Visibility in Physical Internet Port

Use-Case Driven Conceptual Design of
Information Flows to Track and Trace Modular
Containers in Terminal Operating System
in PI-Port

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Challenge the future

Visibility in Physical Internet Port

Use-Case Driven Conceptual Design of
Information Flows to Track and Trace Modular Containers
in Terminal Operating System in PI-Port

By

Rowoon An

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Preface

The last eight months of my life are covered in this thesis. During this time, many things happened both in my academic and personal life. Nevertheless, I have found development in my field, thus hoping this small contribution helps to accelerate the future logistics paradigm, Physical Internet.

My thesis would not have been accomplished without the support and supervision of my committee members. Mainly I would like to thank Lori for being my chair, Jarfar, Patrick, and Farzam for daily supervisions, and Jolien for her help in coordinating my committee and understanding my situation.

As to my daily life, I would like to give thanks to the supports of my family, friends—s, y & conancheol, DFT, Geerweg family—fellow students and finally, I want to wish the best of luck to my little brother during this crucial moment of his life.

R. An
Delft, December 2017

Executive Summary

Today, freight logistics is one of the indispensable services in people's daily lives in enabling goods to be placed at an appropriate point in time. Primarily, its significance is successively increasing in proportional to global economic growth. The economic growth can raise the demand for domestic and international transactions and consequently the need for freight logistics service increase. As its importance in society, freight logistics has not only economic but also environmental and societal leverages. Currently, the freight logistics industry has facing unfavorable symptoms in the economy, environment, and overall society. Behind these symptoms, there are operational issues in freight logistics systems.

This project started from doubt on one the issues, inefficient space utilization of containers and trucks (i.e., loading units). From now on, the freight logistics industry has made various attempts to relieve the adverse issues within logistics systems. As one of the innovative invention in the industry, standards for containers have been set by the International Standard Organization (ISO) since the 1960s, and subsequently standards on pallets, used as the lower level of loading units on shipping containers. Moreover, information technologies (ITs) have been applying throughout logistics information systems. Logistics information systems (LIS) can be a typical example to show the application of ITs in logistics systems.

Through existing research and an interview with Zomer (Appendix A), it was found that "insufficient standards on loading units" is one of the causes of the waste of space. In brief, their insufficient standards can leave space as irregular shipments are stuffed together into a shipping container. More indirectly, loading units encapsulated with less-standardized shipments induce consignors to intentionally remain space to avoid additional operations and costs for the loading units. Additionally, insufficient standards hinder loading units to be tracked and traced within logistics chains. Subsequently, this lack of visibility results in the inefficient composition of loading units. For this project, two primary issues in modern freight logistics can be formulated regarding insufficient standards of loading units:

(1) inefficient space utilization of loading units
(2) Invisibility on loading units

Notably, the idea of Physical Internet (PI, π) introduced by Professor Benoit can be considered as a potential solution to the two main concerns. The PI is a globally open logistics system with advanced visions on interconnectivity in its physical, operational, and digital aspects. For this, PI has been redefining logistics entities existing in current systems to comply with reinforced but versatile standards. With respect to the two issues in current systems, PI proposed "PI container," also known as π-container or modular containers comprised of three standardized layers of loading units: (1) packaging container, (2) handling container, and (3) transport container. Besides, PI has two more major building blocks, the open interface platform, and global protocol, that respectively stand for a communication channel enabling for interconnectivity between PI logistics entities, and the necessary prior consent from stakeholders.

However, the PI still exists in theory and its potentials have been barely verified because of difficulties in implementation commonly inherent in large-scale engineering systems. Due to the limitation on actualization, a conceptual implementation is significant for PI. Current research on PI relatively well establishes physical concepts of each element, such as dimensions, and functionalities, whereas little research reflected information perspective to the

physical ideas. In short, a conceptual design of PI is not completed yet because of unbalanced research, focusing on the physical perspective.

This research aims for filling this fundamental knowledge gap in PI with respect to two current issues on loading units. That is, this research has investigated information flows on modular containers by identifying potentials of the three major PI elements: (1) modular containers, (2) open interface, and (3) global protocol regarding space utilization of loading units and their visibility.

In particular, this research has formulated the information flows in the viewpoint of ports, which tend to extend their range of value-added services (VASs) in perceiving their significance in maritime logistics of today. Concerning loading units and their visibility, (de) composition VAS, also called repositioning operation, has been considered within the context of ports along with Tracking & Tracing (T&T) system.

Synthesizing the knowledge gap and scope, the primary research question is formulated as follows:
How can information flows in modular containers be designed with the help of the PI open interface and global protocols to improve visibility on loading units in (de)composition operations within ports?

For answering the question, three phases in V-Model have guided this project: (1) conceptual development, (2) requirement engineering, and (3) system architecture. The design of logistics systems each of modern ports and PI ports can be developed in the first and third steps, complementary applying the adjusted RAMI 4.0. The second stage plays a role as a bridge between two models by eliciting requirements for PI ports with a use-case approach. Appropriate data in each phase has been collected employing qualitative research methods (i.e., document analysis, case studies, and interviews).

Main Design framework (adjusted RAMI 4.0)

Reference Architecture Model for Industry 4.0 has been adjusted by reflecting the nature of LIS to analyze logistics systems of modern ports and to propose a tentative design of PI ports systems. This research has used the four different aspects linked with different hierarchical elements. Especially, the information layer is the primary concern in this study. Furthermore, the rest layers also help to grasp the information stream by providing logistics entities and interactions in T&T system, external LISs, and ports' operations. Each layer is explained with a design tool as follows:
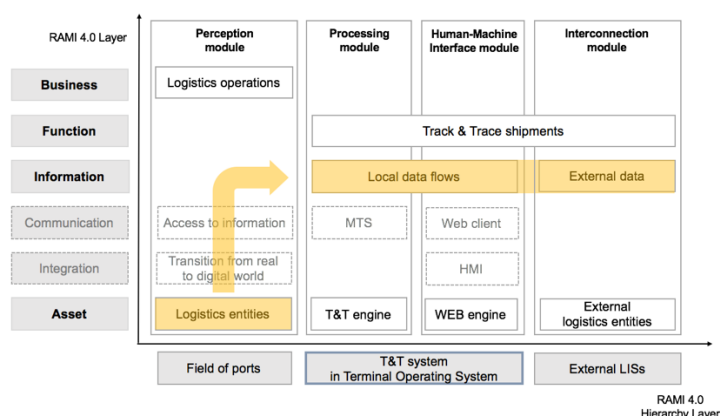
(1) Asset Layer (class diagram): major logistics entities, including loading units, shipments, parts of LISs, are described with their attributes and operations.
(2) Information Layer (data flow diagram): information flows on logistic entities are formulated with the focus on informational interactions between two entities.

(3) Function Layer (activity diagram): activities in T&T system and interactions with external LISs have been elaborated by represents how the information flows have been formulated.

(4) Business Layer (business process management notation): variety operations on handling and transport loading units in ports have been illustrated as a process.

## Current Analysis on Logistics Systems in Modern Ports

Analyzing four layers in the developed RAMI 4.0, the current analysis on modern port systems has concluded with several points of improvement that might be considered as the three PI elements apply. The points of development on modern ports have been summarized behind:

- Expandable operational services in ports within maritime logistics
- Additional information in the T&T system of ports
- Arrangement between actors about information accessibility
- The way of information exchange between the T&T system in ports and external LISs

Use-Case-based Requirements on PI ports

In order to develop plausible use case situations, this research has perceived trends in the current maritime logistics which represent ports have been extending their range of value-added services (VASs) according to increasing their significance today. In-line with the trends, port-centric logistics (PCL) achieved successes in practical cases has been exploited for fundamental settings in the use case scenario.

In brief, a destination port (port of Tees) capable of repositioning operations receives two inbound T-containers encapsulated by different freight forwarders in different arrival ports (port of Shanghai & Hong Kong). Teesport decomposes the two T-containers and recomposes them into appropriate H-containers by considering time window and the next destination (Tesco Superstore) of shipments. The use case scenario has been described in use case description, and the use case diagram has presented possible functions in the T&T system of PI ports.
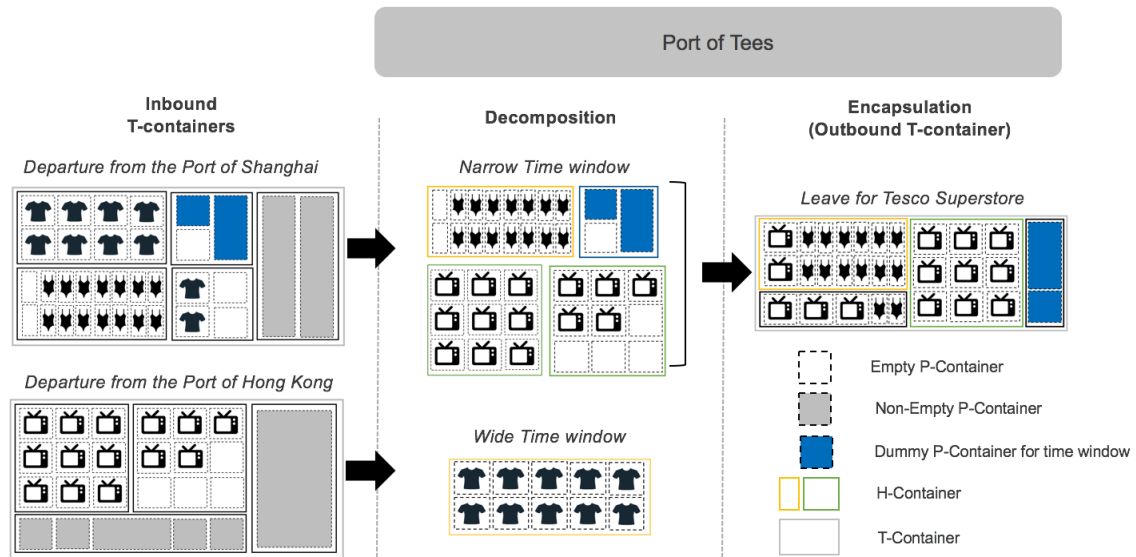
On the basis of the two elements (i.e., use case scenario and diagram), requirements on the three PI components have been elicited and analyzed by highlighting the points of improvement on modern ports:

- Modular Containers: PI ports should have physical accessibility on all three tiers of modular containers to perform repositioning operations. In repositioning operations, PI ports need to determine appropriate modular

containers for the best use of space. Also, the next destination and delivery time window should be taken into account.

- Open Interface Web: PI ports need to be accessible to the public, network, and shipment data on modular containers in the open interface web. These contents of information are prerequisites to perform repositioning operations.
- Global Protocol: PI ports have to induce port-related actors to provide their information into the open interface web. Especially, consignors, VAS providers, and LSP can be significant information sources for PI ports in connection with repositioning operations. Consignors provide the public data on P-containers whose network and shipment data can be generated and updated LSP and VAS providers. The public, network, and shipment data on H-containers and T-containers can be accessible to LSP, VAS providers including PI ports.

