unit load formation equipment)-free |
| PI-composer | • High automation level<br>• Composing and decomposing at high velocity<br>• Snapping device (allows attachment with PI-containers and PI-composites)<br>• ULFE-free |
| PI-conveyor | • Flow of PI-containers along determined paths<br>• PI-conveyor platform built out of single PI-cells<br>• Movement of PI-containers possible in at least 4 cardinal directions<br>• ULFE-free |

| PI-hub key elements | PI-hub key elements characteristics |
|---|---|
| PI-sorter | • Typically embedded in more complex PI-nodes<br>• May incorporate a network of PI-conveyors<br>• PI-matrix platform built out of single PI-cells<br>• Movement of PI-containers possible in at least 4 cardinal directions<br>• ULFE-free |
| PI-identification system | • Exploitation of the IoT (Internet of Things)<br>• RFID-technology<br>• Automated transmission of information<br>• Smart tags able to record, transmit and update information |
| PI-management system | • Routing and monitoring PI-containers<br>• Exploitation of IoT and the high speed of information compared to the much lower speed of logistics operations<br>• Decentralized system<br>• Decision of shipping PI-containers from one hub to another is based on different constraints, e.g. condition of a given distribution network |
| PI-store | • Explicitly designed for PI-containers<br>• Able to stack PI-containers, interlock them or snap them to a rack<br>• Not dealing with SKU's, rather with PI-containers which are all individually contracted<br>• ULFE-free |
| Dispatching different external means of transport (arriving at and departing from PI-hubs) | • Taking advantage of multimodal transport<br>• Taking advantage of different vehicle types, especially vehicles powered with alternative fuels |

## 4.4 Questionnaire Results – Present hubs

The following chapter illustrates the main research results of the questionnaire as well as other interesting relationships between some variables, gained by the completed questionnaires and held interviews.

### 4.4.1 Descriptive data

The first set of questions were formulated to find out at which position of the supply chain the investigated hubs are located.

1. **What type of logistics facility is the investigated hub?**

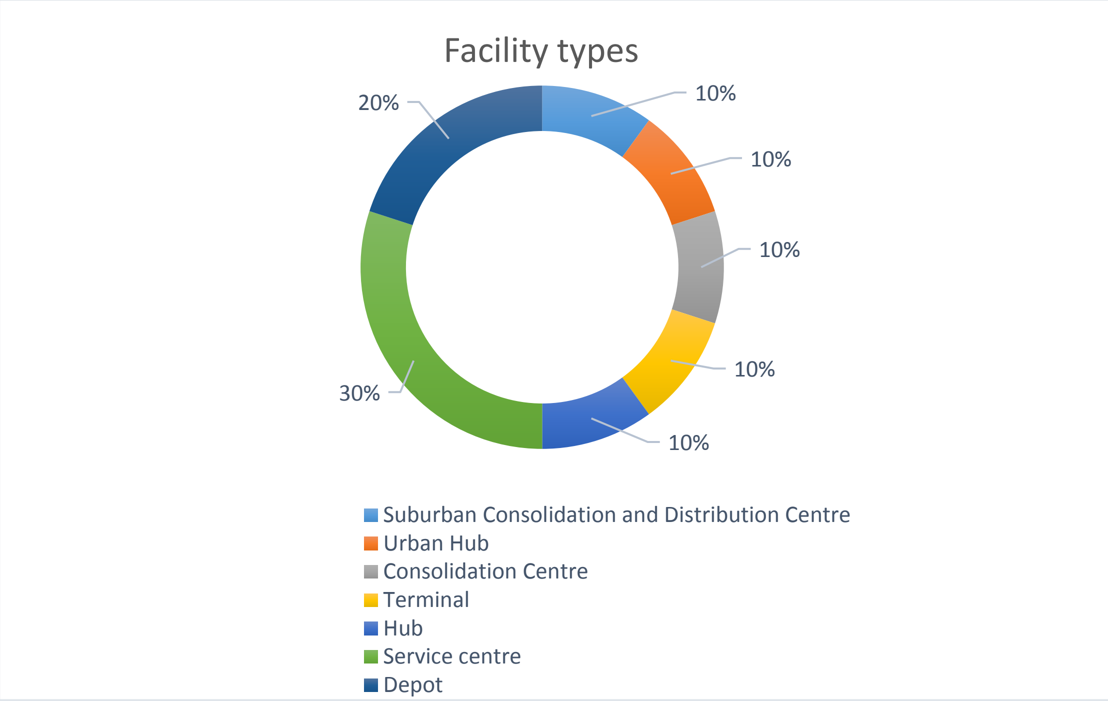



Figure 4-3: Facility types

Table 4-2: Hubs and their corresponding facility types

| Hub | facility type |
|---|---|
| No.1 | Suburban Consolidation and Distribution Centre |
| No.2 | Urban hub |
| No.3 | Consolidation Centre |
| No.4 | Terminal |
| No.5 | hub |
| No.6 | Depot |
| No.7 | Depot |
| No.8 | Service centre |
| No.9 | Service centre |
| No.10 | Service centre |

2. **What is the average volume of handled goods within the hubs (in parcels/day)?**

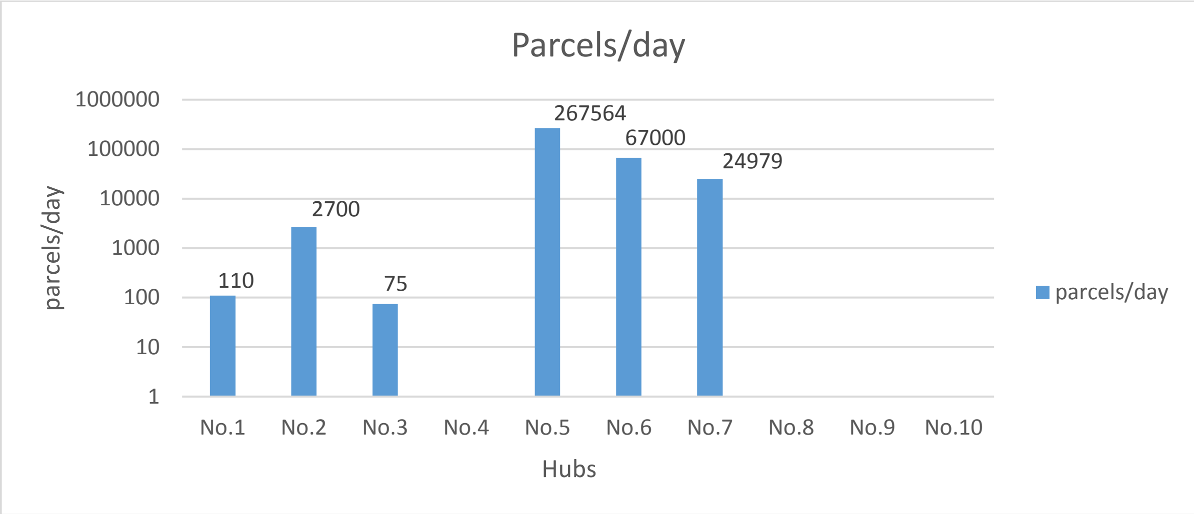



Figure 4-4: Parcels per day figures

Note: Hubs No.4, 8, 9 and 10 didn't provide information concerning this figures.

3. **Of which kind of facilities are the hubs served (What is the previous checkpoint for the external transport vehicles before reaching the hubs)?**

Table 4-3: External transport vehicle's checkpoints before arriving at the hubs

| Hub | Gate-ways | Sub-urban hubs | Consolidation centres | Regional Distribution centres | Direct ship-ments | Depots | Customers | Not known exactly/ no provided information |
|---|---|---|---|---|---|---|---|---|
| No.1 | ✓ | | | | | | | |
| No.2 | | ✓ | | | | | | |
| No.3 | | | ✓ | ✓ | ✓ | | | |
| No.4 | | | | | | | | ✓ |
| No.5 | | | | | | ✓ | ✓ | |
| No.6 | | | ✓ | | | | | |
| No.7 | | | | | | ✓ | ✓ | |
| No.8 | | | | | | | | ✓ |
| No.9 | | | | | | | | ✓ |
| No.10 | | | | | | | | ✓ |

4. **<u>Which kind of facilities do the hubs serve (What is the following checkpoint for the external transport vehicles after departing from the hubs)?</u>**

Table 4-4: External transport vehicle's checkpoints after departing from the hubs

| Hub | Moveable delivery area in the city centre | Sub-urban Hub | Consolidation centre | Depot | Retailer | Shopkeepers | Educational business for colleges/ university, offices | Restaurants | Consumers | Customers | Not known exactly/ no provided information |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No.1 | ✓ | | | | | | | | | | |
| No.2 | | | | | ✓ | ✓ | | | ✓ | ✓ | |
| No.3 | | | | | | | ✓ | | | | |
| No.4 | | | | | | | | | | | ✓ |
| No.5 | | ✓ | ✓ | ✓ | | ✓ | ✓ | | | | |
| No.6 | | | ✓ | | | | | | | | |
| No.7 | | | | ✓ | | | | | | ✓ | |
| No.8 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| No.9 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| No.10 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | |

Note: In questions 3 and 4 the terms "Consumer" and "Customer" are providing only a vague level of information. In this case the term "Consumer" refers to a private household, representing one final position within a supply chain.

Whereas the term "Customer" provides a larger room for interpretation and therefore would have to be differentiated to draw conclusions. Therefore this information is not taken into consideration here.

Although the definitions of the different logistics facilities found in question 1 already allow to identify the location of the facility within a supply chain to a certain extent, the facilities definitions are sometimes misleading and companies are often using them in different ways. Therefore questions 3 and 4 should provide more transparency of the real location of each facility within the supply chain. The clarification is complemented with the provided "parcels per day" figures, showing how much volume is handled within the facilities in one day.

Due to the often very complex distribution systems with many distribution sections and corresponding facilities along the supply chain, the assignment of some of the investigated hubs to a specific position within the supply chain is hard to make. Therefore, taking all the observed data into consideration leads to the final rough classification of the investigated facilities illustrated in Table 4-5, displaying whether they are positioned in the last mile or not.

Table 4-5: Facility type and location in the Supply Chain

| Hub | Facility type | Supply Chain Position: Last Mile |
|---|---|---|
| **No.1** | Suburban Consolidation and Distribution Centre | ✗ |
| **No.2** | Urban hub | ✓ |
| **No.3** | Consolidation Centre | ✓ |
| **No.4** | Terminal | ✗ |
| **No.5** | hub | ✗ |
| **No.6** | Depot | ✗ |
| **No.7** | Depot | ✗ |
| **No.8** | Service centre | ✓ |
| **No.9** | Service centre | ✓ |
| **No.10** | Service centre | ✓ |

5. **Are hubs dispatching different external means of transport or even operate with multi modal transport**

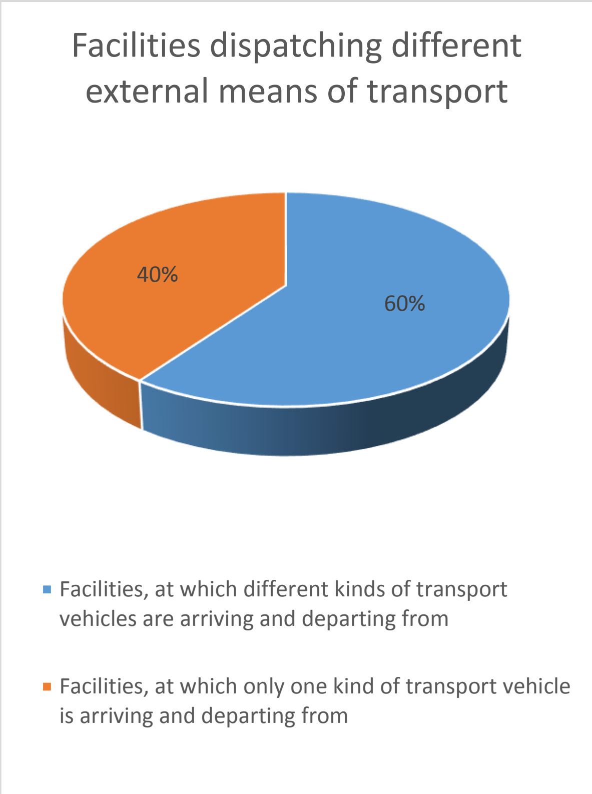



Figure 4-5: Percentage share of hubs dispatching different external means of transport

Table 4-6: Different external means of transport

| Facility | Arriving transport means | Leaving transport means |
|---|---|---|
| No.1 | conventional combustion trucks | E-trucks with trailers |
| No.2 | conventional combustion trucks | E-Vans and E-bikes |
| No.3 | conventional combustion trucks | Small electric cars with trailers |
| No.8 | conventional combustion trucks (all kind) | 3,5 ton truck run by gas |
| No.9 | conventional combustion trucks (all kind) | 3,5 ton truck run by gas |
| No.10 | conventional combustion trucks (all kind) | 3,5 ton truck run by gas |

6. **Is the unloading procedure of goods for the arriving transport vehicles executed manually or automated and which handling equipment is used for that purpose?**

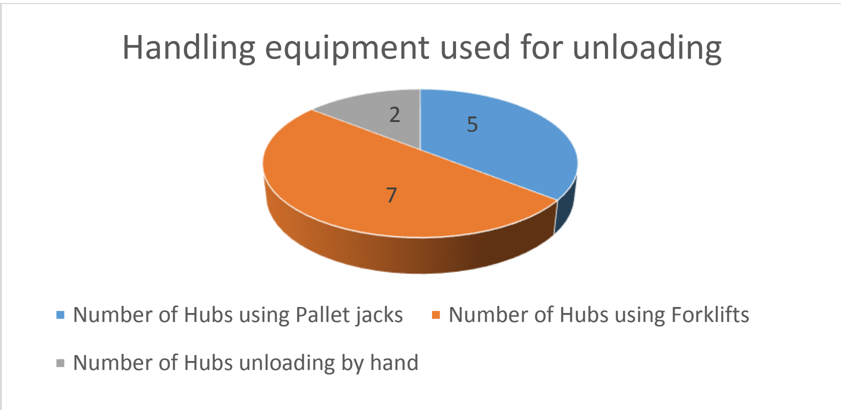



Figure 4-6: Total quantity of hubs using different types of equipment for unloading external transport vehicles

A more concrete assignment of the used unloading equipment to the single hubs is illustrated in Table 4-7.

Table 4-7: Hubs and their used unloading equipment

| Hub | Pallet Jack | Forklift | By Hand |
|---|---|---|---|
| No.1 | | ✓ | |
| No.2 | ✓ | ✓ | |
| No.3 | | ✓ | ✓ |
| No.4 | ✓ | ✓ | |
| No.5 | | | ✓ |
| No.6 | – | – | – |
| No.7 | – | – | – |
| No.8 | ✓ | ✓ | |
| No.9 | ✓ | ✓ | |
| No.10 | ✓ | ✓ | |

Note: Hubs No. 6 and 7 didn't provide information on this question. The unloading procedure is executed entirely manual in the rest of the investigated hubs. In this context, manual execution means that there are no automated systems, like AGVs (Automated Guided Vehicles), in use which substitute human work. In this case, manual execution means that a human operator is needed to accomplish the unloading tasks by either using a pallet jack, a forklift or no additional device at all ("unloading by hand" means that human operators only use their hands to unload parcels step by step).