Conceptual design on PI ports

Requirements on the three PI elements have been used as a foundation for the conceptual design of PI ports. In compliance with the adjusted RAMI 4.0, information flows in PI ports have been proposed using logistics entities and their interactions in the T&T system and ports' operations.
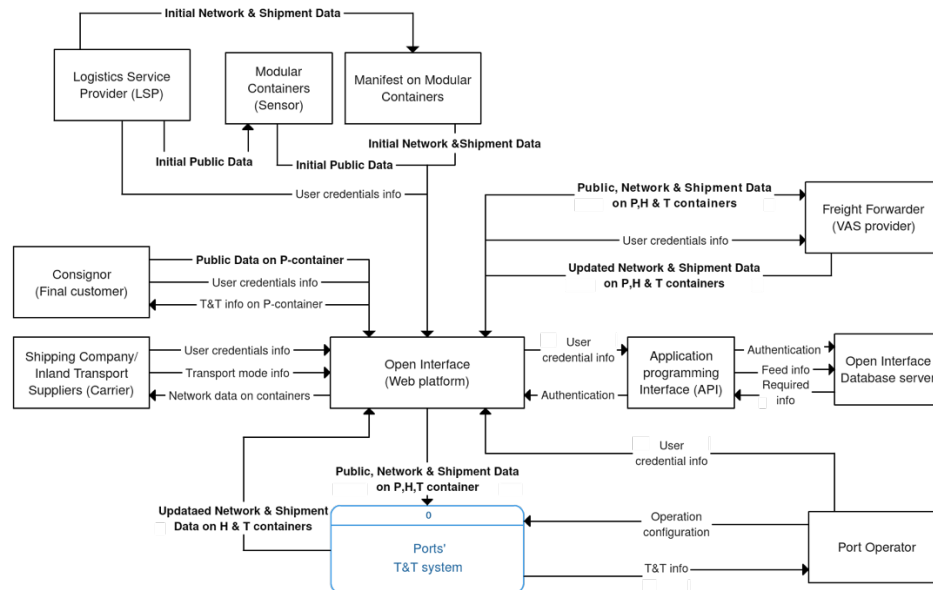
Before the conceptual design being built, a design decision has been made by analyzing alternatives on the way of information exchange between the T&T system in ports and external LISs. The method system integration has been pointed out as one of the points of improvement in modern ports, but the use case cannot describe explicit the manner. Due to the lack of research on the LIS integration in PI, alternatives developed in the context of port community system (PCS) have been considered, and the incorporation for multilateral message exchange has been determined through simplified multi-criteria utility theory.

By reflecting requirements on the three PI elements and the design choice, the conceptual design on PI has been established. The following summary highlights differences from finding in modern ports.

Requirements on the three PI elements have been used as a foundation of the conceptual design on PI ports. In compliance with the adjusted RAMI 4.0, information flows in PI ports have been proposed by means of logistics entities and their interactions in the T&T system and ports' operations.

(1) Asset Layer: asset layer captures increased interactions in operations and information exchange within PI ports. The three classes on modular containers have represented PI ports have physical accessibility on all tiers of them. Moreover, the class of manifest has shown the public, network, and shipment data are available for PI ports. The open interface web is associated with classes of API and database server in compliance with the design decision on system integration for multilateral message exchange. Through API, most actors in maritime logistics can communicate with one another and access to the database for achieving the necessary information. The repositioning operation also falls within the object to be tracked and traced, consequently the tracking and tracing information is shared with the open interface web.

(2) Information Layer: In summary, this layer formulates new information flows in PI ports by adapting the three PI elements. Although the significant functional flows in the T&T system is almost same with that in the current systems, this layer shows the number of interactions on information becomes essential to the T&T system in PI ports. This is because PI ports are capable of handling all tiers of modular containers. Consequently, they are accessible to three types of information on the modular containers. These have been already discussed in requirements on the three PI's components. This information layer is meaningful in that of visualizing them in the sequence of communication between T&T system in PI ports and external information sources. However,

this layer has not covered precise ways of interaction in the open interface, which will be elaborated in the next layer, functional layer.

(3) Activity Layer: To conclude this section, this function layer on PI ports has highlighted interoperability between their T&T system and the open interface web with focuses on information exchange. Contrast to reciprocal communications in current port systems; the open interface web enables all actors to exchange their information in a multilateral manner with the help of the API and database server. In short, the function layer represents which activities and interactions need to be fulfilled in the T&T system for the information flows of PI ports. In-line with the function layer, the next layer will show which operational process is feasible with the information flows.

(4) Business Layer: In brief, this business layer represents potential repositioning operation processes in PI ports by applying modular containers. In the processes, modularity of PI containers is aligned with the decomposing and recomposing operations. Hence PI ports become capable of adjusting loading units across three tiers. Furthermore, the layer briefly describes influences of the loading units on reducing logistics legs through the distribution center and ultimate customer.

Conclusion & Recommendation

This research has proposed the tentative design of information flows to answer the main research question. The tentative model has depicted potentials of the primary PI elements within the context of PI ports capable of repositioning loading units. In short, first, modular containers help to enhance space utilization in loading units through standardized three level in the units. Secondly, the open interface web allows PI ports to manage many informational interactions for repositioning operations and consequently to obtain visibility on loading units by linking the T&T system to external LISs through the platform. Lastly, the global protocol can increase the viability of PI ports by proposing guidelines necessary for negotiation between PI ports and external actors.

However, this research still contains several limitations which can be considered in future studies:
- Insufficient use cases to generalize application of PI elements in PI ports
- Lack of quantitative analysis on the conceptual design of PI ports
- Design choice for LIS integration by using alternatives developed in context of PCS
- Incomplete application of RAMI 4.0

From the limitations, of this research concerns to be considered in future research have been suggested. First of all, further research on PI is required because logistics entities in PI are intimately connected with each other which meaning the lack of research on a part can delay the entire implementation of PI.

In parallel with the fundamental research, various conceptual designs on PI and a specific design framework for the designs can be considered in future studies. Due to the limitations of actualization, PI requires many design models with diverse uses cases to testify its idea. Noticeably, the design models should be in-line with practical situations to enhance the viability of PI not only in theory but also in reality. With respect to this research, future conceptual designs on PI need to dedicate to exploring IT aspects by keeping a balance between IT and operational viewpoint in the designs. To visualize the conceptual models effectively, a design framework specialized in PI can be investigated based on the adjusted RAMI 4.0 in this research.

Time permitting, quantitative methods could have applied in the conceptual model of PI ports in this research. As a typical quantitative method, virtual simulation is expected to verify potentials of PI numerically. The design tools that used in modeling (UML, and BMPN) have diverse software to executable virtual simulations by transforming their models to computational codes. One barrier here is again the fundamental research on each PI element because virtual simulations require their specific configurations, such as concrete functions, performance, processing time and interoperability with other components. Therefore, further research on logistics entities, such as PI sorter, convey, and composer should be preceded. In connection with the PI design framework, the ability of execution can be considered as determining design tools.

Lastly, future research can explore methods of integration between the open interface and external LISs. This research has investigated one of the alternatives (multilateral message exchange) devised for integrating PCSs. Future studies on PI can investigate further options and suggest an optimal design choice that best suits for PI visions.

Contents

1

Introduction

Freight transport logistics by allowing goods to be placed at a proper point in time makes them one the most critical domains in transportation. Therefore, freight transport is essential throughout supply chains for various activities, such as production, commerce, and consumption. (Crainic, 2003).

Developments in the economy, manufacturing systems, and logistic networks increase the demand for freight logistics. In 2011, the annual expenses for freight transport in the U.S.A. accounts for $658 billion. Moreover, it is expected to be a sharp growth in the freight logistic industry in the following years (Montreuil, 2011). Economically, the demand for freight logistics is linearly proportional to economic growth, expressed as change in gross domestic product (Quak, 2008). Cross-continental production lines can increase the need for freight logistic thanks to flexible distribution networks for commodity storage.

Freight logistics perform an important role and offer benefits to society. For this, freight logistics systems must be aligned with various actors' interests in the community by means of physical and technical facilities. In Figure 1.1, a basic logistics process is depicted with its main stakeholders (Stefansson & Woxenius, 2007; Tseng, Yue,Taylor, 2005). Basically, the main goal of the process is the movement of goods from consignors to consignees through freight carriers. Although freight carriers can be independent parties, they often execute transportation for logistic service providers. Additionally, freight carriers can have relationships with diverse suppliers to receive vehicles, equipment, guideways, and so on. Overall, logistics processes are at the national, state, and city levels by authorities.

Figure 1.1 Overview of logistics process with main actors
(Stefansson & Woxenius, 2007; Tseng, Yue, Taylor, 2005)

Hence, interoperation of various systems within freight logistics is likely to expose problems, which can lead to adverse impacts on society. Statistical analysis shows that solid fuel, on which freight transport logistics heavily relies, is responsible for more CO_2 emissions than other contributors of worldwide CO_2 emissions (Montreuil, 2011). On account of these adverse economic and

environmental effects, people might be directly or indirectly affected by air pollution and traffic congestion.

Besides macroscopic analysis, the following operational issues directly occur within logistic systems (Montreuil, 2011):

(1) **Inefficient space utilization of containers and trucks**
(2) Inefficient scheduling of trucks
(3) Shortage of truck drivers
(4) Inefficient storage of products within a supply chain
(5) Long lead time of products
(6) Flawed intermodal transportation
(7) Inconvenient city routes for trucks
(8) Ineffective and unreliable transport network

U.S Department of Transport reported that a transport unit is approximately 60% full out of its total capacity (DoT, 2010). In addition, up to this day it is unknown if the containers are being packed in an efficient manner. Standards for containers had been created by the International Standards Organization (ISO) since the 1960s. Furthermore, the freight logistics industry has made many attempts to reduce problems within logistic systems not only by complying with physical standards but also by using a remarkable trend, information technology (IT) (Maslarić et al., 2016).

The lack of standards during unit loading has been considered as one of the main causes for the waste of space in freights. The pallet, which is a single loading unit, has been commonly implemented in current freight logistics as well as containers. The pallet allows items encapsulated in boxes, cases, and cartoons to be transported as a standardized unit.

As mentioned before, several groups of pallets can be stacked in shipping containers altogether. The problem is that the pallets can be structured in irregular shapes due to the diversity on forms of loading units in the lower level, mentioned as boxes, cases, and cartoons. Therefore, space between the loading units can be left in shipping containers. More indirectly, shipments loaded in unstandardized loading units require additional handlings to sort and consolidate them, which adds up to their logistics costs (G.Zomer, personal communication, November 3, 2017) (Appendix A). Consignors tend to exploit full container load (FCL) logistics to avoid additional costs on freight handling, even if they have no full loading freights for FCL. As a result, empty space in the shipping containers still remains.

The insufficient standards on loading units is also related to visibility challenges on loading units in the current freight logistics. Goel (2008) elaborated the visibility challenge with two characteristics of supply chains: (1) asset hierarchy and (2) multiple actors (Goel, 2008). A container can have hierarchical relations with its contents through several times of bundling operations. That is, goods with different origins can be packed together as a shipment, and the shipment can be grouped with other shipments into the container as described in Figure 1.2. Although items are encapsulated twice in Figure 1.2, the number of encapsulation can be more in practice.
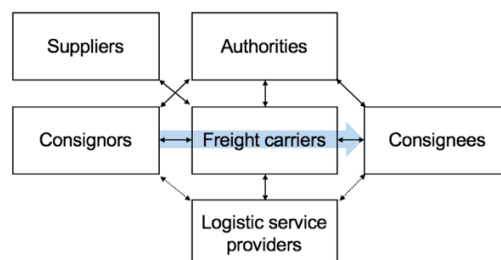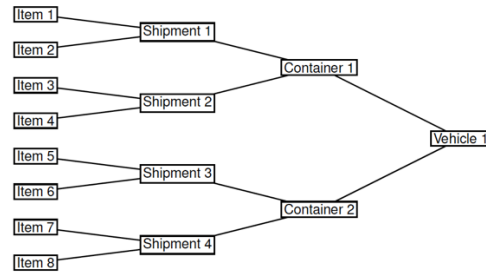
Figure 1.2 Overview of logistics process with main actors
(Stefansson & Woxenius, 2007; Tseng, Yue, Taylor, 2005)

As a result, some actors in the logistics chain can have difficulty to access information regarding shipments or items in lower levels of containers, and ultimately they cannot use the visible information for advanced packing of not only containers, but also items and shipments. Another threat is involvement of multiple actors in the logistics chain. Each actor might require and generate diverse information while performing different roles in the chain. Hence, it is difficult to align informational requirements between actors and information visibility on containers cannot be exchanged seamlessly.

Rönkkö et al (2007) proposed an entity-centric approach, also known as entity-based, to improve visibility in logistics information systems (LIS). The data model built with entity-centric information system mainly concerns a single material unit by focusing events with the viewpoint of each material. Contrastively, location-based design applied in many modern industries focuses on locations and transactions between locations by exchanging messages between different places along with operations. That is, location-based information systems can have difficulties to link transaction data based on locations of individual material units.

To sum up, insufficient standards on loading units in the recent freight logistics can lower space utilization of the loading units and decrease their visibility. Irregular shapes of the loading units leave empty space in shipping containers which requires additional costs for further handling operations. Therefore, consignors remain empty space in shipping containers on purpose by selecting FCL logistics to avoid additional costs in less-than-container loading (LCL) logistics. Moreover, contents of loading units in the current logistics chains are hardly transparent with a single level of loading units (i.e., pallets). That is, it is difficult to know what is inside in boxes loaded in pallets because of a number of encapsulation operations and diverse actors involved in the chains. Additionally, the primary focus in capturing logistics information is location, not loading units. The stretched standards into the lower levels of loading units will be capable of not only reducing waste space in freights, but also designing information flows to track and trace freights in logistics chains with consideration of logistic operations and actors.

1.1 Potential Solution: Physical Internet

Professor Benoit Montreuil has introduced Physical Internet (PI, π) as a potential solution for the current issues in freight logistics. The PI is a globally open system that aims at universal interconnectivity in physical, operational, and digital aspects within and among logistics systems (Figure 1.3). For its ultimate goal, the PI has been established with three main ideas: encapsulation, interface, and protocols. The existing logistics components have been newly defining under the visions of the PI.
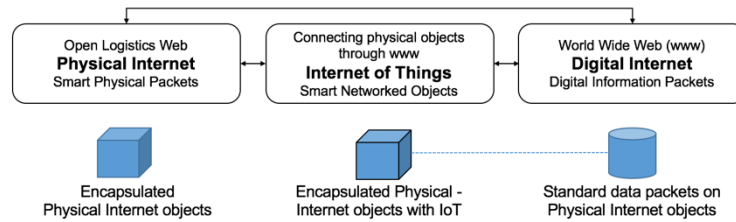
Figure 1.3 Concept of the Physical Internet (Adapted from Montreuil, 2010)

In-line with the vision of encapsulation, PI has devised new loading units by a layer-based approach, "PI container," called π-container or modular containers. Contrast to a single level of loading units in the current status, π-containers are composed of three layers of loading units: (1) packaging container, (2) handling container, and (3) transport container. Moreover, PI has suggested the open interface and global protocols which help to interconnect not only all levels of modular containers, but also other logistics entities with each other. Section 2.3.2 covers detailed explanation of π-container along interface and protocol of PI.

1.2 Research Scope

This research project focuses on the parts of the PI' components rather than all of them, which is beyond the scope of this study because of their diversity. For the selection of key PI elements in this project, the knowledge gap mentioned above are mainly concerned with both the physical and internet aspects of the PI. Another concern is the scope of a logistics system in maritime logistics that is composed of diverse logistics systems and their sub-systems. Hence, this chapter will define the main building blocks of PI in this project and discuss the specific scope in maritime chains by considering the nature of logistics systems.

1.2.1 Main Building Blocks of PI

First of all, in this project modular containers are considered the primary operational objects as potential loading units in a PI system. Moreover, this project is based on two other components of PI to come up with information flows on the modular containers. Details on each component are elaborated in Section 2.3.2.

The second element is an PI open interface platform where all information in PI system are collected from diverse actors in logistics chains. PI defines the open interface as an intercommunication channel enabling logistics service markets to be open at global scale. This project commits to acknowledge contents of information on modular containers which will be shared in the platform.

The third and last component is the global protocol in PI. Global protocols are interpreted as the global cooperation of actors to implement the PI system. This project in particular deals with mutual agreements on information accessibility which should be reached in collaboration with various actors within the PI open interface. Toward this end, actors need to take account of operational interdependencies with other actors in focusing on modular containers in this project. Figure 1.4 summarizes the main building blocks of PI, hereafter the three PI's components in this project stand for modular containers, the open interface web, and global protocols.
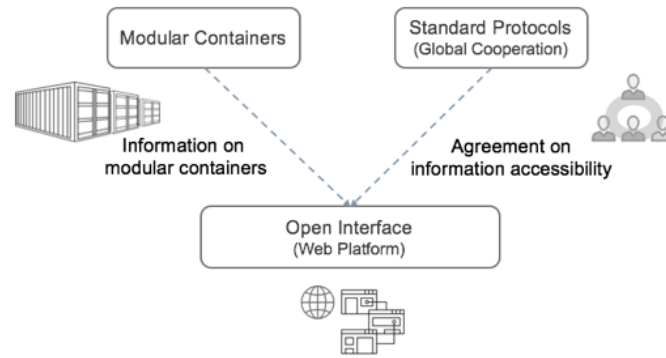
Figure 1.4 Three main building blocks of PI in this project

1.2.2 Tracking & Tracing System in Port Terminals

This project has focused on marine port terminals with their potentials to expand operational roles in maritime logistics through modular containers. A newly-coined word "maritime logistics," is introduced by combining containerized maritime transport and logistics (Panayides, 2006). The word represents maritime transport and entails the requirements of logistics and customer satisfaction, in keeping its original need for transporting goods between ports across the sea. The logistic requirement can be fulfilled by various value-added services (VAS).

This trend of maritime logistics has applied to port terminals which are recently in the spotlight with the increasing demand for international shipping. Port-centric logistics (PCL) is one of the successful cases that move the VAS used to be done by warehousing or distribution centers to departure ports (Waal, 2013). This project found a design space for modular containers from the fundamental VAS in PCL, that is consolidation and deconsolidation of loading units. The (de)consolidation operation deals with different levels of loading units, hence it is suitable to represent uses of modular containers to improve space utilization on loading units and the visibility of their contents. The (de)consolidation operation can be named repositioning operation in this project.

The visibility of the loading units is the primary concern of tracking and tracing (T&T) module in a terminal operating system (TOS). TOS is the specific logistics information system (LIS) in the context of ports, enabling for planning and monitoring transportation activities on shipments. That is, information on modular containers will be handled in T&T module of TOS.

However, information on modular containers will be related to not only T&T system in ports but also other LISs in various logistics sites because of the nature of logistics systems. In a logistics system, diverse actors operate their LISs, and these LISs can interoperate to aggregate information on freights. However, some actors might have more authority on the information according to their roles in the logistics chain. This makes LISs have hierarchical structures; LISs at low levels supply their data to the top-level LISs (Wang et al., 2009). Therefore, the top-tier LIS can receive necessary information from sub-LISs to perform its function.
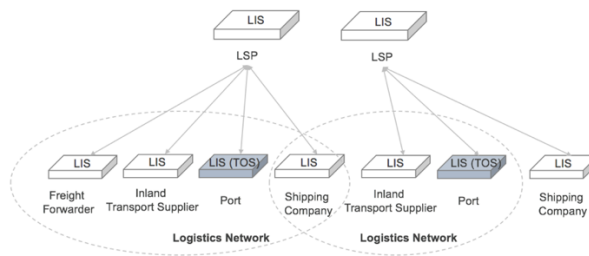
Figure 1.5 Research scope (Adapted from Wang et al., 2009; Woo et al., 2009)

In summary, information flows on the modular containers are interdependent on various LISs in the logistics system. This project is dedicated to exploring information flows on modular containers in a local LIS of ports, explicitly T&T module in TOS (Figure 1.5). Nevertheless, a design of information flows on TOS can include interactions with external LISs to either receive or provide the necessary information. The author of this project hereafter calls T&T module in TOS to T&T system.

1.3 Core Knowledge Gap

There are still barriers to implement modular containers in practical, even though it seems they have potentials to solve the current issues in loading units. The core research gap can be formulated based on the research scope:

How can information flows on modular containers be designed to improve visibility

on loading units in (de)composition operations within ports?

The conceptual design in this project is twofold, firstly with the operational aspect and secondly with the information as aspect. Most existing research on PI has been done in the operational perspective by presenting physical characteristics of its each component. For instance, dimensions, and functionalities of modular containers.

However, the information perspective in the conceptual design is still lacking. Consequentially, it is not clear how information should be formulated between modular containers and logistics entities in the PI system (i.e., open interface, and global protocol). Generally, a design of information flows is an essential part of system implementation. It is more important in the system that requires advanced interconnections between physical objects, as in PI. The is because the design clarifies which physical objects should turn into information sources and how the information sources should be bound with each other through information flows. As for the project, PI needs an information flow design on modular containers to use them for improving space utilization on loading units and increasing visibility of their contents, shipments.