In comparison to that, an automated execution of the unloading process means to use automation technology (definition in chapter 2.1) like AGVs, which are computer-controlled and wheel-based load carriers that travel along the floor of a facility without an onboard operator or driver. The movement of AGVs is directed by a combination of software and sensor-based guidance systems. Because they move on a predictable path with controlled acceleration and deceleration, and include automatic obstacle detection bumpers, AGVs provide a safe option for the movement of loads. Typical applications for AGVs include transportation of raw materials, work-in-process, and finished goods in support of manufacturing production lines, and storage/retrieval or other movements in support of picking in warehousing and distribution applications (cf. [MHI17]).

7. **Are there any other additional conveyor techniques used within the hubs and if so, what kind of systems?**

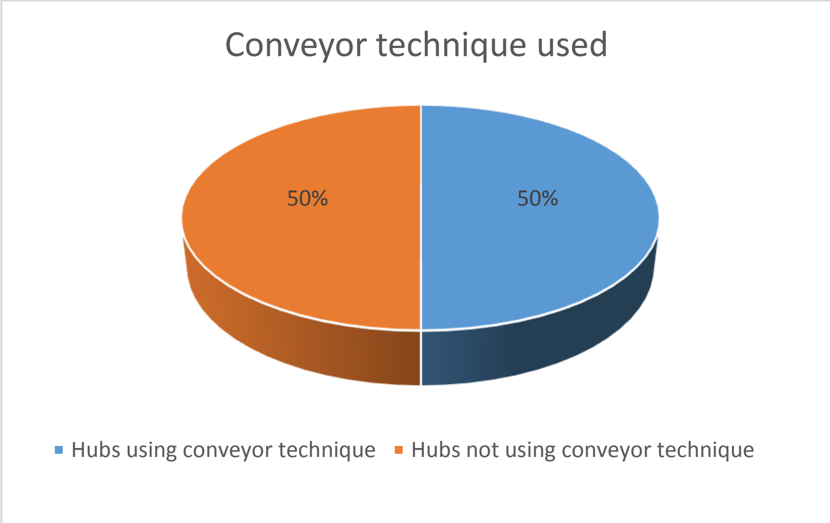



Figure 4-7: Percentage share of hubs using conveyor technique

Note: Conveyor systems in use are conventional belt and roller conveyors as well as combinations of these two. The distinction between a conveyor and a sorter is described in chapter 2.1.

8. **What kind of unit load formation equipment is used?**

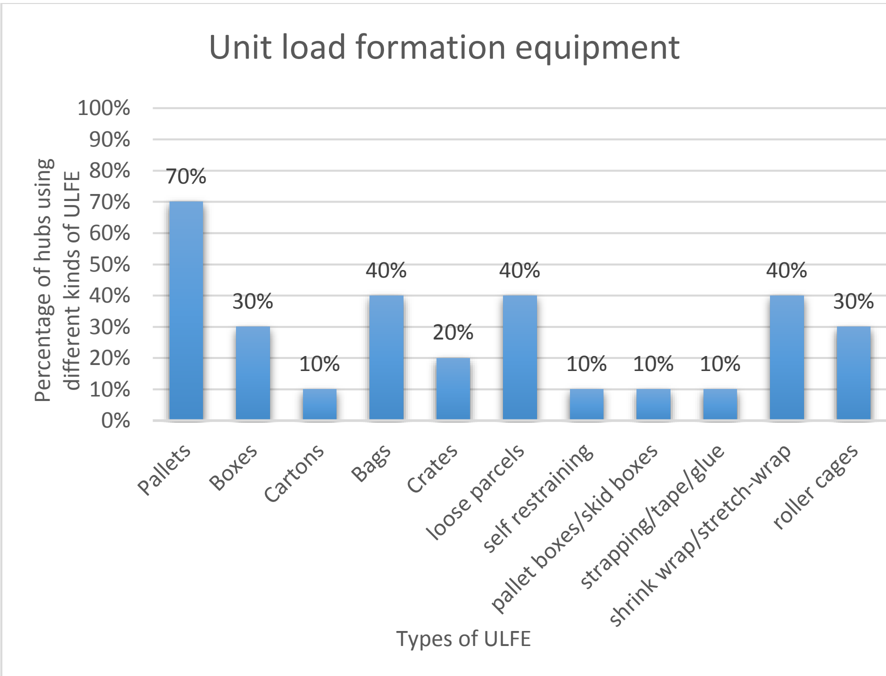



Figure 4-8: Percentage share of used ULFE

9. **Are hubs using an Identification system for identifying the incoming goods and if so, is the process of identification executed manually or automated and which equipment is used for it?**

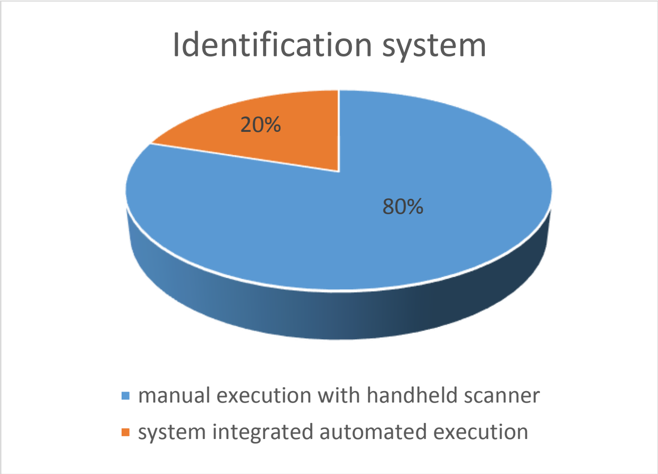



Figure 4-9: Execution of goods identification

Note: All of the investigated hubs were using an identification system, each working with barcodes, representing the goods related data. One facility was also using magnetic stripe technology. In this context, manual execution means, that the capturing of data is executed by a human being with the use of a handheld scanning device.

In comparison to that, an automated execution means, that the task of identification is executed by an automated system (definition in chapter 2.1), integrated in the conveyor system (scanning device mounted on the conveyor), which is capturing the data when goods are passing the scanners laser beam automatically. In this case, no human operator is needed to execute this task.

10. **Is there any equipment used for sorting operations?**

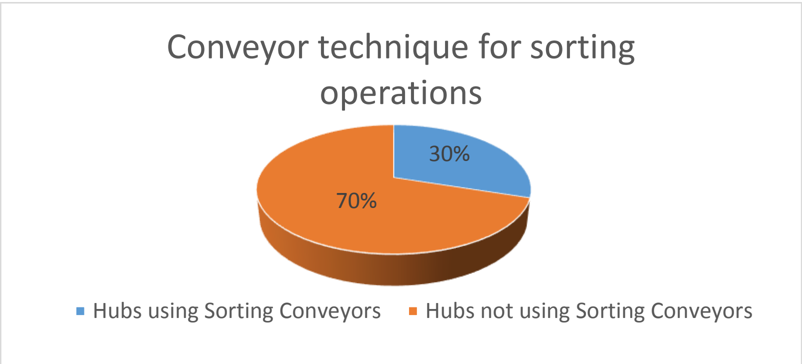



Figure 4-10: Percentage share of hubs using sorting conveyors

Note: The general distinction between a conveyor and a sorter is described in chapter 2.1. Answers of the questionnaire showed that automated as well as semi-automated conveyors were used for the specific purpose of sorting goods according to certain constraints. It is important to mention that the terms "automated" as well as "semi-automated" give only a general information of the conveyors real level of automation.

### 11. What kind of freight is handled within the hubs?

Table 4-8: Handled freight inside hubs

| Hub | Parcels | Letters | Unit loads | Individual packaged goods | Bulky goods |
|---|---|---|---|---|---|
| No.1 | ✓ | ✓ | | | |
| No.2 | ✓ | ✓ | ✓ | ✓ | ✓ |
| No.3 | ✓ | ✓ | ✓ | ✓ | ✓ |
| No.4 | ✓ | | ✓ | ✓ | ✓ |
| No.5 | ✓ | | | ✓ | ✓ |
| No.6 | ✓ | | | | |
| No.7 | ✓ | | | ✓ | ✓ |
| No.8 | ✓ | | ✓ | ✓ | ✓ |
| No.9 | ✓ | | ✓ | ✓ | ✓ |
| No.10 | ✓ | | ✓ | ✓ | ✓ |

### 12. Do hubs store goods and if so, is the storing executed manually or automated?

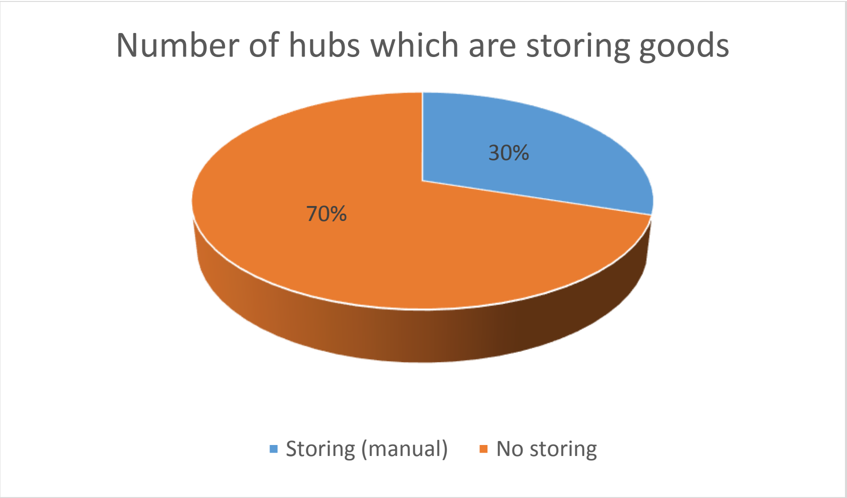



Figure 4-11: Percentage share of hubs which store goods

Note: In this context, manual execution means that the storage process is executed without the help of any automated system (defintion in chapter 2.1). The investigated hubs, which are storing goods have no specific system for that purpose. These hubs are simply storing goods on dedicated areas on the floor by hand or by using forklifts and pallet jacks.

Automated execution means that the storage process would be executed with any kind of an automated storage system without the intervention of a human operator.

13. **Do hubs use buffer areas for the incoming goods and if so, is it executed manually or automated?**

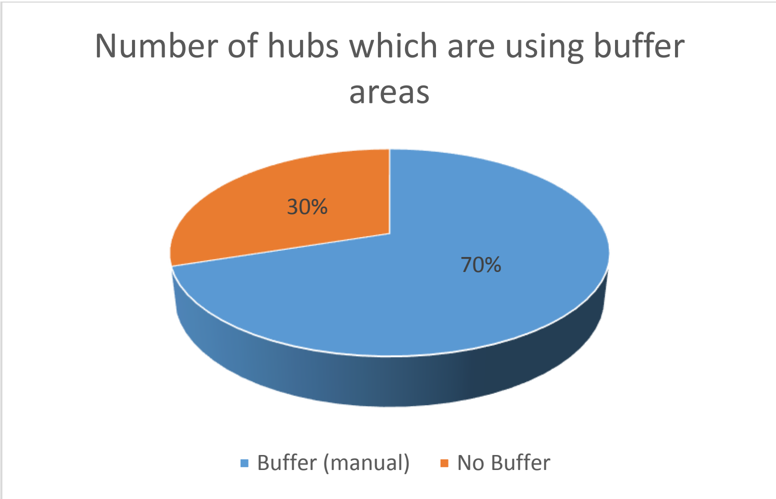



Figure 4-12: Percentage share of hubs having dedicated buffer areas

Note: The distinction between a store (storage) and a buffer area is described in chapter 2.1. In this context, manual execution means that the placement of goods into the buffer area is executed without the help of any automated system (defintion in chapter 2.1). The investigated hubs, which are using buffer areas have no specific system for that purpose. These hubs are simply placing the goods on dedicated areas on the floor by hand or by using forklifts and pallet jacks.

Automated execution means that the placement of goods into the buffer area would be executed with any kind of an automated system, without the intervention of a human operator (comparable with an automated storage system).

**14. Are hubs managed by a WMS (warehouse management system)?**

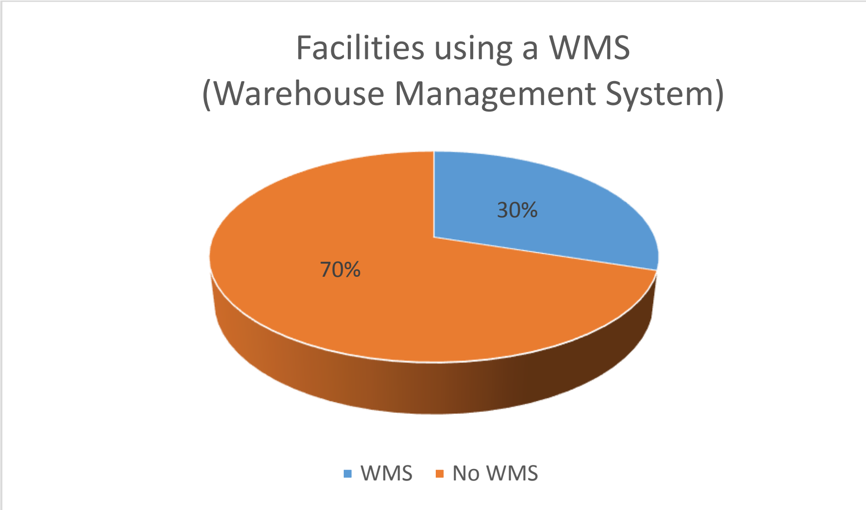



Figure 4-13: Percentage share of hubs using a WMS

Note: The definition of a Warehouse Management System is given in chapter 2.1.

**15. Is the consolidation/compilation of goods/parcels, assigned to the same leaving transport vehicle executed manually or automated and which equipment is used for this purpose?**

Note: Previous to the final compilation of the parcels and goods for further distribution, the necessary consolidation takes place. This consolidation is realized as illustrated in Figure 4-10, either by using conveyors for sorting operations or simple by hand. Among all investigated hubs, the following compilation of parcels and goods is executed entirely by hand and is therefore regarded as manual.

Regarding this final compilation of goods, manual execution means that the compilation process is executed entirely by human operators without any other automated technology (definition in chapter 2.1). An automated execution means that the compilation process would have been accomplished with any kind of an automated system, without the intervention of a human operator.

**16. Is the loading of goods into the leaving transport vehicles executed manually or automated and which equipment is used for this purpose?**

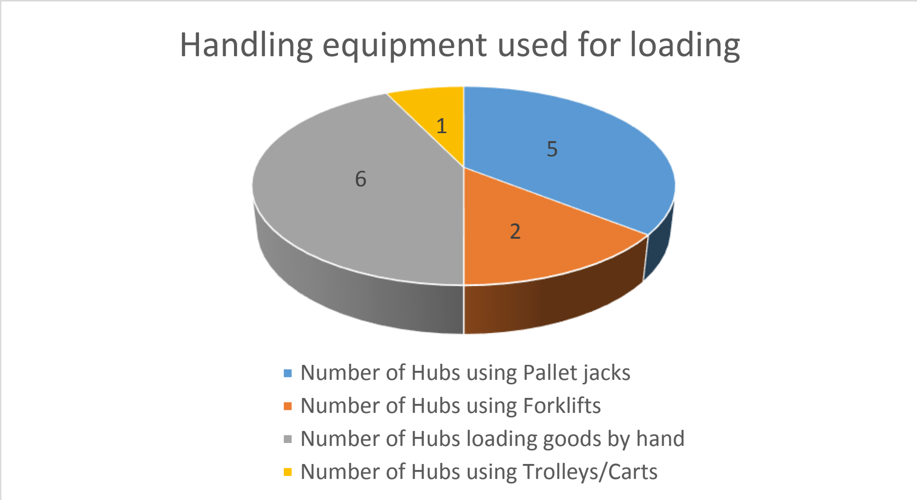



Figure 4-14: Quantity of hubs using different types of handling equipment for loading transport vehicles

A more concrete assignment of the used loading equipment to the single hubs is illustrated in Table 4-9.