1.4 Research Objectives

This research project aims for representing potentials of new three-layered loading units, namely modular containers, in an improvement of space utilization on freights. This project will attempt to align the possibilities of the new loading units with the current business needs in ports for VAS—repositioning operation in this project. Additionally, the project considers the modular containers as not only physical assets in logistics operations but also informational sources to improve the visibility of freights in logistics chains. That is, this project needs to explore how the loading units in three layers

can be adjusted with the existing information exchange models. And what are information flows required for the original business need in ports?

For this, the project needs to suggest a tentative design of PI ports based on the three primary building blocks in PI: (1) modular containers, (2) open interface web, and (3) global protocols. The conceptual design needs to pre-visualize PI ports by a proper framework capable of reflecting both operational and informational aspect. With the operational viewpoint, potential deployment of the modular containers has been analyzed along with actors in maritime logistics. More importantly, this project proposes information flows in T&T system of ports by comparing alternatives on information exchange between LISs in a logistics system.

At first, this project sets a framework for the design of PI ports. The design framework also enables modern ports described in many works of literature today to be visualized in aligning logistics operations into activities of T&T systems and their information flows. The model on modern ports shows design rooms for potential uses of the three PI's elements. Based on the current model, realistic use-case on PI ports can be devised using the three PI's components. Finally, this project establishes the tentative design of PI ports by deciding between design alternatives of the PI's elements.

Research objectives in this project have been summarized with the following bullet points:

- Explore a design framework capable of representing not only logistics operations of ports, but also activities and information flow in their T&T system for the visibility of shipments.
- Visualize modern ports documented in literature through the design framework.
- Investigate a potential use case of the three PI components in-line with the trends of ports.
- Analyze alternatives for system integration between the PI open interface and T&T system in ports, and determine the most suitable design.
- Generate a tentative design of PI ports with the focus on the three PI elements in the design framework.

1.5 Research Question

The following research questions can be formulated to achieve research objectives. The three PI's elements stand for modular containers, open interface web, and global protocol.

How can information flows on modular containers be designed with the help of the PI open interface and global protocols to improve visibility on loading units in (de)composition operations within ports?

The main research can be well answered with three sub-questions:

1. How the current state of the T&T system in modern ports can be presented in the design framework?
   1.1 Which design framework can represent ports both in logistics operations and T&T system?
   1.2 Which logistic entities are important for activities in T&T systems of modern ports?
   1.3 Which informational flows in the T&T systems are required for the main operation?
   1.4 What is the primary operational process of modern ports?

2. Which requirements should be considered for the T&T systems of PI ports?
   2.1 What are operational and informational use case of the PI's components in PI ports?
   2.2 What are requirements on the three PI's components in PI ports?

2.3 What are limitations of the use case considered in a design of PI ports?

3. How a conceptual design of PI ports can be presented in the design framework with th
    ree PI elements?
    3.1 What are alternatives in the design of PI ports and which alternative is selected?
    3.2 Which logistic entities are important for activities in T&T systems of PI ports?
    3.3 Which informational flows in the T&T systems are required for repositioning operatio
        -ns?
    3.4 What is the primary operational process of PI ports?

1.6 Research Methodology

A freight logistics system is a typical large-scale engineering system that consists of various functional subsystems and stakeholders at the macro level (DAG & Ethic, 2000). Therefore, this project can be conducted by system engineering specialized in defining, realizing, and deploying systems (Sage et al., 2000). This project can use V-Model to formulate the entire process. Besides, this project needs complimentary research methods not only to structure each phase of V-Model with a logistical and consistent view but also to accomplish a different goal of each phase. Appropriate design tools have been applied to visualize the result of each stage in V-Model.

In this chapter, the author has briefly elaborated on the use of V-Model, and moreover, the author has included a short explanation of complementary research methodologies on each phase of V-Model, i.e., RAMI 4.0 for the first and third steps and requirement engineering process for its second phase. More precisely, the third phase in V-Model (system architecture) is comprise of two sub-phases: preliminary conceptual design and conceptual design. However, this chapter has given the overview of research methodology, therefore all details on the methods tools are explained in Chapter 3.

Three phases in V-Model have guided this project: (1) conceptual development, (2) requirement engineering, and (3) system architecture. The reasoning behind this decision is twofold. Firstly, V-Model explicitly differentiates a conceptual implementation of a system from its practical implementation. The conceptual design corresponds to the three phases of V-Model in this project except for the actual implementation which is described in the vertex in Figure 1.6. This is because this project perceives the importance of a conceptual implementation in large-scale engineering systems due to the enormous scale that might require massive investments as the systems practically are implemented (DAG & Ethic, 2000). PI, the desired system at the global level, also has difficulties to be executed because of expected investment as well as incomplete research. Therefore, this project has been carried by phases of conceptual implementation in V-Model.

Secondly, V-Model is suitable for software-related projects transposed to T&T system of ports in this project. The software has been developed by the V-Model because of its capability to verify and test its progress in each phase. As a result, V-Model is relatively flexible on changes compared to a waterfall model. Although the verification and test are out of the scope of the project, this project opens the possibility of changes in ports' operations, and consequently, information flows in their T&T system.

Details on the three phases in V-Model have been elaborated in Section 3.1.
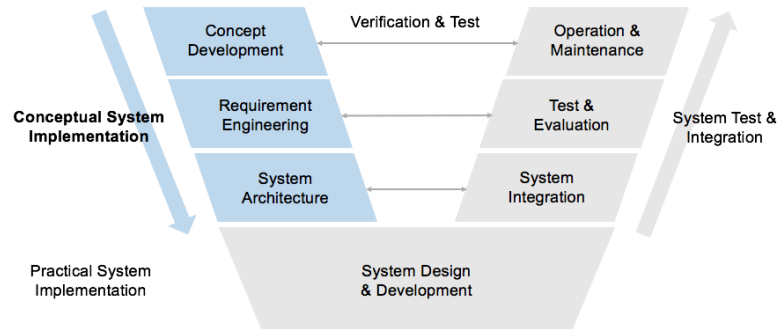
Figure 1.6 V-Model for the project structure (Adapted from The MITRE Corporation, n.d.)

1.6.1 RAMI 4.0

Reference Architecture Model for Industry 4.0 (RAIM 4.0) complements the first and third phases in V-Model by offering a solid structure for the analysis of ports each in terms of current state and PI. The structure in this project consists of four layers (i.e., business, function, information, asset layer) based on layers and hierarchy levels in RAMI 4.0. The solid structure helps this project to have a logistical and consistent view on the two models.

The reason why the project has used RMAI 4.0 is its possibilities to reflect interconnected LISs in hierarchical relations as described in Section 1.3.2. RAMI 4.0 has been developed for manufacturing systems whose physical objects are interconnected with each other by Internet of Things (IoT) technologies. In order for better understanding on the interconnectivity, RAMI 4.0 are built with three-dimensional coordinates: layer, lifecycle, and value system and the hierarchy layer (Figure 1.7). Hence, this project has used RAMI 4.0 to describe ports in a variety of perspectives by considering interactions between its T&T system and other LISs in a logistics chain.

The way that this project has adjusted RMAI 4.0 is covered in Section 3.1.1.
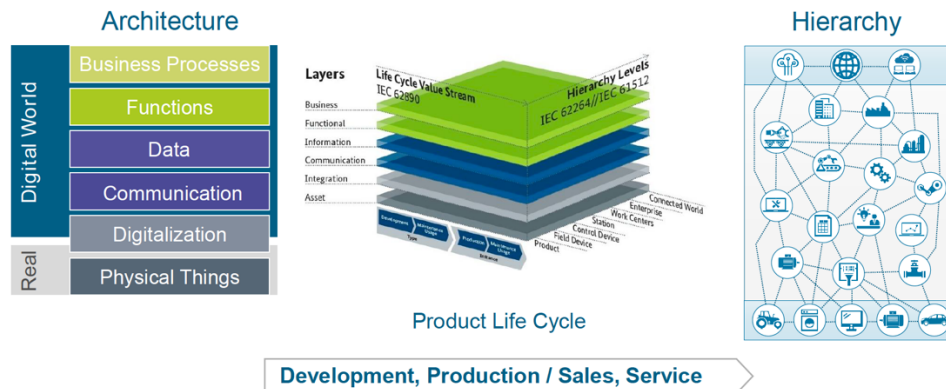
Figure 1.7 Reference Architecture Model for Industry 4.0, RAMI 4.0 (Hankel, 2016)

1.6.2 Requirement Engineering Process

To move forward with a conceptual design, the second phase of this project can be clarified by the requirement engineering process, as seen in Figure 1.8. Requirement engineering is discipline in which the requirements of a system's objects are regarded as sub-fields of a system development process (Agarwal, Tayal & Gupta, 2010). However, all phases of the requirement engineering process are beyond of the research scope of this project because this project concentrates on the visualization of a conceptual design of a T&T system for ports, not the documentation of requirements. In particular, this project exploited a use case for the two phases of requirement elicitation and analysis, termed

design tool. The detailed method with which to elicit and analyze requirements is explained in Section 3.1.2.

Figure 1.8 Requirement engineering process (Agarwal, Tayal & Gupta, 2010)

Table 1.1 summarizes research methodologies by matching them into corresponding research objectives and questions.

Table 1.1 Summary of research methodology

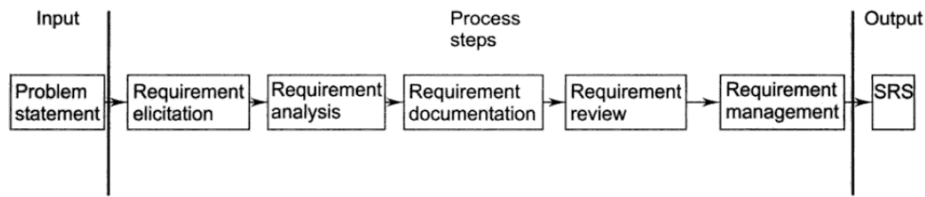| Research Objective	# Research Question	Research Method
Explore a design framework capable of representing not only logistics operations of ports, but also activities and information flows in their T&T system	1.1	RAMI 4.0
Visualize modern ports written in literature by means of the design framework	1.2- 1.4	Design tool conformed in the adjusted RAMI 4.0
Investigate a potential use case of the three PI's components in-line with the trends of ports	2.1- 2.3	Use-case-driven requirement engineering
Analyze alternatives for system integration between the PI open interface and T&T system in ports, and determine the best design.	3.1	Preliminary conceptual design based on multiple attribute utility theory
Design a tentative design of PI ports with the focus on the three PI's elements in the design framework	3.1-3.4	Design tool conformed in the adjusted RAMI 4.0

1.7 Research Contribution

This project contributes to complete a conceptual design of PI by filling the gap on the information perspective. That is, this project suggests information flows on modular containers complemented by the PI open interface web and global protocols. This main finding of this project carries critical meanings concerning both logistics industry and the PI academia.