**Table 4-9: Hubs and their used loading equipment**

| Hub | Pallet Jack | Forklift | Trolley/Carts | By Hand |
|---|---|---|---|---|
| No.1 | | | √ | |
| No.2 | √ | √ | | |
| No.3 | | √ | | √ |
| No.4 | √ | | | |
| No.5 | | | | √ |
| No.6 | - | - | - | - |
| No.7 | | | | √ |
| No.8 | √ | | | √ |
| No.9 | √ | | | √ |
| No.10 | √ | | | √ |

Note: Hub No. 6 didn't provide information on this question. The loading procedure is executed entirely manual in the rest of the investigated hubs. In this context, manual execution means that there are no automated systems, like AGVs (Automated Guided Vehicles), in use which substitute human work. In this case, manual means that a human being is needed to execute the loading tasks.

In comparison to that, an automated execution of the loading process means to use automation technology (definition in chapter 2.1) like AGV's without any intervention of a human operator.

17. **Is the assignment of goods to the leaving external transport vehicles executed within a planning software?**

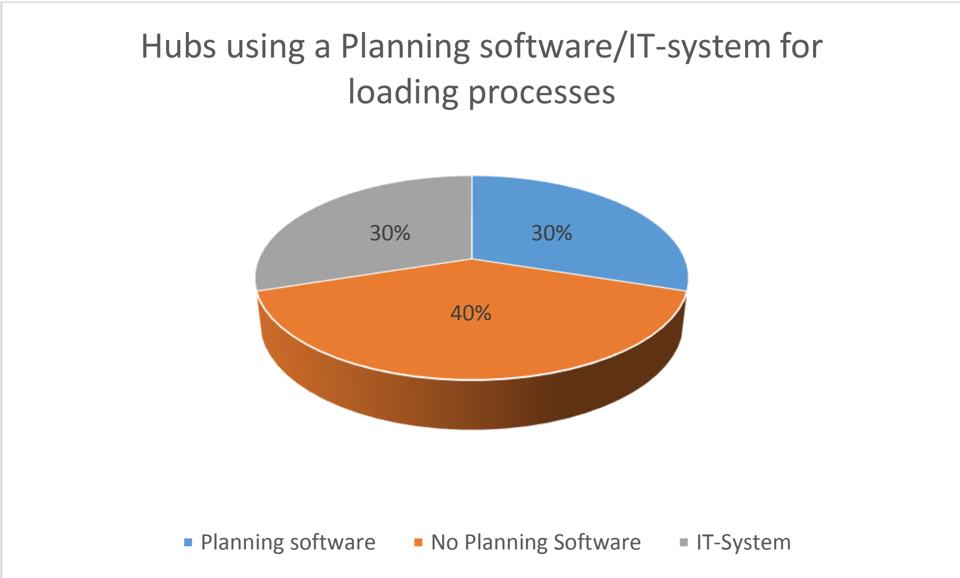



Figure 4-15: Percentage share of hubs using a planning software/IT-system for the assignment of goods to corresponding transport vehicles

Note: Investigated hubs which are using a WMS are also using a planning software for goods assingment operations. In this connection the term planning software describes one subtask of a Transport Management System (defintion in chapter 2.1).

Upon the 70% of the investigated hubs which aren't using a traditional WMS, 30% have been using an IT-system, provided by their shippers. This IT-system is working with digital data concerning the goods. Shippers upload these data and when goods arrive at the hub, they get scanned and the IT-system gets updated. This IT-system is taking care of the assignment of goods to the external departing transport vehicles (and so delivery routes) and can therefore be declared as a sort of a planning software.

**18. Where do you see room for improvement concerning your processes?**

- Improvement in scaling up to cover more delivery areas.
- Improvement in scaling up the concept in terms of acquisition of new partners and companies to make it easier to offer a sophisticated solution.
- Improvement of IT-systems and delivery zones.

Note: Not all of the participants provided information to this last question.

Building upon the findings of this questionnaire, the following hub processes shown in Table 4-10 have been selected and the corresponding means, which are necessary for their execution have been added.

Table 4-10: Selected hub processes and their corresponding means for execution

| Selected hub processes | Present means for execution |
|---|---|
| **Loading** and **unloading** external means of transport | • **Forklifts,**<br>• **Pallet jacks,**<br>• **By hand** (human operators load/unload parcels only with their hands without any additional device) |
| **Decomposing** unit loads into parcels/goods; **Composing** parcels/goods into unit loads | **By hand** (human operators compose parcels into unit loads or decompose unit loads only with their hands without any additional device) |
| **Transportation/Sortation** of goods | **Transportation:**<br>• **Roller conveyor** (for single parcels)**,**<br>• **Belt conveyor** (for single parcels)**,**<br>• **Fork lifts** (for unit loads),<br>• **Pallet jacks** (for unit loads)<br><br>**Sortation**(Conveyor technique with sortation function)**:**<br>• **Semi-automated conveyor**<br>• **Automated conveyor**<br>• **By hand**(human operators sort parcels without any additional device) |

| Selected hub processes | Present means for execution |
|---|---|
| **Identification** of goods | • **Human operator using a handheld scanner** (manual execution)<br>• **Conveyor integrated scanning system** (automated execution) |
| **Planning** and **managerial** processes | • **WMS**<br>• **Planning Software**<br>• **IT-System** |
| **Storing/Buffering** goods | **Storing:**<br>• **Goods are placed on dedicated areas on the floor** (no specific system for storing)<br>**Buffering:**<br>• **Goods are placed on dedicated areas on the floor** (no specific system for buffering) |
| **Dispatching different external means of transport** (arriving at and departing from hubs) | **Only hubs located in the last mile are dispatching different external means of transport:**<br>• Conventional combustion trucks(all kind) are arriving at the hubs,<br>• Vehicles powered with alternative fuels are departing from the hubs |

## 4.5 Visualisation and investigation of hub internal processes

After receiving the questionnaire and PI-literature results from chapter 4.3 and 4.4, EPC's (Event-driven Process Chains) were used to visualize the sequence of all the processes executed within the investigated present hubs and future PI-hubs as well as to assign material handling systems, necessary for the execution of these processes. The sequence of processes designed in the EPC's were based on the sequence of the main process steps of the DCRM (Distribution Centre Reference Model) outlined in Figure 3-2. These main processes have already been explained in chapter 3.1.1, prior to the more detailed breakdown into their underlying process steps executed within this chapter. The illustration of the process steps for a PI-hub has been extended by the assignment of PI-key elements (derived from the literature study, discussed in chapter 3.4 and 4.3) to their corresponding process steps.

To cover as many questionnaire results as possible, the created EPC of a present hub was based on the combination of the questionnaire results of two investigated hubs with also considering the main process steps of the DCRM as a guideline for the process sequence. For this purpose two hubs have been chosen, whose data was gathered through telephone interviews, because this kind of data gathering method (discussion with respondents enabled additional insight of the hub internal processes) was providing a more exact identification of hub internal processes than only a filled out questionnaire. The assignment of the processes to their corresponding material handling devices and systems were based on the questionnaire results as well.

### 4.5.1 Present hub – Main Processes

All explanations of symbols used in the following EPC are given in the legend below in chapter 4.5.1.5. The main processes executed inside a present hub were set up as illustrated in Figure 4-16. It becomes clear, that the following sequence of processes differs from the original sequence, defined in the DCRM. This is because the two investigated hubs had no typical "Storage and Picking" area as classified in the DCRM. The storage process is more like an added service, provided by the hub operator, which enables customers like retailers and shopkeepers to store their goods at the operator's facility, due space shortage in their own shops. Therefore the "Storage and Picking" process was replaced by a "Storage" process and also the sequence was adapted, to better reproduce the real processes inside the present hub. After the first executed identification of goods in the process "receiving", the decision was made to either store goods meanwhile or to further process them in the "consolidation and packing" area. Goods which moved in the "storage" area are kept there till the customer (e.g. a shopkeeper) is ready to receive their goods (e.g. when there is enough space for goods in their shop again). Then these goods leave the "storage" area and are moved to the "shipping area.

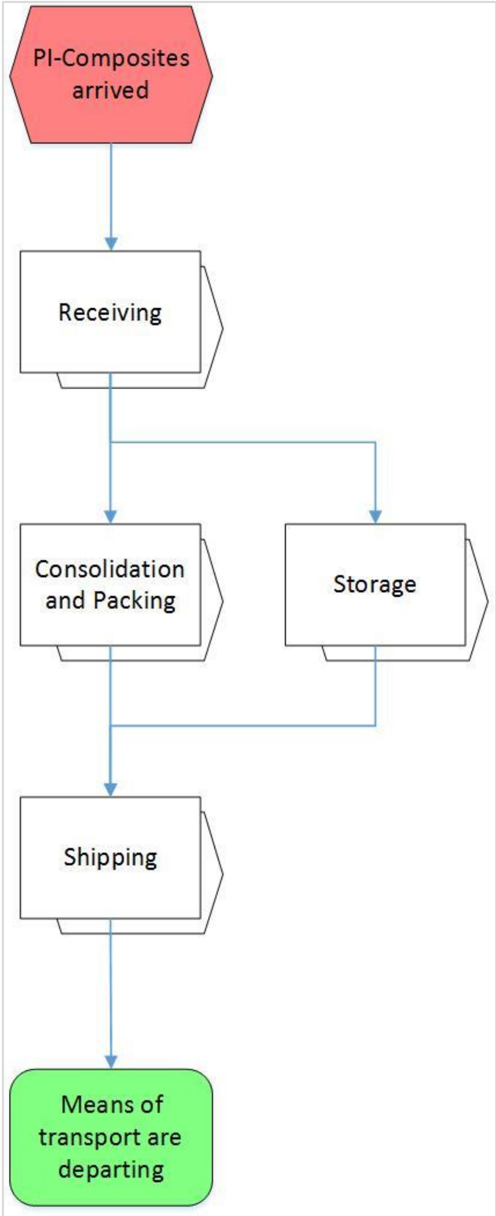
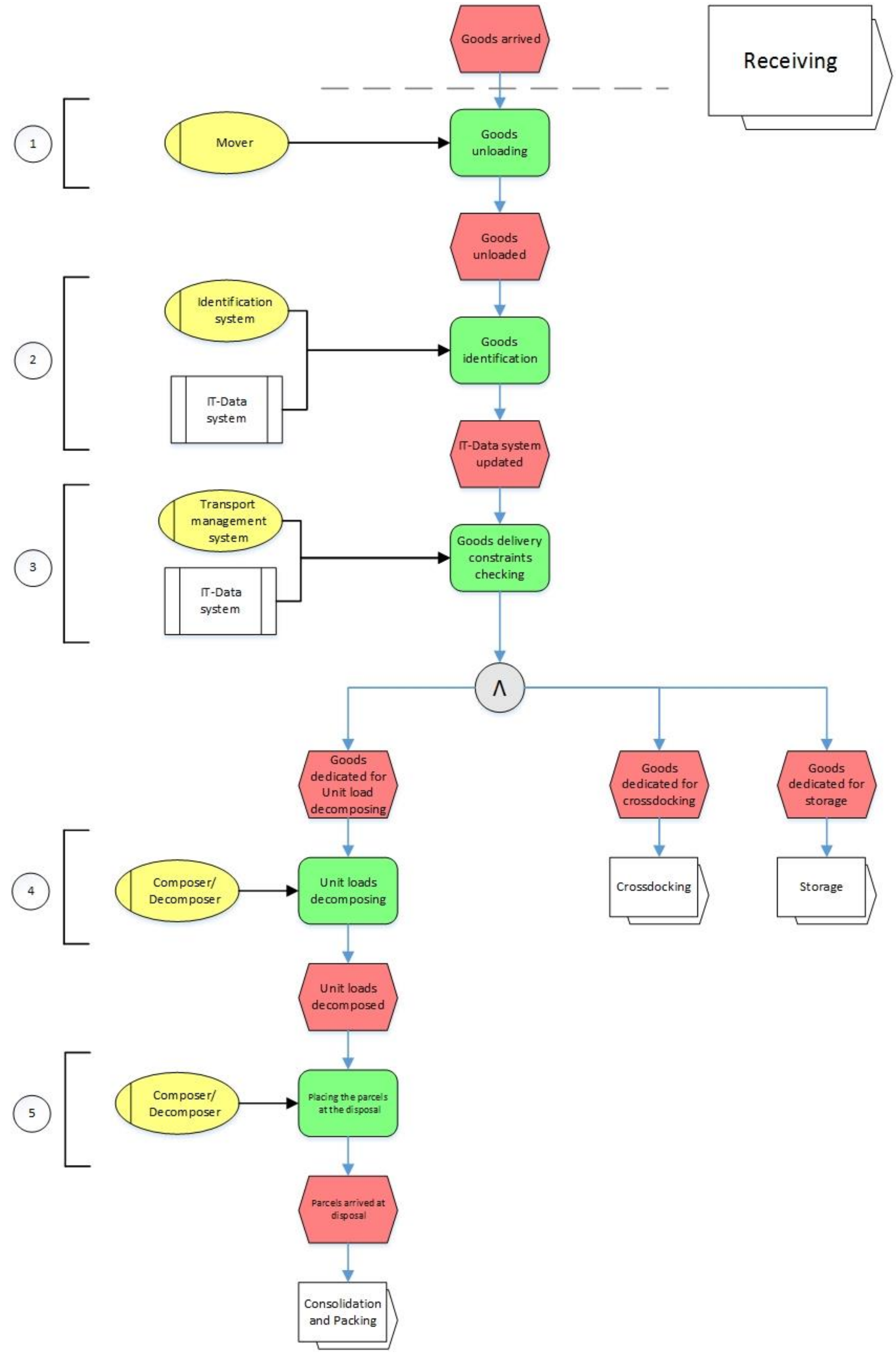
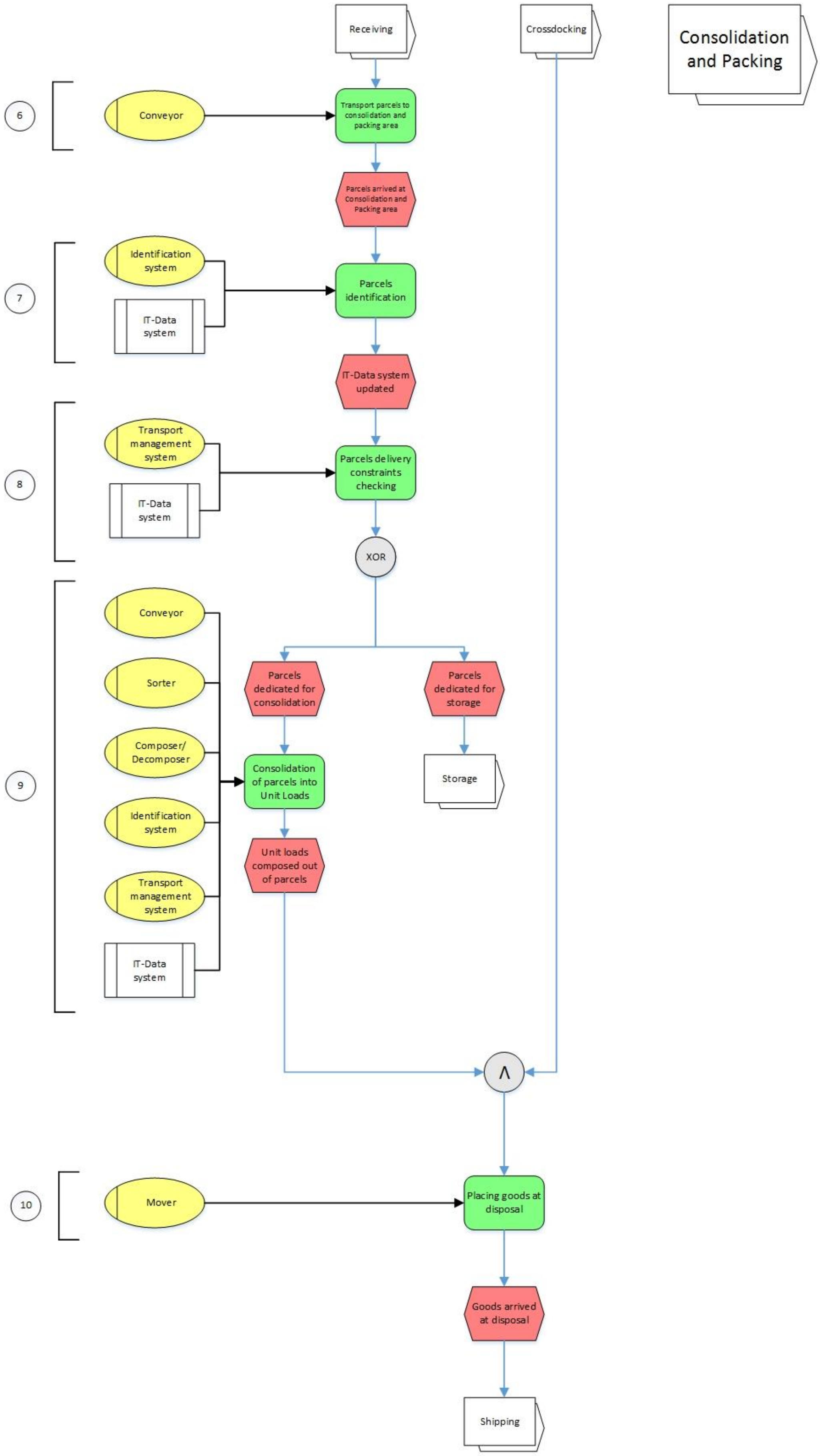



Figure 4-16: Present hub - Main processes

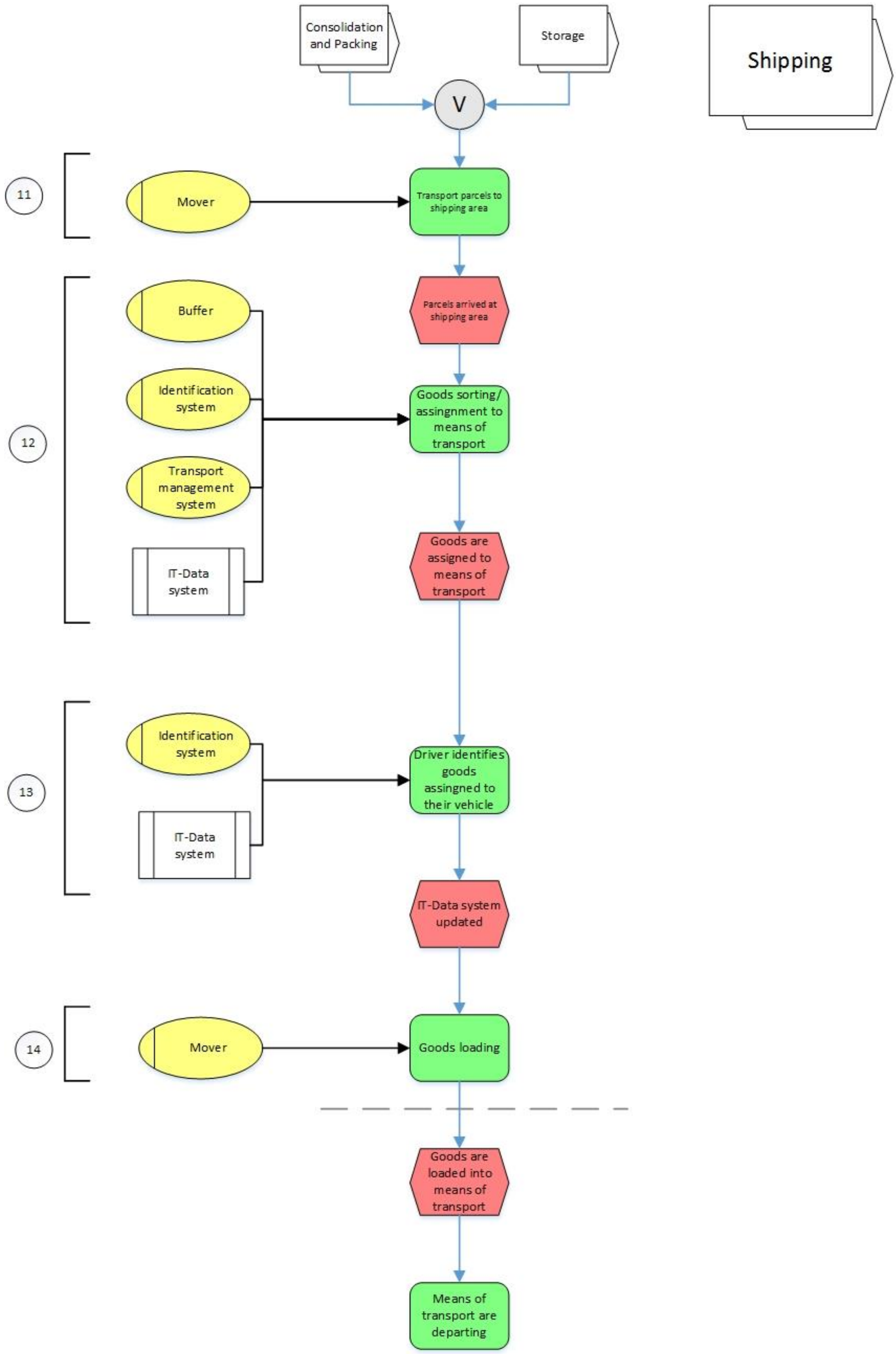
#### 4.5.1.1 Present hub - Receiving



#### 4.5.1.2 Present hub - Consolidation and Packing

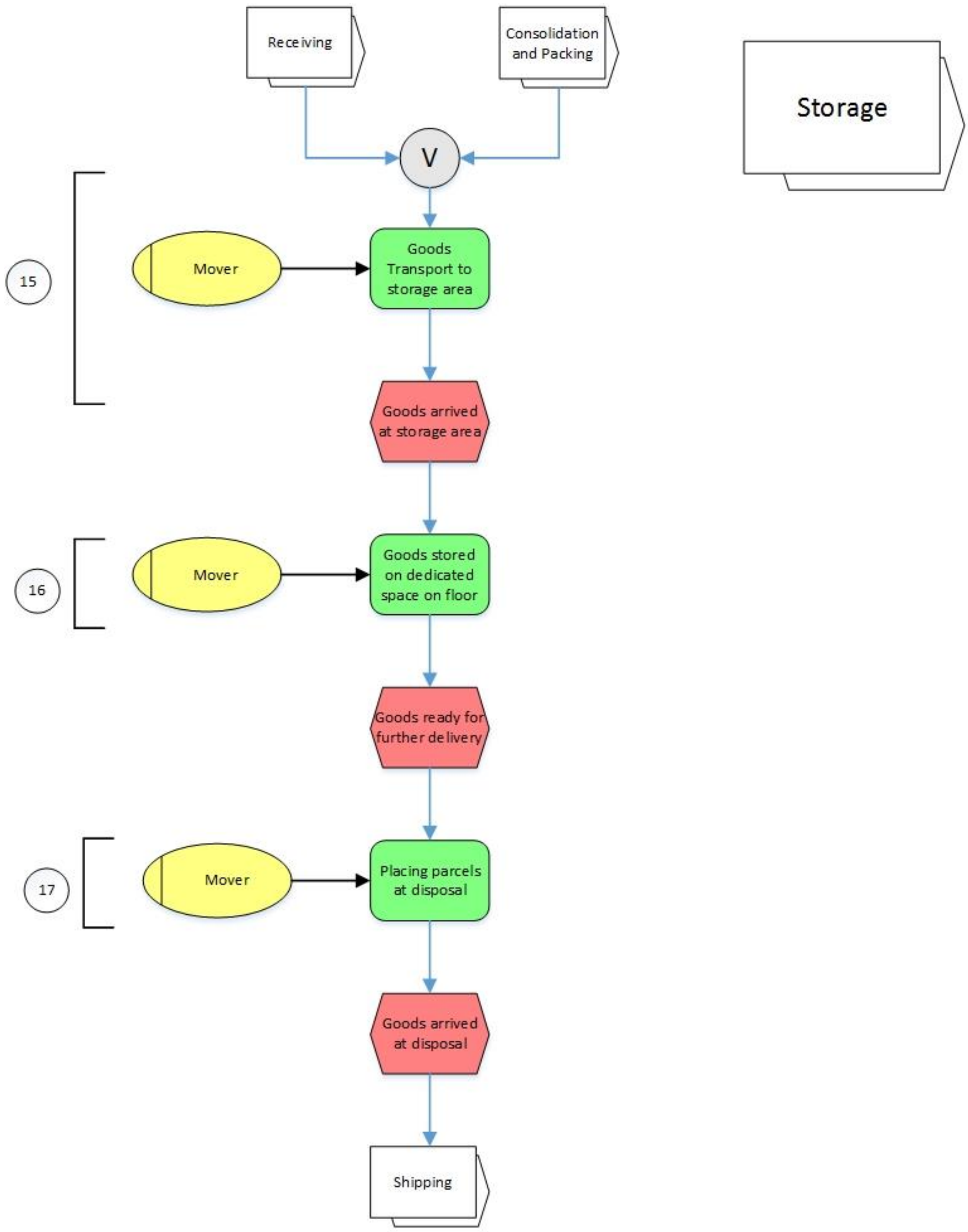


### 4.5.1.3 Present hub – Shipping



### 4.5.1.4 Present hub – Storage and Picking

The investigated hub had no typical Storage and Picking area as classified in the DCRM. As mentioned before, the storage process is more like an added service, provided by the hub operator, which enables customers like retailers and shopkeepers to store their goods at the operator's facility, due space shortage in their own shops. Therefore the sequence of processes differs in some extend from a typical process chain based on a DCRM.



## 4.5.1.5 Present hub – Symbols and Explanations

| | |
|---|---|
| Goods | An umbrella term for unit loads, bulky goods and individually packed goods. |
| Unit load | In this case the term unit load refers to paletts and roller cages filled with parcels. |
| Parcels | In this case the term parcels refers to packets and letters. |
| Storage unit loads | Parcels placed on pallets or in roller cages for storing purpose. Different degrees of capacity utilisation of pallets/roller cages. |
| Storage area | A storage area refers to a space on the floor dedicated for storage purpose. |
| Mover | Floor conveyor for transport of unit loads. Main responsibility is to move unit loads from one place to another, especially between the single process steps (receiving, storage and picking, consolidation and picking, shipping) |
| Identification system | Device for the identification of goods. Main task is to read information from goods. In this case realised with a handheld scanning device for barcodes. |
| Transport management system | System responsible for executing tasks like determining parcels for building proper unit loads for further shipping or assigning unit loads to corresponding means of transport, etc. All decisions are based on information provided by the IT-Data system. |
| Composer/ Decomposer | In this case, a Composer/Decomposer is a human being, responsible for the composition of unit loads (built out of single parcels) as well as their decomposition into single parcels. Also the packaging (Stretch wraps) for load secure reasons is executed here. |
| Conveyor | Conveyor for the transport of parcels from one place to another without any sortation tasks. |
| Sorter | In this case a Sorter can either refer to a conveyor system with sortation functions or simply to a human being who is executing the sortation tasks by hand. |
| Buffer | In this case, the term Buffer represents an area for „storing“ goods within a very short time window, just for the period of time until the following process can be executed. |
| IT-Data system | System, responsible for data storing and processing information provided by the Identification System as well as preparing this information for the Transport Management system. |
| Storage | The process „Storage“ doesn‘t include any additional system or device necessary for storage purpose. Only a dedicated area on the floor is used to store goods. |
| | Material flow |
| 1 | Numeration of functions and their corresponding systems |
| | Information flow |
| | System boundary: Hub |

## 4.5.2 PI-hub – Main Processes

All explanations of symbols used in the following EPC's are given in the legend below in chapter 4.5.2.5. The main processes executed inside a PI-hub were set up as illustrated in Figure 4-17.