Frist of all, the complete conceptual design helps to accelerate implementation of modular containers in practical cases. As a result, the logistics industry can increase the space utilization of loading units by exploiting modular containers. Additionally, each loading will be visible in a logistics chain through its information flows design. In-line with PI's visions, logistics industry can lead economic, societal, and environmental benefits. Furthermore, modular containers applied in practical cases can make the implementation of other PI elements smooth, by gradually connecting with them.

This project offers a practical guideline on PI for port-related actors. Especially, port authorities and operators can identify not only new business opportunities and the critical actors in information exchange. Besides, port-related actors, such as shipping companies, LIS, and inland transport suppliers, can also prepare the future implementation of PI and changes in maritime logistics. They can devise their strategies, roles, and relationships with ports or even new opportunities from PI components.

More academically, this work can be considered as further study of Modulushca project. The Modulushca project is one of few research with the information perspective, this further study can be more meaningful. This project allows the Modulushca common data model to stretch to modular containers in all tiers. Moreover, this project adjusted the work in Modulushca project in the context of ports by aligning with the idea of open interface web and global protocols. Taking a more long-term view, this project can be parts of the entire information architecture in PI that include a collection of appropriate information flows in diverse business cases and actors.

This thesis contributes to clarify the concept of the PI open interface web that is hardly researched in PI. The current literature on PCS has been heavily analyzed as a corresponding idea to the PI open interface. Although the PCS started from a port-centric concept, it has a similar vision of PI in that both systems aim for the interconnectivity between actors in maritime logistics. Therefore, the idea of PCS is aligned within the context of PI, and this thesis suggested the PI open interface as the multilateral message exchange platform.

As the last contribution, this project proposes a design framework in aligning RAMI 4.0 with PI. The design framework visualizes the conceptual implementation of PI's elements in diverse aspects. Therefore, future research can reuse the design framework in implementation of other components. Even, this project can be inspiration on the research, exploring the optimized framework for PI.

1.8 Thesis Outline

Starting from the current issues on freights, this project is structured according to the project process: (1) conceptual development, (2) requirement engineering, and (3) system architecture. Prior to the beginning, this project has reviewed relevant research mainly in terms of maritime logistics, LIS, and PI in Chapter 2. As one of primary research methods, RAMI 4.0 has been adjusted into PI in Chapter 3. On the basis three inputs (introduction, literature review, and research methodology), the current analysis of logistics systems is described in the RAMI 4.0 model in Chapter 4. In Chapter 5, a potential use case with three PI components represents requirements for PI ports. Finally, a conceptual design on PI ports is proposed in Chapter 6 in compliance with RAMI 4.0 as in the current model of modern ports. Then, the project been concluded in Chapter 7. The overview of the project outline is illustrated in Figure 1.9.

Chapter 1

Introduction

Chapter 2

Literature Review

Chapter 3

Research Methodology

Current issues on freights
- Waste of space on loading units
- Lack of visibility on shipments

Preliminary acknowledgement
- Maritime logistics
- Logistics Information System
- Physical Internet

Research methods
- V-Model with RAMI 4.0 & Requirement engineering

Conceptual design

Modern ports

Use Case of PI Ports

Design of PI ports

Conclusion

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Current model
- Asset layer
- Information layer
- Functional layer
- Business layer

Use case of PI
- Modular containers
- Open interface
- Global protocols

Conceptual Model
- Asset layer
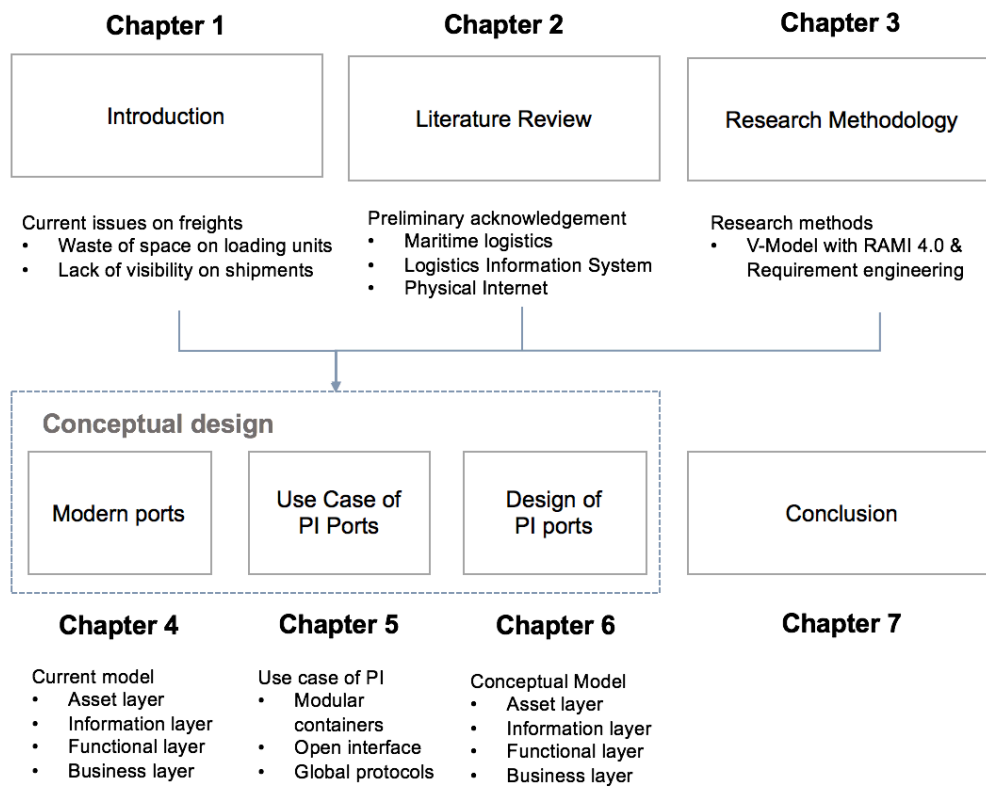- Information layer
- Functional layer
- Business layer

Figure 1.9 Thesis outline

2

Literature Review

In-line with the research method document analysis, this chapter contains a scientific literature review. The literature on the most relevant fields are covered to address critical issues of freight logistics in the research: (1) maritime logistics, (2) logistics information system, and (3) physical internet. These reviews help to capture backgrounds of the major issues in freights logistics, and the scientific knowledge is used as significant sources for the models each about the current port systems and PI ports.

2.1 Maritime Logistics

Due to the increasing demand for global transport, maritime transport has become important in the freight logistics industry since it is the most appropriate mode of transport for international shipping (Panayides, 2006; Song & Panayides, 2012). In the beginning, the concept of maritime transport was primarily limited to transportation between ports, whereas flows of shipments in ports were distinguished as elements of logistics. However, the fields of maritime and logistics can be integrated while maritime transport involves multimodal transportation from the sea to land. The choice of intermodal modes was originally an activity of logistics, but it can be a critical performance of maritime transports considered as efficient distribution of freights into appropriate modes (Brooks, 1999).

Under the convergence of maritime transport and logistics, a new term, "maritime logistics," was created by integrating the goals of the two areas: port-to-port transportation and flows of shipments in a supply chain. As critical interfaces in maritime logistics, ports are a regional scope in this project. To apply the PI to ports, it is necessary to acknowledge recent trends and their functions in port logistics chains, governance, layout, and operation.

2.1.1 Maritime Logistics Process

Although the detailed operations of maritime logistics are discussed later in Section 2.1.2, the whole process can be covered by a helicopter view, as shown in Figure 2.1. As vital logistics hubs, two port terminals can be linked to each other by waterborne transport. One can be called to an origin port or a departure port, which exports shipments from the consignors' side. The shipments are imported by a destination port on other side of the water body. The incoming shipments in the arrival port can be called inbound shipments.

Besides ports, the logistics chain can include additional logistics sites where cargo go through for any reason. However, agreement on a term is not yet reached in recent literature to refer the logistics points, such as freight forwarding centers, and distribution centers. This project herein tentatively names the logistics sites to "logistics centers" including ports.
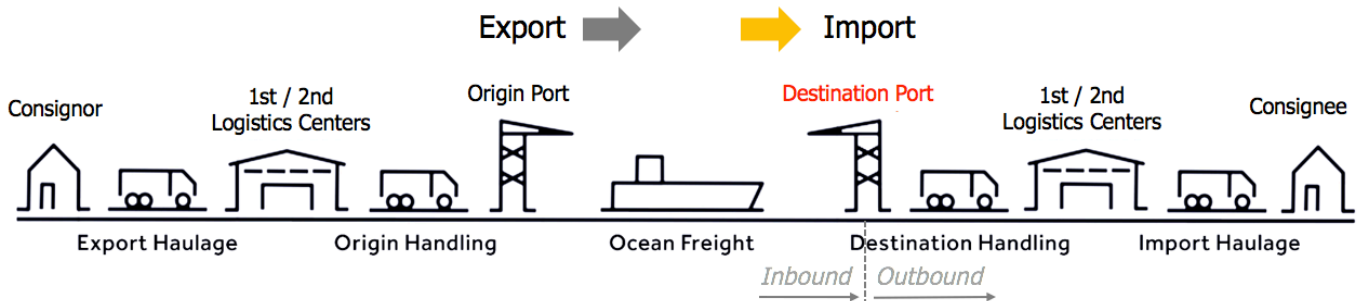

Figure 2.1 Maritime logistics process

In this project, ports will signify the destination ports, and consequently, T&T system stands for that of the destination ports. This is because modern ports have found more business opportunities from downstream logistics chains than their upstream processes (Montwiłł, 2014). The trend has been elaborated in more detail in Section 2.1.3.

2.1.2 Ports in Maritime Logistics

Shipments in a logistics chain go through appropriate operation activities by obtaining additional characteristics, functionality, or form on the previous one (Berglund, 2000). Those activities are called value-added service (VAS).

A lot of works in existing literature have used VAS to categorize logistic centers according to what extent that logistic centers include VAS. Grundey (2007) categorize logistic centers into six categories: logistics nodes, logistics centers (not the same as the provisional term used in this project), freight villages, transport terminals, distribution centers, and warehouses. Seaports and large-scale terminals fall within logistics nodes. This decreases their functions from the large-scale integration of transportation modes within the logistics node to storing cargo in warehouses. More importantly to this project, Higgins et al. (2012) described international seaports as the most outstanding logistics center—mainport terminal—because of their advanced capabilities of VAS, scales, and cargo capacities.