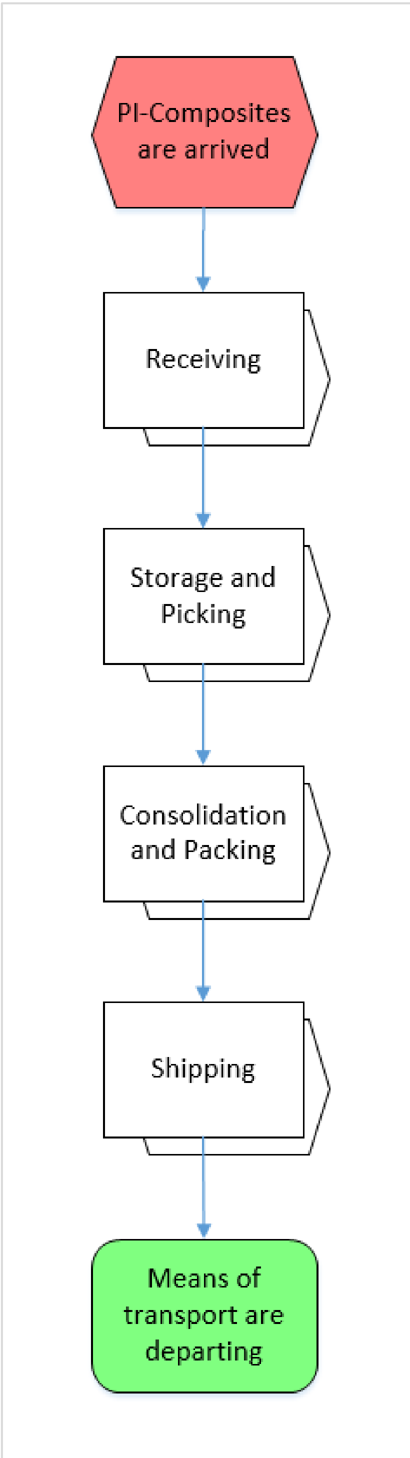
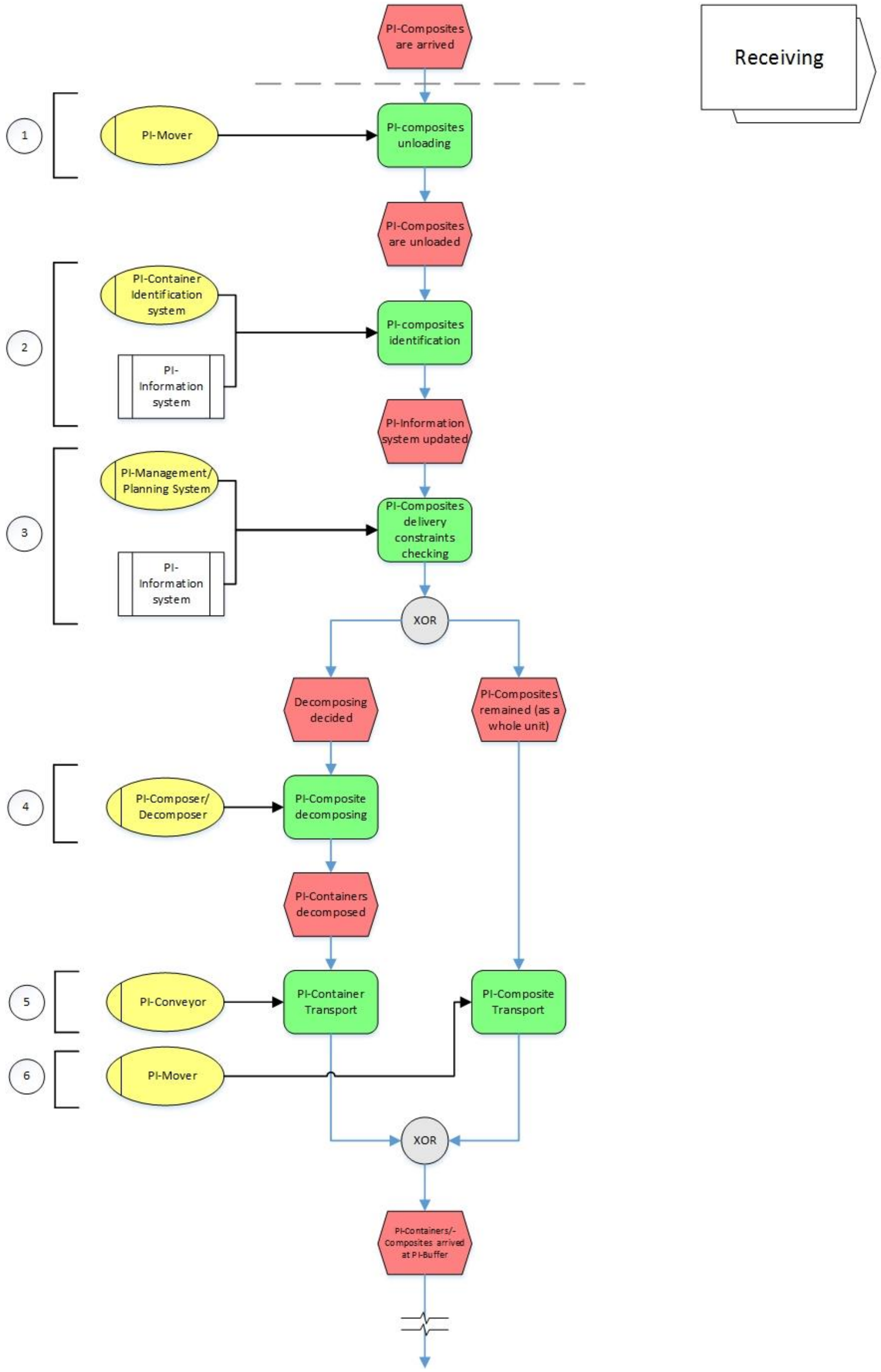
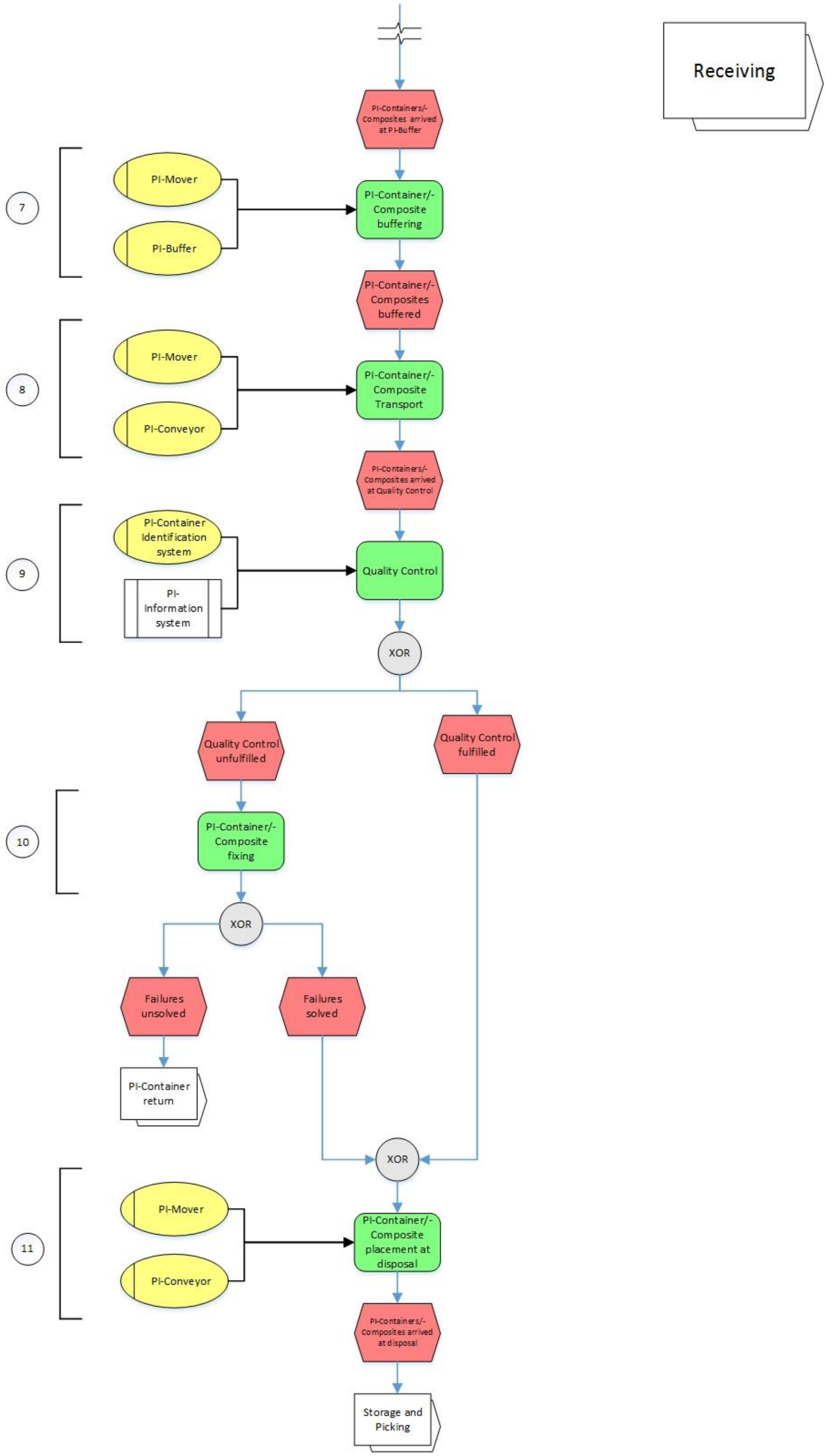



Figure 4-17: PI-hub – Main processes

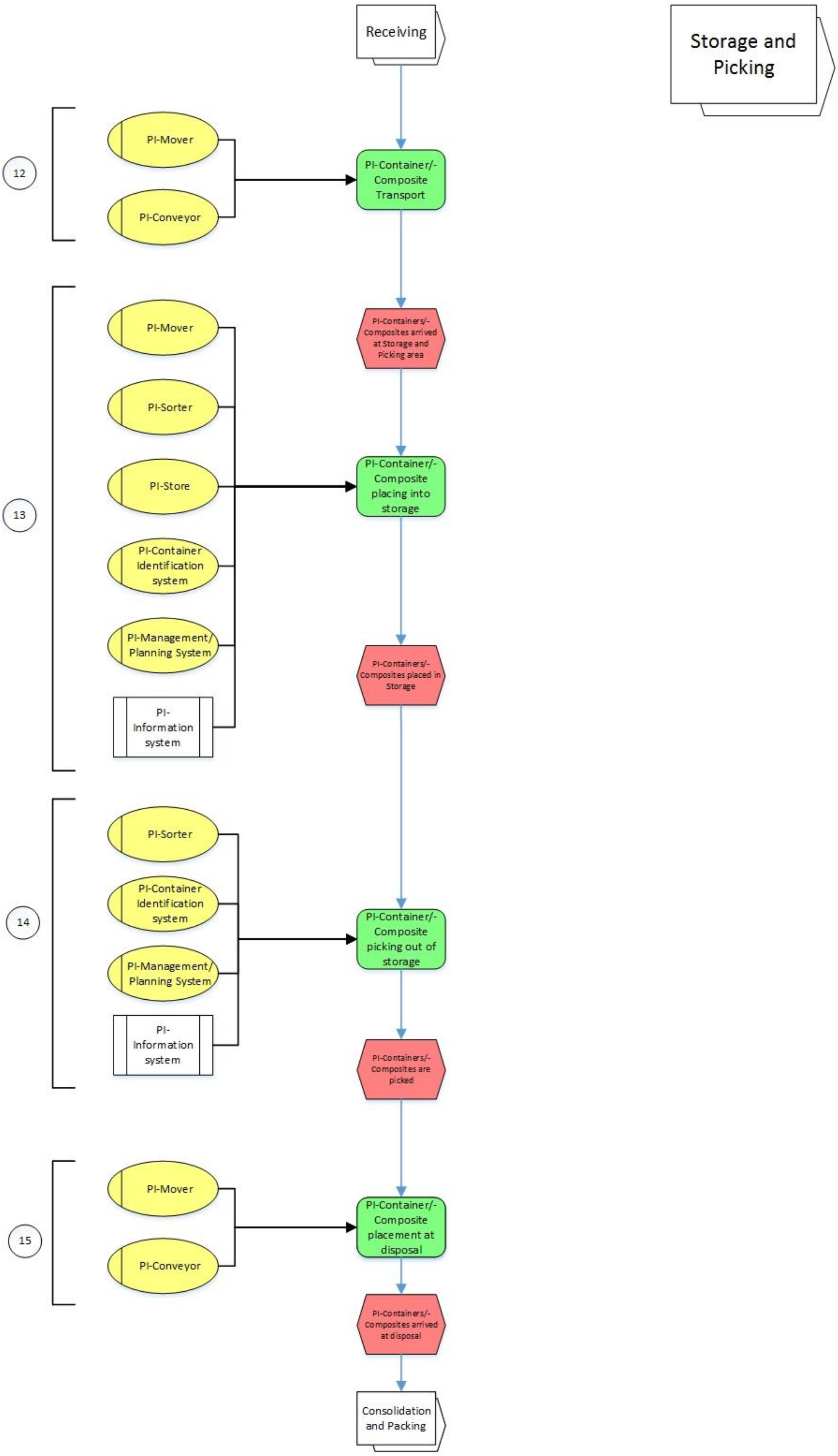
### 4.5.2.1 PI-hub – Receiving



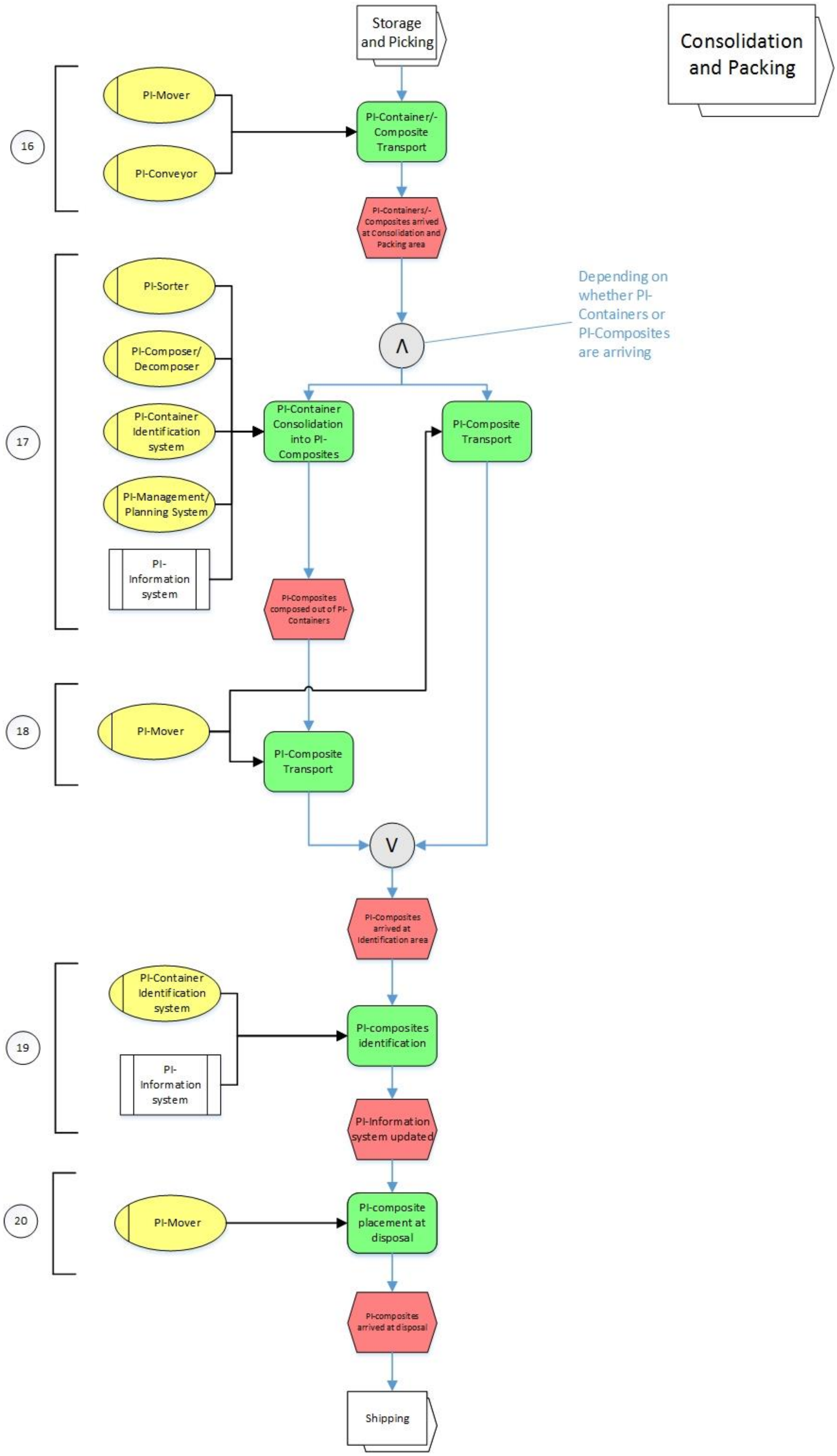


Receiving
PI-Containers/-Composites arrived at PI-Buffer
7
PI-Mover
PI-Buffer
PI-Container/-Composite buffering
PI-Container/-Composites buffered
8
PI-Mover
PI-Conveyor
PI-Container/-Composite Transport
PI-Containers/-Composites arrived at Quality Control
9
PI-Container Identification system
PI-Information system
Quality Control
XOR
Quality Control unfulfilled
Quality Control fulfilled
10
PI-Container/-Composite fixing
XOR
Failures unsolved
Failures solved
PI-Container return
XOR
11
PI-Mover
PI-Conveyor
PI-Container/-Composite placement at disposal
PI-Containers/-Composites arrived at disposal
Storage and Picking

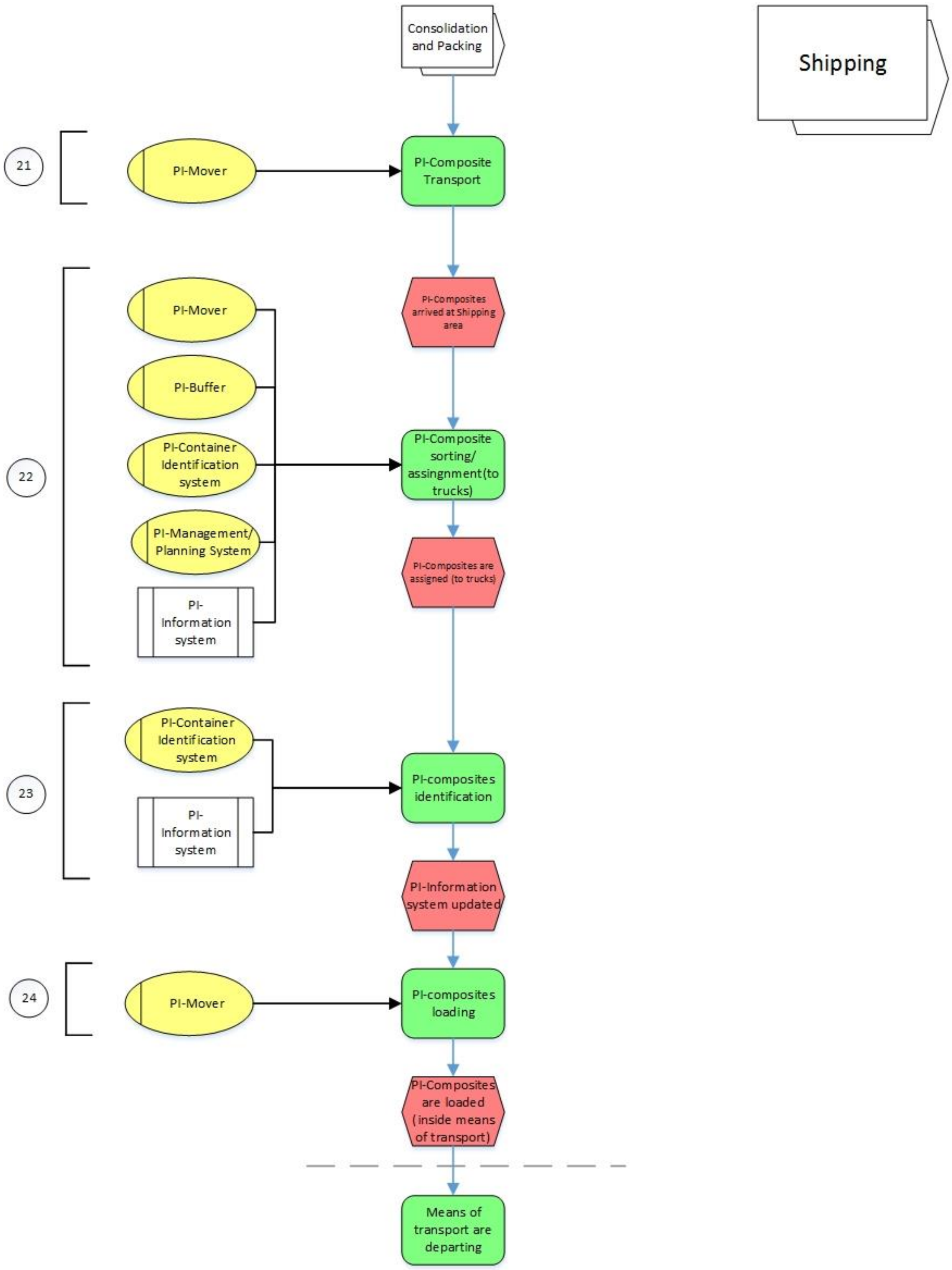
### 4.5.2.2 PI-hub – Storage and Picking



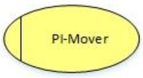
### 4.5.2.3 PI-hub – Consolidation and Packing



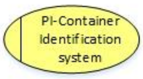
### 4.5.2.4 PI-hub – Shipping



### 4.5.2.5 PI-hub – Symbols and Explanations

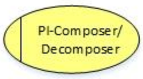



Floor conveyor for PI-container and composite transport. Main responsibility is to move PI-Containers and Composites from one place to another, especially between the single process steps (receiving, storage and picking, consolidation and picking, shipping)




Device for the identification of PI-Containers. Main tasks are reading and writing information from and on the PI-Containers.

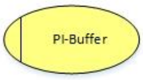

System embedded in the overall PI-network, responsible for executing tasks like determining PI-Containers for building proper PI-Composites or assigning them to different means of transport, etc. All decisions are based on information provided by the PI-Information System.




Device for both building PI-Composites out of single PI-Containers and decomposing PI-Composites into single PI-Containers.

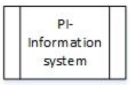

Conveyor for the transport of PI-Containers from one place to another without any sortation features.


Conveyor for the transport of PI-Containers from one place to another by sorting them according to different constraints.




System dedicated to store PI-Containers and Composites for a short period of time.


System dedicated to store PI-Containers and Composites for long period of time.




System embedded in the overall PI-network, responsible for processing information provided by the PI-Container Identification System and all other information providing systems within the PI-network as well as preparing this information for other devices within the PI.

Material flow


Numeration of functions and their corresponding systems

Information flow

System boundary: Hub

# 5 Approach assessment

## 5.1 Present vs. Future – Variance comparison

The following chapter displays the gaps between the processes executed in current hubs and future PI-hubs by comparing the questionnaire results from chapter 4.4.1 with the corresponding PI-hub key element characteristics derived in chapters 3.4 and 4.3. For this purpose a "level of accordance" (between present hub and future PI-hub key element characteristics) has been set up, to rate the degree of overlap between the present hub system characteristics and PI-hub key element characteristics. The rating is described in Table 5-1.

Table 5-1: Variance comparison - Rating

| Level of accordance | Rating |
|---|---|
| **No** or only **marginal** overlaps between present hub system characteristics and PI-key element characteristics. | **Poor** |
| **Several** overlaps between present hub system characteristics and PI-key element characteristics. | **Medium** |
| Overlaps between present hub system characteristics and PI-key element characteristics in **many** or even **all areas.** | **Strong** |

### 5.1.1 Different external means of transport get dispatched at hubs

**System characteristics of present hubs:**

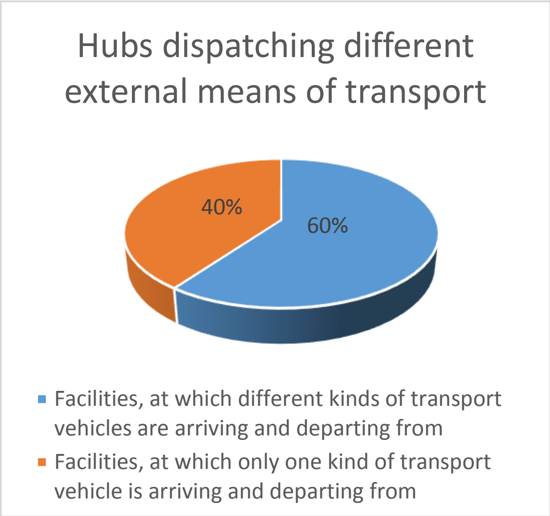



Figure 5-1: External means of transport

**PI-key element characteristics:**

Especially for sustainability reasons (pollution reduction, last mile efficient delivery, etc.), the use of different vehicle types (especially vehicle types powered with alternative and renewable fuels like biodiesel, electricity, ethanol, natural gas, hydrogen etc.) is inevitable for realizing the Physical Internet.

**Level of accordance between present hub and future PI-key element characteristics:**

Results of the questionnaire are showing, that especially hubs which are placed in the last mile are taking advantage of different means of transport. As illustrated in Figure 5-2, 5 out of the 6 hubs which are dealing with various vehicles types are placed in the last mile.

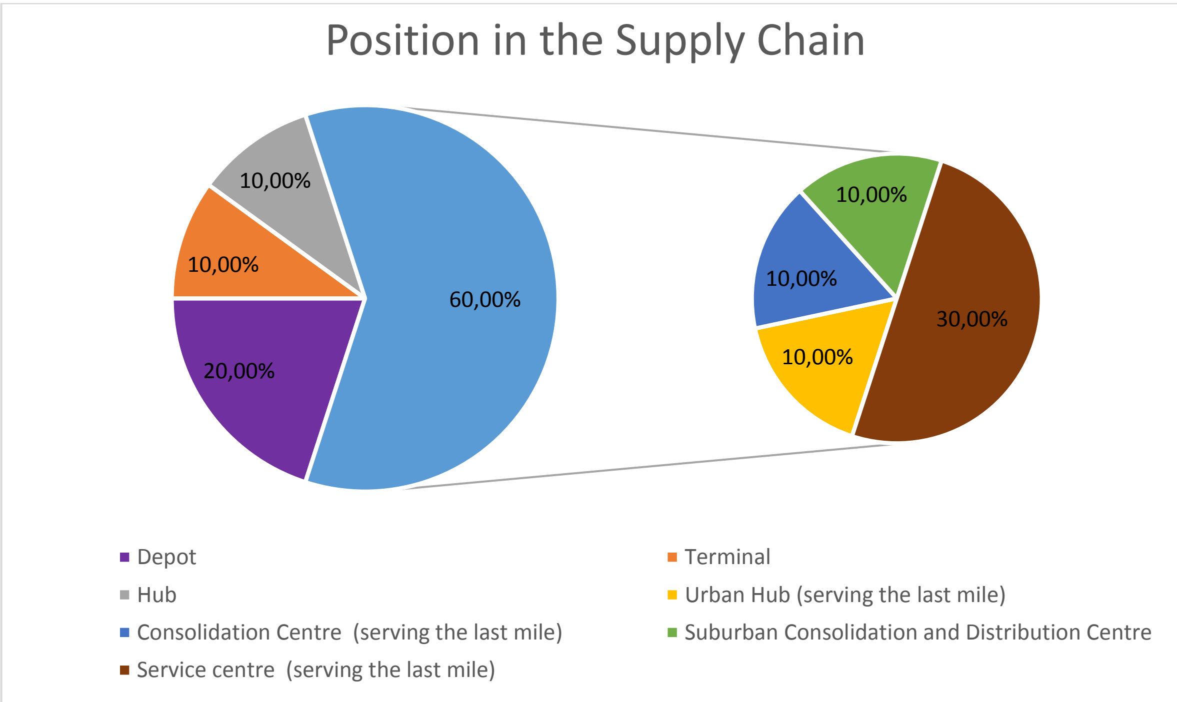



Figure 5-2: Percentage share of hubs located in the last mile.

From this, it can be concluded that future PI-hubs will have to perform with different types of vehicles, especially when it comes to the last mile.

Therefore the level of accordance is rated as strong, due to the fact that most of the existing hubs positioned in the last mile are already taking advantage of operating with various vehicle types.

### 5.1.2 Processes for loading and unloading of goods

**System characteristics of present hubs:**

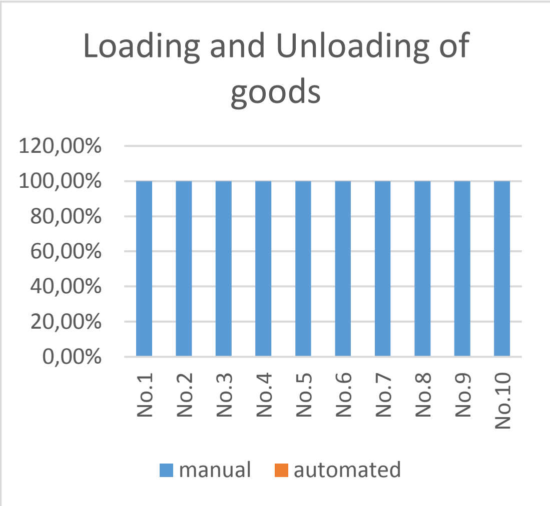



Figure 5-3: Execution of loading and unloading processes

**PI-key element characteristics:**

The level of automation of PI-movers, responsible for moving PI-containers, is not clearly defined yet and will be either executed manually or automated.

**Level of accordance between present hub and future PI-key element characteristics:**

As in this case the PI-system characteristics are not specified yet, the estimation of a corresponding level of accordance between the present way of execution and the future PI-system is not meaningful.

### 5.1.3 Equipment used for loading and unloading operations

**System characteristics of present hubs:**

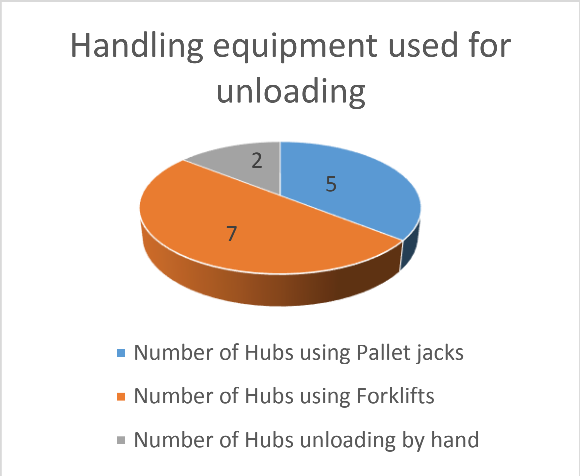



Figure 5-4: Equipment for unloading

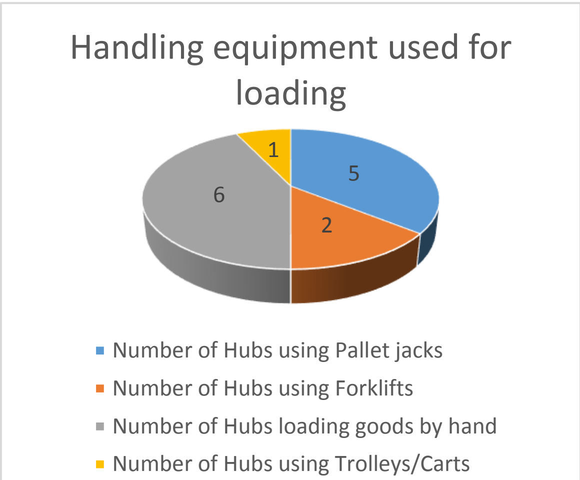



Figure 5-5: Equipment for loading external transport vehicles

**PI-key element characteristics:**

PI-movers with adequate system design suitable for handling PI-containers will be needed for future. The desired system of PI-movers will have to be designed with a kind of snapping device, allowing the PI-containers to attach to the PI-movers

**Level of accordance between present hub and future PI-key element characteristics:**

To avoid handling with pallets and other comparable unit load formation equipment, new PI-mover systems have to be designed. Due to the fact that pallets are the most common unit load formation equipment around the world, with billions circulating through global supply chain (2 billion only in the United States), most of the systems to move goods available right now are not suitable for the PI-system requirements (cf. [SLA17]). Therefore the level of accordance is rated as poor.