The analysis on logistics centers shows ports' importance in maritime logistics by classifying them as the most advanced logistics centers. For the big leverage, ports should have diverse capabilities in VAS activities, infrastructure and supra-structure, dimension, and cargo capacity in ports. However, not all of ports are available to offer the best level of logistics services, described as in logistics node or mainport terminal. Therefore, there are various efforts of ports to extend their capabilities in modern ports, elaborated in the next section. Before that, operations in modern ports have been briefly covered behind.

Modern ports are generally used as transshipping points by linking between the sea and land as seen ports' layout in Figure 2.2. The main operation operation can be captured at a glance through their layout. Most literature can be compared by describing a port into several regional segments: ship to shore, waterside transfer points, storage area, and landside transfer points (Brinkmann, 2011;

Gharehgozli et al., 2014; Kemme, 2013; Meersmans, 2002; Cheng et al., 2005). Although some authors add facilities of VAS in layouts, such as Container Freight Station, depot, maintaining and repairing area, but fundamental facilities will be firstly explained along with operations.

Port operation processes can give insights on the current functionalities of ports in maritime logistics as main contents of the Business Layer on modern ports. Along with the current processes, novel operations in PI ports can be conceived by adding reconsolidation operations in the light of uses of PI's components.
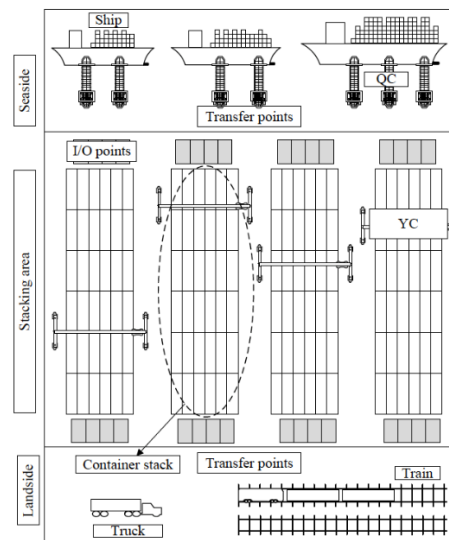

Figure 2.2 General layout of ports (Gharehgozli et al., 2014)

2.1.3 Trends in Ports

Veenstra and Zuidwijk (2010) took notice of the gate of ports possible due to the cooperation with other ports and transport suppliers. The authors propose the concept of "extended gate," literally meaning the physical expansion of port gates to hinterland ports or distribution centers. The physical expansion implies extensions of the roles of ports in managing the modal shift toward hinterland ports and additional services in the ports. For example, the Port of Rotterdam is developing a web platform called Navigate (Navigate, 2017) that allows customers to search for proper intermodal transport methods depending on departure, destination, and VAS. Through this platform, the Port of Rotterdam can benefit by offering smooth transfers, and consequently, hinterland ports can easily attract customers from the port. Although the main purpose of the extended gate is to explore multimodal networks rather than VASs, the expansion of gates can be a good starting point in the cooperation between ports and hinterland ports. Considering this proactive attitude of ports, it will be worth considering ports to be the first movers in applying PI components.

Port-Centric Logistics

A generation model of ports has similarities with defining logistics centers into diverse categories, as discussed in Appendix B, in that ports can be classified with specific standards. One of differences is that the port generation model only deals with ports, not other logistics centers. However, it is noticeable that the desired ports in the generation model are intended to approximate main port terminals (Higgins et al., 2012) as new ports emerge.

Verhoeven (2010) suggests a port model that is divided into three generations. Among them, the third generation of ports (3GP) can be led by two main factors, global containerization and intermodal

transportation between 90 and 20s. The ports need to guarantee continuous flows of shipments by offering handling services and transportation modes that link the sea and the land. VASs in this period can be enhanced through the uses of modern equipment and IT on ships, vehicles, and cargo, such as the decomposition of containers, electric administrative services, and customs clearance.

Some authors highlight the importance of united management within fourth generation ports (4GPs) because the expansion of VASs requires cooperation between actors and, consequently, tightens their relationships. Therefore, a common operator, a port operator, for example, can manage the cooperation between the related facilities and actors within a 4GP (Pettit & Beresford, 2009).

Lee et al. (2015) focus on ITs in fifth generation ports (5GPs). The authors compare features of IT in 4GPs to those in in 5GPs. In 4GPs, IT is dedicated to providing cargo clearance and tracking services, whereas 5GPs have one stop services by means of a single window for information exchange about tracking, containers, and performance measurement (Lee et al., 2015). The single service point of 5GPs can be applied into implementation of the PI open interface by fulfilling its vision to become an open logistics market.

PCL is an idea that has recently appeared in maritime logistics. Managan et al. (2008) defined it as providing distribution and other VASs in logistics at ports. VASs at ports enable logistics networks to be simple without the necessity of stopping by other logistics centers for VASs. Although it can be in contract with current logistics systems that are used in distribution centers and other similar logistics centers to decrease the congestion of ports, if ports have VAS capacities, then PCL can be a potential solution to minimizing the complexities of logistics networks.

In the context both of 4GP and PCL, Montwiłł (2014) expected inland-sided operations in ports are the new core business due to various potentials on VAL, including consolidation and deconsolidation of containers in this project. Figure 2.4 describes ports' functionalities both in seaside and landside with the focus on business opportunities of landside in ports (UNCTAD, 2004). Additionally, the figure shows potential interlinks from ports directly to an urban area through VAL performed by ports.
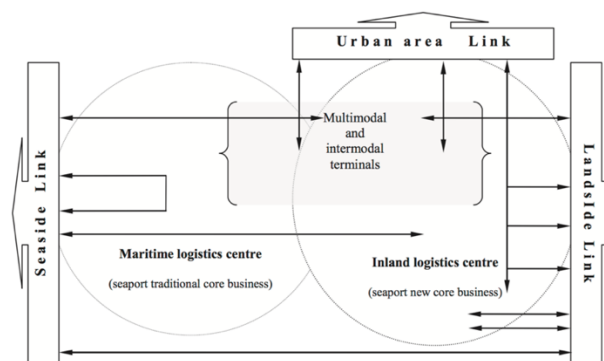
Figure 2.3 Potential of seaports (UNCTAD, 2004)

This project is aware of business opportunities for destination ports through providing logistics services often done by other logistics centers in downstream logistics processes. Therefore, the project will conceptually implement three-layered loading units (i.e., modular containers) in a new VAS of ports, repositioning operation. Although the repositioning operation might have been performed in some ports, this project considers most ports mainly deal with transshipping operation with shipping containers.

2.1.4 Freight Consolidation

Repositioning operations are the main tasks of freight forwarding centers and distribution centers in current logistics chains. Therefore, this project can heavily refer a process of repositioning operation from current distribution centers when moving the operation in the context of ports. Figure 2.2 represents the entire process on freight consolidation (Wu, 2013).

Figure 2.4 Freight consolidation process (Adapted from Wu, 2013)

In the current freight forwarding center and distribution centers, shipments can be composed and decomposed several times within a logistics chain when the expected benefi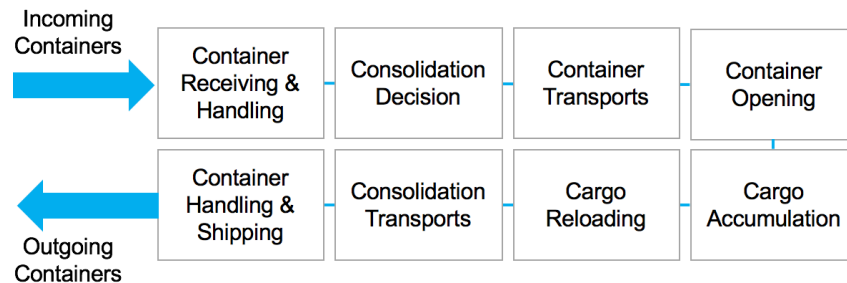ts from the operation outweighs its costs. However, what is the meaning of freight consolidation in current logistics and in this project?

According to the research on cargo consolidation, the process can decrease the number of outbound containers through the improved space utilization of containers, which has several benefits: (1) less demands on container transports, (2) a reduction in the number of movements of empty containers, and (3) improved processing for urgent freights.

At first, outgoing containers have a direct influence on the quantity of transportation modes. Hence, if the number of containers is reduced, then there is less need for intermodal transportation as well. As a result, the consolidation process can mitigate negative impacts such as road congestion and environmental contamination. Another issue in logistics chains is the fact that repositioning empty containers accounts for 15% of all container movements, costing around $20 billion a year worldwide according to the Boston Consulting Group (Veenstra, 2005; Whiteman, 2016). Furthermore, it is expected that the cost of moving empty containers can be dramatically reduced thorough freight consolidation. The last expected advantage of freight consolidation is the flexibility in-process of urgent freights. Freight consolidation can be used sort freights depending on shipping specifications, time in this context, and consequently, urgent freights can be moved by trucks capable of fast delivery, whereas for non-urgent freights, it is suitable to use barges or trains that are affordable, slightly slow, and clean transportation modes.

The benefits from freight consolidation seem like be in-line with one of visions of PI, sustainability. However, this project highlights the relation between the freight consolidation and the visibility of containers as well as space utilization of containers. The operation deals with various transportation units not only containers but also smaller units than containers under the principle of encapsulation. That is, the operation might lead unnecessary space of containers while encapsulating groups of small transportation units into shipping containers. Moreover, the operation on freight consolidation generates information on asset hierarchy between containers and their contents inside. This information should be visible to track and trace an individual shipment. Additionally, this information on contents of containers can be combined with detailed information of each content, (i.e., the next destination and time window) for repositioning containers in the context of this project.

2.1.5 Port Governance & Stakeholders

Ports bridged ships and the shore to transfer containerized shipments (Goss, 1990; Kim & Günther, 2006). Besides their main function, each port may have different capabilities in terms of operations and services to create diverse value through its governance structure and various types of cooperation.

Ports can be governed in different manners depending on the extent to which they rely on public and private properties (Suykens & Van DE Voorde, 1998; Fiedler, 2016). Fiedler (2016) summarizes several structures of port governance in accordance with the ownership of infrastructures, supra-structures, and port operation management, as seen in Table 2.1.

For the subdivision, the author differentiated port components into two categories: infrastructure and supra-structure (Fiedler, 2016). Port infrastructure consists of physical and fixed technical facilities used for the transportation and handling of logistic entities within seaports, such as quay walls, terminal areas, and rail tracks. Supra-structure is generally regarded to include surface apparatus and supplementary equipment, such as cranes, handling equipment, and internal transport vehicles.