### 5.1.4 Composing and decomposing of parcels / PI-containers

**System characteristics of present hubs:**

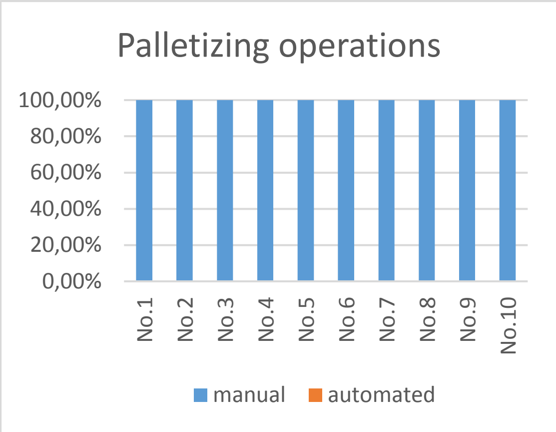



Figure 5-6: Composition and Decomposition

**PI-key element characteristics:**

PI-composers will be designed for composing and decomposing composite PI-containers at high velocity. PI-composers are prime candidates for automation, notably integrating PI-conveyors and PI-sorters.

**Level of accordance between present hub and future PI-key element characteristics**:

PI-composers play a role similar to current palletizers and depalletizers, but with standard easy-to-interlock modular PI-containers rather than diverse arbitrarily sized objects. At the present point it is hard to estimate a level of accordance between the present systems and the future scenario as it is not clear yet, whether the future PI-system will need palletizers and depalletizers like we know them right now, or not. Either there will be an adaption of the present systems or entirely new handling techniques will arise for satisfying the PI-requirements. In the developing process, a strong uncertainty also arises from the nature of the PI-container itself, as it is not sure yet how the interlocking feature of the PI-container will look like in the end and how it will affect the composing and decomposing processes.

Nevertheless, when only looking at the level of automation of the investigated hubs, it appears clear that the present execution of composing and decomposing is not sufficient for the PI-System, in which a higher automation level is aimed to be achieved. Therefore the level of accordance is rated as poor.

## 5.1.5 Current and future conveyor techniques

**System characteristics of present hubs:**

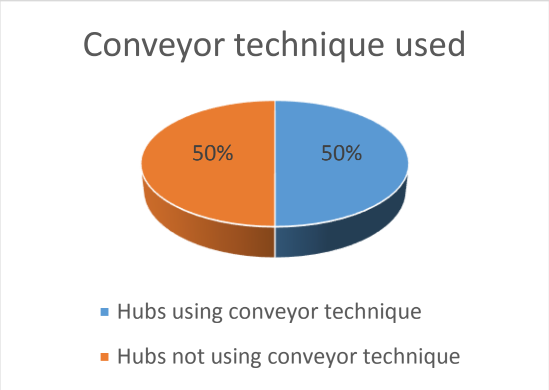



Figure 5-7: Percentage of hubs using conveyors

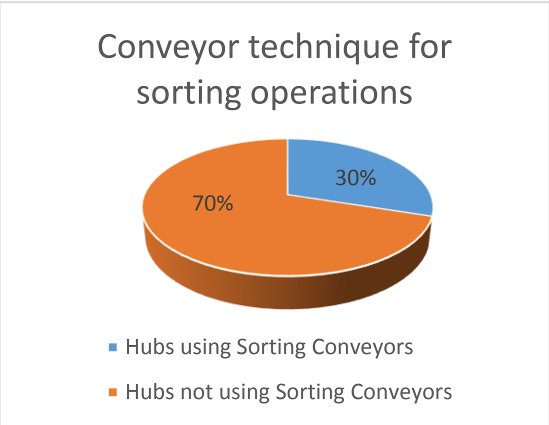



Figure 5-8: Percentage of hubs using sorting conveyors

**PI-key element characteristics:**

PI-conveyors will also play an important role for PI-facility processes and in realizing the Physical Internet.

PI-conveyors may will differ from present conveyor techniques, as they will be explicitly designed for modular PI-containers

The PI-sorters are typically embedded within more complex PI-nodes, such as PI-hubs.

The movement of PI-containers placed on PI-cells of the PI-sorter should be possible in at least the four cardinal directions on each of the PI-cells.

**Level of accordance between present hub and future PI-key element characteristics:**

50 % of the investigated hubs were using belt- and roller-conveyors for the very simple purpose of moving goods from one place to another. Among these 50%, 30% were also using automated as well as semi-automated conveyors for the specific purpose of sorting goods according to certain constraints. This means an overall use of sortation conveyors of only 30%, which can be explained by the different volumes of parcels processed in the different hubs. Investigated hubs which are handling more than 60000 parcels per day are using such sortation conveyors. Nevertheless, it is difficult to draw conclusions from the relationship between “parcels per day” figures and the need for sortation conveyors, when considering the survey results. This derives from the fact, that one of the investigated hubs handles less than 200 parcels a day but still uses a sortation conveyor.

The percentage of facilities using sortation conveyors appears comprehensible and coincides with the PI-requirement described above, that especially more complex PI-nodes will use PI-sortation conveyors, implicating that they will not be necessary in all kinds of PI-nodes. In this context the corresponding level of accordance in rated as strong.

Even though modular PI-Containers could be moved from one place to another by conventional belt- and roller-conveyors, the aim of the Physical Internet is to develop specialized conveyor techniques, more matching with the PI-Containers and able to exploit their features in the best way possible.

As the PI-conveyors as well as the PI-sorters are therefore PI-container related key elements, they will be explicitly designed for moving and sorting modular PI-containers. In this context the corresponding level of accordance in rated as poor.

### 5.1.6 Identification systems

**System characteristics of present hubs:**

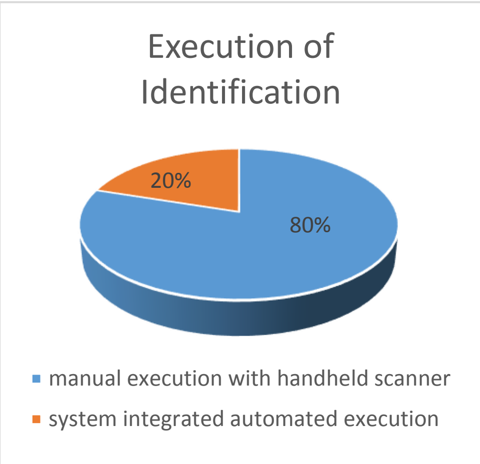



Figure 5-9: Identification of goods

**PI-key element characteristics:**

The PI-Container-Identification-System and all corresponding technologies to achieve a proper identification is considered to be an important issue for the Physical Internet.
PI-containers will be equipped with a unique physical number and means to automatically capturing information via a smart tag and then resorting to other technologies derived from the Internet of Things.
RFID technology is currently perceived to be suitable for building PI-container tags.

**Level of accordance between present hub and future PI-key element characteristics**:

All investigated facilities are using an Identification System. As illustrated in Table 5-2, mostly barcode-based technology is used, which is not considered of having enough potential for satisfying the needs of the Physical Internet. Another factor is the level of automated capturing of information, which is relatively poor in present systems with only 20% of the investigated hubs using an automated system for item identification. This means an identification system, fully integrated in the facility system's infrastructure, enabling to get rid of manual identification processes by humans.

In terms of automation, the level of accordance is therefore estimated as poor. In terms of the used technology, the level of accordance is also poor, as barcodes not sufficiently satisfy the PI-requirements. The only positive level of accordance which can be derived in this case, is the fact that each of the investigated hubs were using an identification system, which is an absolute necessity for realizing the Physical Internet.

Table 5-2: Type of identification medium

| Facility \ Type of Identi- -fication | Barcode | Magnetic Stripe |
|---|---|---|
| No.1 | √ | |
| No.2 | √ | |
| No.3 | √ | |
| No.4 | √ | |
| No.5 | √ | |
| No.6 | √ | √ |
| No.7 | √ | |
| No.8 | √ | |
| No.9 | √ | |
| No.10 | √ | |

### 5.1.7 Stores and buffers

**System characteristics of present hubs:**

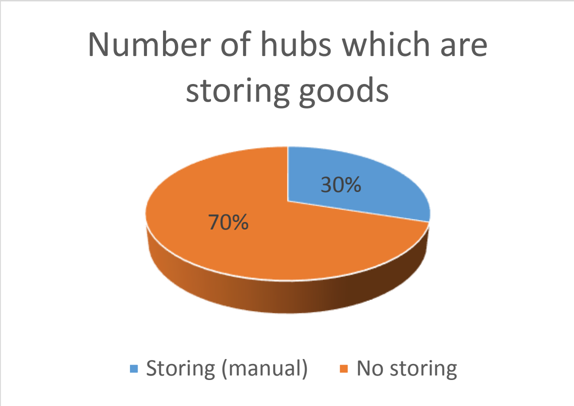



Figure 5-10: Percentage of hubs using stores

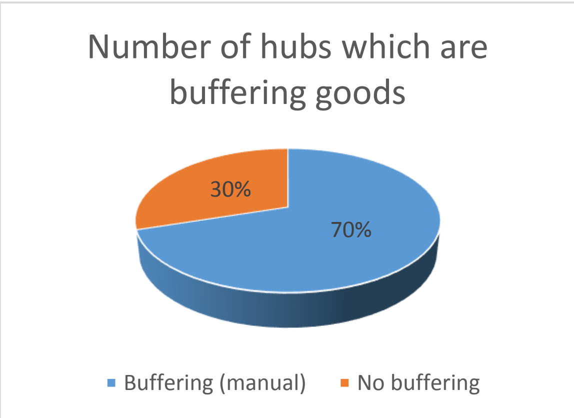



Figure 5-11: Percentage of hubs using buffer areas

**PI-key element characteristics:**

Even though it is not sure yet which type of storing and buffering system will be used in the end, there's no doubt that there will be some sort of storing and/or buffering systems within the Physical Internet.
New kinds of PI-store technologies will have to be developed to exploit the powerful functional characteristics of PI-containers and the dynamics of the Physical Internet.

First PI-stores, will be explicitly designed for PI-containers: They will be able to stack PI-containers, interlock them, snap them to a rack and so on. Second, they will not deal with products as stock-keeping units (SKU's), but rather focus on PI-containers, which are all individually contracted, tracked and managed to ensure service quality and reliability.

**Level of accordance between present hub and future PI-key element characteristics:**

30% of the investigated hubs are storing goods by simply using the floor as storage area. In contrast 70% of the investigated hubs are taking advantage of buffer areas for short time storage of goods.

Nevertheless, when looking at the level of execution, it is difficult to interpret the accordance between present systems and the PI-requirements because present systems simply don't use any storage systems for storing goods or to buffer them. They only put goods on dedicated places within the hub. Therefore the level of accordance is estimated as poor.

### 5.1.8 Warehouse management system and planning software

**System characteristics of present hubs:**

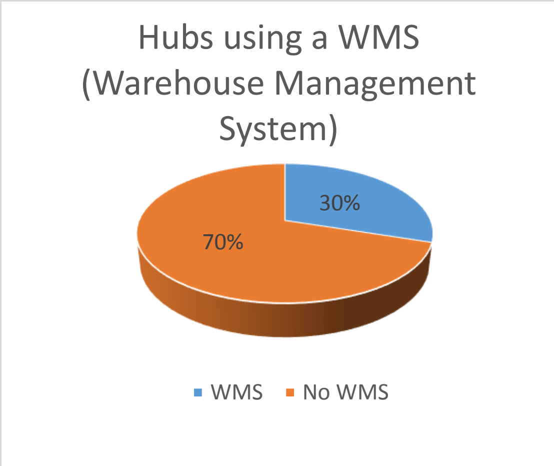



Figure 5-12: Percentage of hubs using a WMS

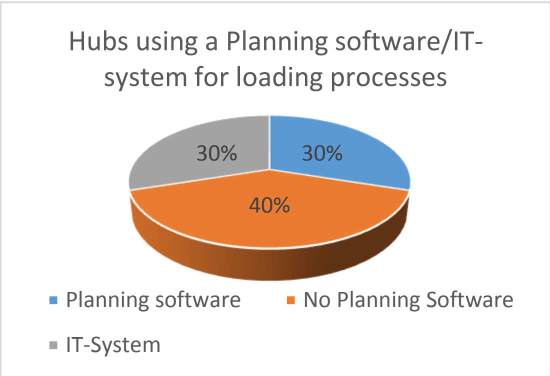



Figure 5-13: Percentage share of hubs using a planning software/IT-system

**PI-key element characteristics:**

The Physical Internet's general aim to create a decentralized system also influences the information infrastructure. This furthermore influences the management system in the broadest sense.

More precisely, the Internet of Things will be exploited to enable information exchange between PI-Containers (and other relevant PI-elements like handling equipment, means of transport, infrastructure, etc.) and stakeholders.

Several types of applications will have to be set up in the Cloud to enable a flow control logic but also a proper network management for decision making and planning tasks.

**Level of accordance between present hub and future PI-key element characteristics:**

30% of the investigated hubs have been using both a Warehouse Management System (WMS) as well as a Planning Software for assigning goods to different departing external transport means.

In addition to that, upon the 70% of the investigated hubs which haven't been using a traditional WMS, 30% have been using an IT-system, provided by their shippers. This IT-system is working with digital data concerning the goods. Shippers upload these data and when goods arrive at the hub, they get scanned and the IT-system gets updated. With the data provided by the IT-system, the goods are assigned to corresponding means of transport departing to the next destination within the supply chain. Even though these 30% haven't been using systems classified as a typical WMS or a planning software, they are using this IT-system for addressing a similar purpose.

Nevertheless, all systems with managerial and planning purpose used within the investigated hubs are centralized and provider specific and far away from a uniform solution. They are only taking advantage of the Internet of Things in a manageable scope.

As the Physical Internet wants to create a decentralized information infrastructure by exploiting the Internet of Things at a great level, the level of accordance is rated as poor.

## 5.2 Comparison of processes

In addition to the executed variance comparison in chapter 5.1, processes in present hubs and PI-hubs have been also compared by using the created EPC's in chapter 4.5. By analysing the resulting processes, illustrated in chapter 4.5.1 and 4.5.2, it becomes clear that there exist differences between processes in the present hub and the PI-hub.

It is important to mention here, that drawing conclusions from this comparison is difficult due to the nature of the data gathering method used for identifying present hubs processes. As the questionnaire approach provides only a limited quantity of data caused by the limited amount of asked questions, there always exists a certain level of uncertainty about the present hub internal processes. This can also be seen by comparing the total number of executed process steps inside the present hub and the PI-hub, represented by the functions (green symbols) in the EPCs. As illustrated by the numeration on the left side of the of the EPC's process visualisation in chapter 4.5.1 and 4.5.2, the present hub executes 17 functions whereas the PI-hub executes 24 functions. Therefore this comparison only provides a superficial inspection of processes, additionally to the main comparison executed in chapter 5.1.

One major difference between the processes in the present hub and the PI-hub is the main process "Storage and Picking". In the EPC of the present hub can be seen, that this step is replaced by the process termed "Storage", because questionnaire results showed, that the two investigated hubs (whose data was used for the creation of the present hub EPC) had no typical "Storage and Picking" area as classified in the DCRM. As already mentioned in chapter 4.5.1.4, in this case, the "Storage" process is more like an added service, provided by the hub operator. The present hub simply doesn't use any additional storage systems (only movers, as illustrated in chapter 4.5.1.4, have been used) for storing goods or to buffer them, in fact goods are put on dedicated areas on the ground. In comparison with the PI-hub, in which the storing is realized with a PI-store, there exist no extra material handling devices for storage purpose in the present hub.