Table 2.1 Port governance (Fiedler, 2016)

Types of governance	Public service port	Tool port	Landlord port	Corporate port	Private service port
Infrastructure	Public	Public	Public	Mostly private but own by public	Private
Supra-structure	Public	Public	Private	Mostly private but own by public	Private
Port operation management	Public	Private	Private	Mostly private but own by public	Private

Facing competition in terms of port performance, ports are willing to contract with private terminal operators that favor investments in the supra-structures of seaports (Heaver, 1995; Heaver et al., 2000). As a result, a governance structure of the landlord port is pervasive in current ports under diverse types of cooperation (Fiedler, 2016). The cooperation can be related to the shared accessibility of services, infrastructure, and supra-structure in a freight village, as mentioned in the previous section.

Generally, logistics services can be completed with the cooperation of diverse actors within a logistics chain who aim to achieve their own interests, such as consignors, carriers, logistics service providers, suppliers, and authorities, as mentioned in the introduction. With ports as the regional scope in this project, actor involvement needs to be aligned with the context of maritime logistics along its overall process, as mentioned in Section 2.1.1.

Actor analysis in this project can be dispensable since actors within a maritime logistics chain are potential users of T&T systems, to either receive or provide information that is necessary to their

operations. Furthermore, each actor might be interested in different contents of information in an appropriated form, depending on their operational roles, which is discussed in Section 2.2.2.

Table 2.2 Actor analysis in ports (Adopted from H.R.P.C. Van Hövell tot Westerflier, 2009)

Actor	Description	Possible Resource
Consignor	A consignor creates orders on shipments to Freight Forwarder or Third-Party Logistics (3PL) Provider.	• Production line • Contracts with Freight Forwarders or 3PL Provider
Freight Forwarder /Third-Party Logistics Provider (3PL)	As an intermediary, Freight Forwarder or 3PL Provider organizes appropriate plans for consignors' transportation needs under contracts with carriers and other stakeholders of logistics services. In particular, 3PL Provider is capable of supporting entire supply chains with not only shipping, but warehousing, handling, decomposing services.	• Managerial knowledge on supply chain and logistics • Contracts with transport suppliers
Carrier (Shipping company)	Carriers transfers containers across deep sea based on Freight Forwarder or 3PL Provider.	• Deep sea vessels
Terminal operator (Stevedore)	Once vessels of carrier arrive at ports, terminal operator is in charge of handling containers including stevedoring.	• Infrastructure • Supra-structure
Port Authorities	Port authorities can take responsibilities on all or parts of operations, administration, and construction of ports depending on governance structure of ports. As main roles, they can be a landlord of a private port terminals or they can be an operator by doing port terminals' roles themselves.	• Infrastructure • Supra-structure
Inland Transport Operator	Inland transport operator provides interconnection transportation modes between ports to inland logistics centers generally by barge, rail, and trucks.	• Fleet of barge • Trucks • Rail
Inland Terminal Operator	Inland terminal operator can offer various VASs depending on the final destination and specifications of shipments.	• Terminal • Fleet of barge • Trucks
Local Transporter	A local transporter generally provide trucking transportation between inland terminal and the final destination (i.e., the consignee).	• Truck
Consignee	As the endpoint of logistics service, the consignee receives the shipment from the consignor.	-

These operational and informational dependencies between actors will be changed with the application of PI components in ports. Therefore, ports in the PI environment can require new

collaborative relationships and agreements known as standard protocols, one of the key PI elements in this project.

In Table 2.2, the actors in maritime logistics are covered concerning their primary roles and possible resources, even though their resources can be different according to different types of cooperation and individual capabilities (Heaver et al., 2000). The relationships and resources of the actors can help to analyze information flows between them.

2.2 Logistics Information System

Plenty of researchers accept the value of information and IT within logistics systems (Zuidwijk & Veenstra, 2014; Asadi, 2011; Elkington, 2004). Logistic systems are capable of offering advanced functionalities through information and IT, such as transaction management, system control, tactical planning, and strategic planning. Behind these functionalities, the LIS within logistics systems is working to bind all system constituents of logistic operations by using data or information as a dispensable resource.

2.2.1 Overview of Logistics Information System

General knowledge on T&T technologies can help with the comprehension of how T&T systems interact with various information systems in the entire logistics systems. Li, Cao, and Xu (2016) present a whole logistics system for tracing containers with the viewpoint of an operator on in-transit visibility (ITV). The framework in Figure 2.5 focuses on interactions between sensors on containers and information systems through wire-less communication technologies, such as general packet radio service (GPRS) and internet.

Briefly, containers can be identified within a logistics chain, probably either in a transportation mode or in logistics center. The perception layer depicts this identification process with a perception device (PD) that has a positioning antenna (PA) and multi-sensor detection unit (MsDU). The MsDU recognizes the status information of containers or the contents inside of containers, while the PA tracks transportation routes. The information is updated with their physical movements and transmitted to a variety of system applications to be used for user requests for visibility. Networking technologies (i.e., GPRS and the internet) need to be applied to interlink the physical and application layers.

More importantly, ports' T&T system can be corresponded to one information system in the perception layer of the framework, even though the framework has not described. Along with operations in ports, their T&T system can interexchange information on freights with other information systems represented in the application layers. For example, LSP's logistics information systems within the scope of this project.
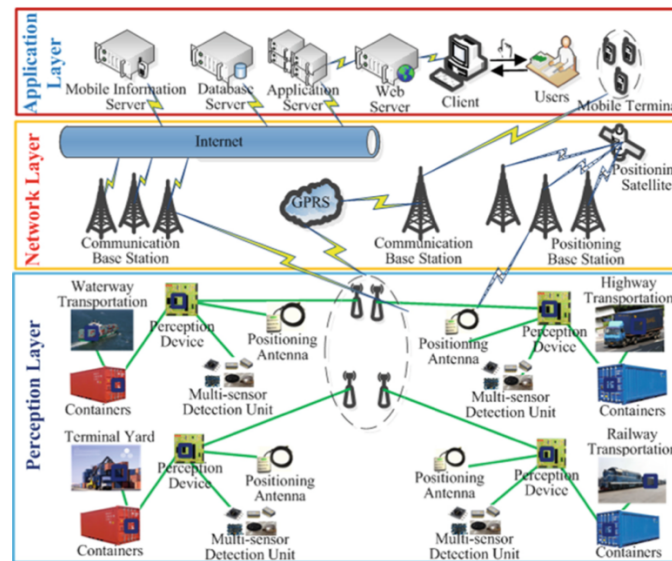
Figure 2.5 Overview of in-transit status perception device architecture (Li, Cao, & Xu, 2016)

2.2.2 Terminal Operating System

As sub-systems of a logistics system, LISs are established with diverse components according to users and their logistic roles. The LISs can be differently called, for example terminal operating system (TOS) for the LIS in ports. This section has reviewed functional components in LISs and mainly covered the structure of TOS in-line with this project scope.

Asadi (2011) researches the general structure of LISs with three components: inputs, databases, and outputs. In the input phase, data is collected from logistic entities and transferred in diverse forms to the LIS. Then, raw data is stored in the database in which the raw data is processed as useful information and knowledge. On the basis of the results of this data processing, the LIS can contact customers as its ultimate output.

Frazelle (2011) categorizes LISs into several modules, depending on their principal functions, as follows:

- Customer Response System (CRS)
- Supply Management System (SMS)
- Warehouse Management System (WMS)
- Inventory Management System (IMS)
- Transportation Management System (TMS)

In general, an order management system (OMS) contains CRS and SMS by processing orders from both customers and other stakeholders within a supply chain as the front-end system of an LIS. Moreover, IMS can be operated in WMS, where inventory operations are mainly dealt with, such as receiving, discharging, and managing inventories. Therefore, it can be concluded that LIS consists of three modules: OMS, WMS, and TMS. Consistent to this project, TMS is in charge of planning and managing inbound and outbound transportation from the selection of transport modes, routing and planning shipments, and tracking them. However, all modules in an LIS are interdependent on one another in terms of information. For instance, TMS can monitor the flows of a container on the basis of customers' orders, and its movement can affect the level of inventories in a warehouse.

More specifically, every port terminal has been using Terminal Operating System (TOS) that is aligned with port operations while having similar functionalities with TMS, that is tracking the flow of container throughout all operations within ports (National Academies of Sciences, Engineering, and Medicine, 2011).

Figure 2.6 shows a general organization of information system in a port terminal by means of TOS. Each operation area in ports consists of its corresponding system as seen in the second layer of Figure 2.6 (i.e., maritime system, yard system, and gate system. These sub-systems not only manage information on the execution of each operation but also collect and update results of the operation.
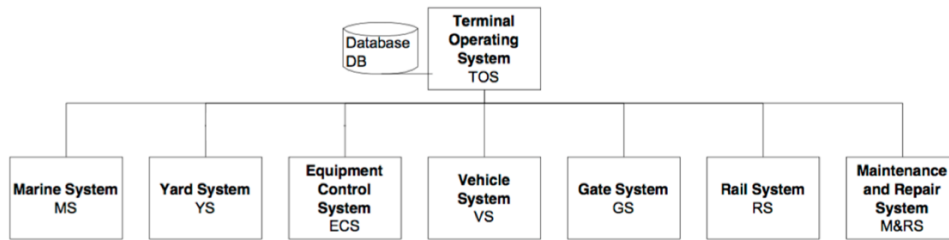

Figure 2.6 General organization on terminal operating system (Abajo, 2009)

T&T in this project can be seen as the part of TOS in which recording the operating activities on containers are considered as the main tasks.

2.2.3 Track & Trace System in Terminal Operating System

Although the two terms "track" and "trace" seem similar, the difference between them in T&T systems is evident. In T&T systems, tracking is a functionality with which to determine the current state of logistics entities at any point of a logistics chain, whereas the tracing function can determine the historical states of the logistics entities on the basis of accumulated tracking data that changes along with logistics operations. As seen in Figure 2.7, the terms can be clear with time dimension of past, present, and future corresponding to trace, track, and predict, respectively.
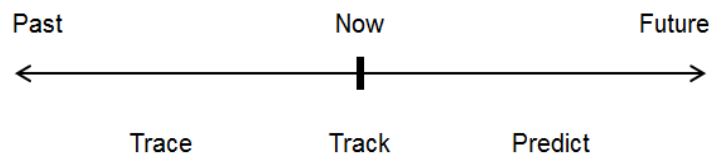
Figure 2.7 Track and Trace time dimension (Goel, 2008)

Besides the time dimension, the tracking and tracing functions can be performed either internally in a local logistics system or across the entire logistics chain, as mentioned in Section 1.5.3. This project focuses on the viewpoint of internal T&T systems in ports along with coordinated LIS at high levels.

Current uses of T&T System & Structure

Kärkkäinen et al. (2004) found that current tracking systems in most of the practical cases are operated by a logistics service provider (LSP), even though some of them rely on tracking service providers that specialize in tracking services. In most tracking systems, proprietary number identifiers are used, and these numbers are recognized by the predominant technology—barcoding.