The absence of a typical storage area in the present hub also influences the sequence and structure of main processes and process steps of the DCRM to some extent. It can be seen, that the structure and the sequence of the main process "Receiving" within the present hub is different compared to its PI-counterpart. Right after the process "Goods delivery constraints checking" (process number

3 in chapter 4.5.1.1) there exist three possibilities of further processing in the present hub, compared with only two possibilities after the process “PI-composites delivery constraints checking” (process number 3 in chapter 4.5.2.1) of the PI-hub. This is also caused by the different tasks of the described “Storage” in the present hub and a typical “Storage and Picking” area in the PI-hub, which is usually placed right after the “Receiving”. In contrast to that, in the present hub the decision whether an unloaded good has to be stored meanwhile (added service) is made during the “Receiving” process.

Note: It is important to mention here, that this comparison doesn’t represent a generalization for all kind of distribution centres.

## 5.3 Variance comparison - Results

To provide a more compact representation of findings, evaluated in the variance comparison of chapter 5.1, the following Table 5-3, Table 5-4, Table 5-5, Table 5-6 illustrate the main results from chapter 5.1. The subject (Process, equipment or system) of the rating is always listed in the left column of the following tables, followed by the rating in the column “level of accordance between present hubs and PI-hubs”. Some processes have been rated twice, but on different aspects, which are described in the column “Note/Context”.

Table 5-3: Level of accordance between present hubs and future PI-hubs - Part1

| Process, Equipment or System | Level of accordance between present hubs and PI-hubs | Note/Context |
|---|---|---|
| Handling **equipment** for **loading** and **unloading** | **Poor** | • Most common ULFE in present hubs is the pallet. Therefore most systems are designed for moving pallets or other ULFE’s.<br>• New systems have to be designed for moving PI-containers ULFE-free. |

Table 5-4: Level of accordance between present hubs and future PI-hubs – Part2

| Process/Equipment/System | Level of accordance | Note/Context |
|---|---|---|
| Unit load **composing** and **decomposing** | **Poor** | • Low automation level of execution in investigated present hubs. No automated palletizing/depalletizing operations (all executed by hand).<br>• PI-composers are prime candidates for automation. |
| **Conveyor/Sorting** techniques | **Strong** | Only 30% of investigated hubs use sortation conveyors. Differentiation of hubs into:<br>• More complex hubs (higher amount of parcels/day)<br>• Less complex hubs (smaller amount of parcels/day)<br>The PI also differentiate between more and less complex PI-nodes. |
| | **Poor** | • Roller- or belt-conveyors are used in investigated hubs.<br>• PI-conveyors and sorters will be explicitly designed for PI-containers. |

Table 5-5: Level of accordance between present hubs and future PI-hubs – Part3

| Process/Equipment/System | Level of accordance | Note/Context |
|---|---|---|
| **Identification** system | **Strong** | • All investigated hubs use an identification system.<br>• Using an identification system is an absolute necessity for realizing the PI. |
| | **Poor** | • Extensive use of barcodes which not sufficiently satisfy the PI-requirements.<br>• Low automation level of the identification process in investigated present hubs. |
| **Stores** and **buffers** | **Poor** | • All investigated present hubs, which are storing goods, are simply using the floor as a storage or buffer area.<br>• PI-stores will be explicitly designed for PI-containers. |

Table 5-6: Level of accordance between present hubs and future PI-hubs – Part 4

| Process/Equipment/System | Level of accordance | Note/Context |
|---|---|---|
| **Warehouse management** system/**Planning** software | **Poor** | • Management and planning systems are not frequently used in investigated present hubs.<br>• Existing management/planning systems are user specific and not uniform.<br>• Negligible exploitation of the IoT in investigated present hubs. |
| Use of **different external means of transport** (powered with alternative fuels) | **Strong** | • Most of the existing hubs positioned in the last mile are already taking advantage of operating with various vehicle types.<br>• Especially for sustainability reasons, the use of different vehicle types is inevitable for realizing the Physical Internet.<br>Note: This rating is only valid for the supply chain position "last mile". |

# 6 Conclusions and Suggestions for further research

Even though some system requirements of the Physical Internet already exist to some extent in present hubs, there is one major concern, strongly connected with many of the necessary developments which have to be fulfilled for successfully realizing a Physical Internet: The modular PI-container.

When taking a closer look at the comparison between system characteristics of present hubs and the desired PI-key characteristics of a PI-hub in chapter 5.1, it can be seen that the reason for a low level of accordance of system characteristics between present hubs and PI-hubs mostly refer to the nature of a modular PI-container. As most of the material handling systems nowadays are designed for pallet handling operations, there was no need for adapting the used conventional systems for a palletless handling system like the Physical Internet so far, which automatically leads to the low levels of accordance seen in chapter 5.3.

The mutual influence between the PI-container development and the development of matching material handling systems for the Physical Internet is inevitable, not least because of the amount of handling systems which the PI-container will be eventually handled with. As illustrated in Figure 6-1, the PI-requirements are also influencing the development of PI-containers and corresponding material handling systems, but as the PI-requirements are influenced to some extent by the uncertainty of technology trends and developments, the whole Physical Internet development suffers from a certain degree of uncertainty.

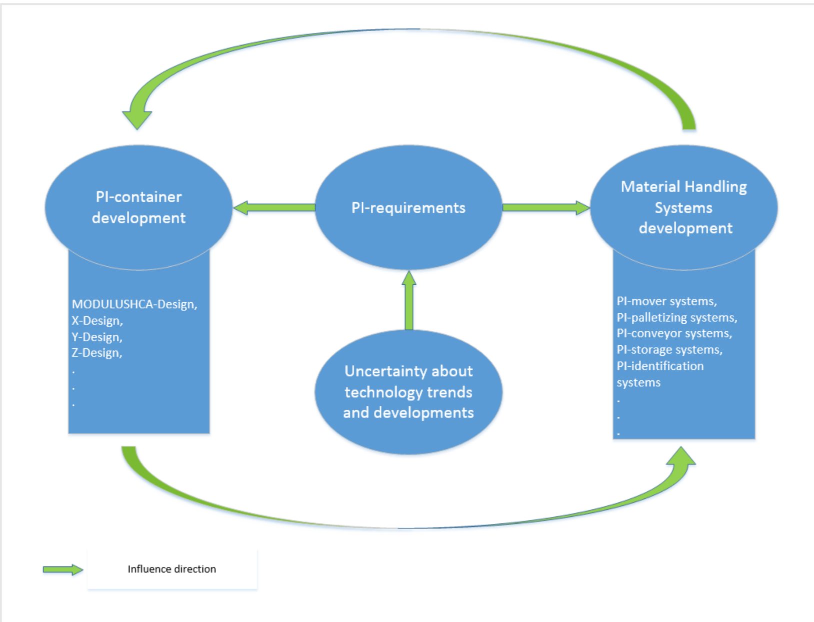



Figure 6-1: Influence of PI-requirements, PI-container development and material handling systems development

As the multidirectional movement of goods is at least already possible by using technologies like grid conveyors, flex conveyors or other modular cognitive conveyor prototypes, further research should focus on the ongoing development of the PI-container in strong cooperation with the development of material handling systems (cf. [VHR12]). Herein one focus should be the development of a uniform snapping interface, enabling the connection between PI-containers and all kind of PI-material handling systems as well as PI-storage systems. This interface should ideally enable fast and secure attaching of PI-containers and PI-composites to all kind of necessary PI-material handling systems. Progress in these fields would mean a great success for the development of the whole Physical Internet idea, especially for the practical development stage.

Nevertheless, it seems extraordinary important to establish a uniform PI-container, eventually under cross country collaborative development, but much more important is it, to set the result afterwards as a common uniform definition of a PI-container. By setting up a commonly agreed design of a PI-container would in result ease the way for developing corresponding PI-material handling systems.

The purpose of this thesis was also to point out, which kind of devices for material handling are really in use in present hubs, independent from all the various possibilities that technological progress has provided in the past. Some results in chapter 4.4.1 showed e.g. that simple, conventional technologies like roller forks and pallet jacks are used in almost all of the investigated hubs (illustrated in Table 4-7). There were no systems in use for unloading and loading operations which have a higher level of complexity and automation. In some of the investigated cases, the reason for using these conventional technologies is simply the low amount of handled goods per day processed by the specific hubs. There is no need for investing in better technologies right now, as work can be executed within the specified time windows and investments in more automated systems would only reflect in big expenses.

Another big issue for the unloading and loading processes is the number of various vehicle types arriving at and departing from the hubs. As the various vehicle types are mostly differing from each other in many characteristics, it is difficult to create a uniform hub-side unloading and loading dock interface, satisfying each of the different requirements for unloading and loading procedures arising from the different vehicle types. Beside differences in height, length and width of loading areas, vehicles differ in the way how goods can be unloaded from and loaded onto their loading area either by different vehicle-integrated loading area conveyor techniques or without vehicle-integrated techniques. In Figure 6-2 current automated truck loading and unloading systems are displayed.

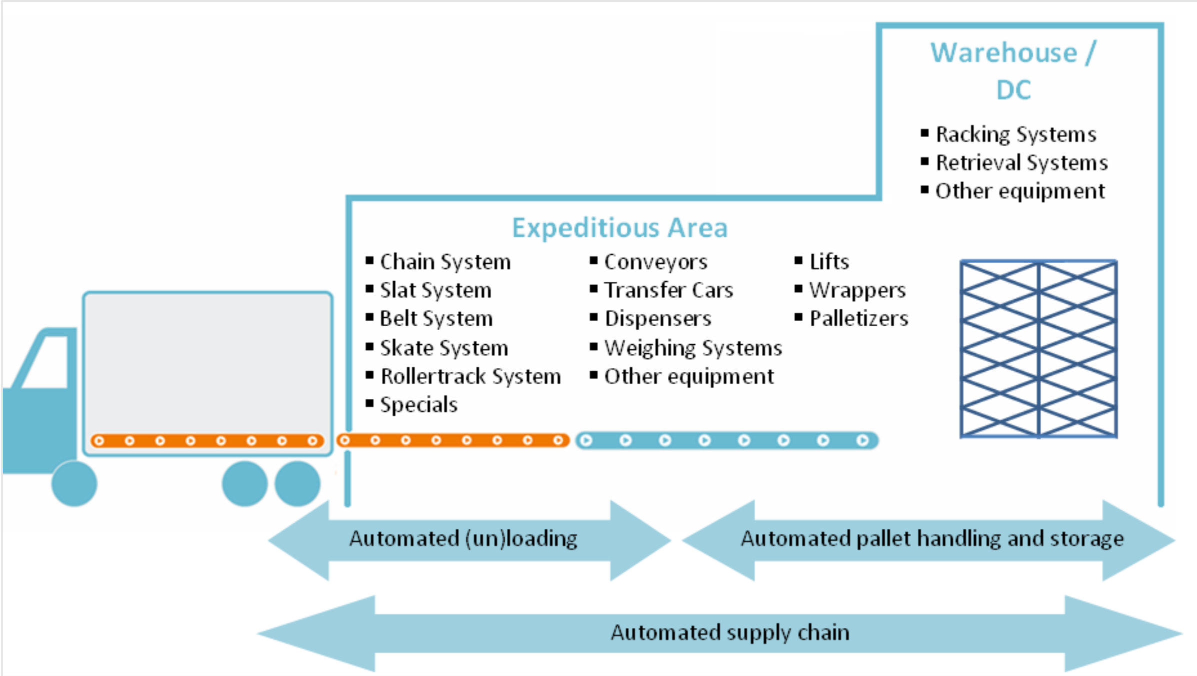



Figure 6-2: Current automated truck loading systems (ATLS) ([VdD10], p. 6).

As the use of different vehicle types at single hubs will also be an issue in the realization of the Physical Internet, further research on developing uniform, adaptable loading and unloading systems is of great interest.

Another trend can be derived from (cf. [PRG17]). Analysing the BMCs (Business Model Canvas) of the transport and delivery industry shows that all operators offer to their customer segments, a value proposition consisting in time sensitive transportation services and express delivery. This could result in a shortfall of storage areas in hubs and a shift to a use of more short time buffers. This will also influence the development of buffer systems for the Physical Internet.

The willingness of companies to deliver goods to the customers as fast as possible also affects the development of the Physical Internet. This concern will especially challenge the development of a proper WMS and planning software, enabling a sufficient load capacity utilization of transport vehicles.

From all this can be concluded, that there are still many things left to investigate in terms of material handling systems and processes, in order to pave the way for realizing the Physical Internet.

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# 8 Register

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# 9 Appendix

## 9.1 Published abstract


## Abstract

The current way physical objects are transported, handled, stored, realized, supplied and used throughout the entire world's supply chains is not sustainable economically, environmentally and socially. One approach to address these drawbacks is the concept termed "Physical Internet" proposed by Eric Ballot, Benoit Montreuil and Russell D. Meller.

This master thesis contributes to this approach by evaluating present material handling systems and investigating their readiness for the Physical Internet. In the first step literature about the Physical Internet and current state of the art intralogistics was analysed. Afterwards a variance analysis between intralogistics processes executed in present distribution centres and future Physical Internet distribution centres was conducted. The ascertainment of the present situation of intralogistics processes was achieved by a survey strategy. The corresponding key processes for the Physical Internet solution were derived by relevant literature about the Physical Internet. Based on these findings, Event-driven Process Chains for a present hub and for a future Physical Internet hub were created. After the execution of the variance comparison, technology gaps between the processes in current hubs and Physical Internet hubs were identified, highlighted and assessed.

# Kurzfassung

Die heutige Art und Weise in der Güter innerhalb der weltweiten Lieferkette transportiert, gehandhabt, gelagert und verwendet werden ist weder wirtschaftlich, ökologisch noch gesellschaftlich nachhaltig. Ein von Eric Ballot, Benoit Montreuil und Russell D. Meller entworfener Ansatz namens „Physical Internet“, versucht diesem derzeitigen Trend der Logistik entgegenzuwirken.

Im Sinne dieses Ansatzes evaluiert die vorliegende Masterarbeit Material-Handhabungsgeräte in gegenwärtiger Distributionszentren (Hubs) und untersucht deren technologische Einsatzbereitschaft für ein logistisches System gemäß eines Physical Internet. Hierzu wurde im ersten Schritt sowohl relevante State of the Art Literatur bezüglich Intralogistik als auch des Physical Internet analysiert. Anschließend wurde ein Soll-Ist Vergleich der intralogistischen Prozesse zwischen bestehenden Hubs und zukünftigen Physical Internet Hubs durchgeführt. Die für diesen Vergleich notwendige Erfassung der intralogistischen Prozesse und Handhabungsgeräte in gegenwärtigen Hubs erfolgte mittels Fragebögen und Experteninterviews. Die intralogistischen Schlüsselprozesse und Handhabungsgeräte für Physical Internet Hubs wurden aus entsprechender Physical Internet Literatur abgeleitet. Auf diesen Informationen aufbauend, wurden daraufhin erweiterte ereignisgesteuerte Prozessketten für einen gegenwärtigen Hub als auch für einen zukünftigen Physical Internet Hub erarbeitet. Basierend auf dem Soll-Ist Vergleich zwischen aktuellen und zukünftigen Systemen wurden technologische Lücken identifiziert, aufgezeigt und beurteilt.