This tracking information, currently manually collected, is gathered in a central information system that is owned by the provider of the tracking services. Explaining in more details with port operations, clerks in port gate determine whether inbounding containers correspond with their manifest, and manually enter information of the containers with confirmation (National Academies of Sciences, Engineering, and Medicine, 2011). Other actors can access the information through the centralized information system through manual queries through interfaces or integrated system. Hence, in this project, the LSP is the critical actor for current ports and port authorities.

Lee et al. (2002) researched a technical structure of a T&T system that was implemented in the form of a web portal, as seen in Figure 2.8. Even though the final deliverable of this project is not a logistics web service for a T&T system, the structure of a T&T system shows how requests for tracking and tracking logistics entities are processed from front-end applications to T&T systems that are linked to other modules of an LIS.

Requests for tracking and tracing logistics entities can be created by customers in a logistics web portal. Then the internal interface analyzes the requests and sends request messages through a tracking or tracking engine by using message transport system (MTS). Before sending the messages, the T&T manager will check whether clients are qualified to access the information. As a core function of a T&T system, a tracing engine provides tracing information by classifying it as either a finished or in-process trade based on trading information tracked by the tracking engine. For example, order numbers, item information, customer information, and transport fee. A tracking and tracing engine can access to TMS or other LIS modules to gather necessary data when creating tracking and tracing information following customer requests. These transactions that occur in tracking and tracing engines are stored in T&T databases.

Figure 2.8 T&T system structure (Lee et al., 2002)

Ahn (2005) also visualizes a mechanism of web-based logistics T&T systems whereby a database structure needed for the web portal is briefly covered. The author distinguishes databases based on their main contents as follows: carrier DB, container DB, consignee DB, tracking DB, GIS DB, weather DB, and operating information DB. Then these data sources can be accessed via the internet with the permission of the information providers.

Limitations of T&T system in modern ports
Issues of T&T systems in ports can be summarized into two bullet points based on the analysis on their current application in practice:

(1) Manual access on external information
(2) Visibility challenges on loading units caused by several reasons:
    • Repeated composing operations on shipping items

- Multiple actors involved in logistics chains
- Location-focused information exchange rather than loading units

The author of this project has been herein elaborated the two primary issues one by one. Firstly, current T&T systems in ports send manual database queries to LSP's centralized information system by demand on information on containers. A question that may have jumped is—isn't it possible to directly access to information on containers through radio frequency identification (RFID) tags pervasively attached on containers? The question implies RFID technologies allow people to acquire information on container without their manual interventions by storing the information into RFID tags (Jerry et al., 2007).

In order to retrieve the information from RFID tags, ports should equip the RFID reader in the same radio frequency with its tags. However, this seems difficult because there is no a single standard on RFID technologies, which mean ports need various types of RFID readers to handle containers forwarded by different shippers. Therefore, this project will explore the efficient way of information exchange on modular containers in the PI open interface.

The work by Goel (2008) explained the lack of visibility has occurred because of asset hierarchy in shipments involved with various actors in logistics chains. In the chains, logistics assets can be consolidated and deconsolidated by forming hierarchical relationships between the assets. Thus, this physical hierarchy should be recognized in informational associations. Moreover, the hierarchy should be considered for interoperability with other logistics entities, as well as requests for specific information from actors in logistics chains. That is, some logistic entities need to be linked to consolidated containers but others to individual consignments. Actors may also have different interest regarding the entities and their data.

Rönkkö et al. (2007) pointed out a conventional location-based design applied in many current information systems complicates track and trace individual products in the context of an enterprise. The location-based design is built around locations and transactions between different locations in an operating sequence. These drawbacks in location-based design can be coupled with asset hierarchy. The authors found materials in an enterprise are often handled in a lot, a unit of transportation. Thus, information on individual materials in the lot are supposed to be anonymous in the enterprise information system. When the idea of the lot is transposed to containers consistent with this project, the visibility on individual containers might be unavailable within the location-based design.

In contrast to location-based design, the authors suggested an alternative approach in enterprise information system with entity-centric data model by focusing materials flows instead of locations. In-line with this project, it is expected the use of modular containers bring forth superior visibility on containers by enabling the entity-centric design in a T&T system of a port.

2.2.4 Main Concerns in Track & Trace System

Well-designed T&T systems hardly have limitations regarding visibility. Kärkkäinen et al. (2004) propose primary considerations about T&T system. The authors analyze practical cases to represent how tracking systems have been operated in multi-company networks. Then the authors elicit the requirements of T&T systems that require the prior consent of stakeholders. The requirements are given as follows:

- Main operator of systems
- Asset identification technologies
- The use of codes on tracking items

- **Information architecture on locations and ownership of databases**
- **Contents of tracking information to be shared**

- Technologies of accessing tracking information

This project more highlights information architecture and contents of information for new loading units, (i.e., modular containers) than other technical concerns. This is because information technologies already exist and just need to be applied through alignment between PI's elements and an appropriate information architecture. In-line with research gaps of this project, the project is dedicated to defining contents of information on the modular containers required in repositioning operations within ports. In addition, the proper information architecture has been discussed to suggest a proper method to share the contents in PI system in the viewpoint of PI ports.

Related works on Information Architecture

Various research has suggested new information architectures in different context aiming for efficiency in logistics chains. The work in the study has been foundations of this project for exploring uses of PI's components in ports because the research has been already validated with various pilot projects in Europe.

ARKTRANS is a Norwegian ITS framework architecture for multimodal freight. The framework allows transport sectors to explore IT solutions with a generic, nevertheless diverse viewpoints. More importantly, ARKTRANS project has been structured in a similar approach with this project. ARKTRANS project was established in a hierarchical framework in technical, logistical, and conceptual level from the bottom. The reference model in the conceptual level gives overviews of information systems with relations between sub-systems. In the next level, function and information flow in the information systems have been suggested by UML, structure and class diagram respectively.

e-Freight explored a paperless process of co-modal transport in the context of the air cargo industry by means of information exchange among relevant actors in in a single point. For what we are interested, the project is involved with a blueprint of LIS, namely the reference model, also known as the common framework, which describes informational interactions between different functional domains in transport and logistics (Takis, 2012).

More comprehensive than e-Freight, iCargo aimed at building an open information architecture for efficient and sustainable cooperation in logistics services. iCargo has been interpreted by two perspectives each fro business and technical context (Dalmolen et al., 2012). Concerning in this project, the reference value chain in the business viewpoint was defined with diverse actors' roles based on their business needs and benefits in logistics chains.

These business visions in the reference model have been aligned to technical visions consisting of common semantic framework, virtualization of information, and entity-centric-approach. The work in technical visions has defined an architecture of information exchange to represent the way of interactions between various actors in the reference value chain with the help of interfaces for different systems of actors.

Related work on Contents of Information

Some authors deeply explore the LIS at the information level rather than from a holistic point of view of its structure and architecture. The literature on the content of information is a valuable source for the asset and information layer, both in the current analysis and the conceptual design of the project. This is because the literature can help this project to recognize critical logistics entities and specific information under operational and informational dependencies between actors.

Grabara et al. (2014) briefly explain the essential elements of logistics, such as transportation costs, the types of shipments and their quantities, transportation modes, and the physical parameters of shipments, to support transportation activities. Then they suggest prerequisite information to realize the transportation process.

- Information on the selected transportation mode
- Information on physical parameters of shipments (size, quantity, weight, height, type)
- Information consignors and consignees (name, organization name, address)
- Time information on dispatch and receipt

Besides this basic information, Marcario and Reis (2008) analyze different types of "data" along each phase of the logistic process. As a trigger, a logistic operation requires relevant data in accordance with each functionality. Details on sorts of data are elaborated on in Table2.4.

Klievink et al. (2012) analyze data sources depending on the operational roles of the actors involved in a maritime logistics chain. More related to repositioning operations in ports in the project, a consignor knows about goods better than anyone involved in the logistics chain. That is, they have the original packing lists of goods with the right to make decisions to disclose the information to others.

As another significant type of data, information about the consolidation or deconsolidation of shipments before reaching a port of departure should be considered (Hesketh, 2010). Shipments from diverse consignors can be enveloped into containers to take advantages of containerization, such as economies of scale, handling automation, and security. During containerization, new packing lists on containers are generated.

The figure by Klievink et al. (2012) is adjusted with the containerization operation highly occurs in inland port as follows. In Figure 2.9, the main interesting data related to consolidation and deconsolidation operations in this project is highlighted as yellow boxes.
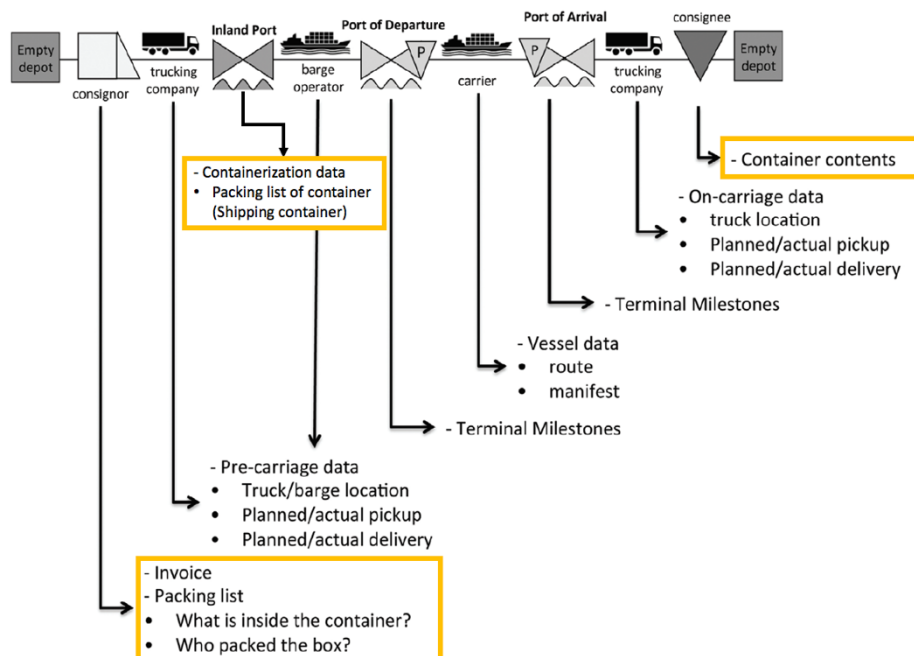

Figure 2.9 Data sources in a logistics chain (Adopted from Klievink et al., 2012)

Each actor involved in a logistics chain is particularly interested in specific parts of the logistics information depending on the assigned functionalities in the chain. Hence, current logistics chains

have different access restrictions for each actor, as shown in Figure 2.10. When it comes to this project, it is noticeable that freight forwarders share their information, including consolidation or deconsolidation information on shipments, under regional restriction with the boundary of waterborne transport. That is, information from the exporting freight forwarder is not shared with the port of arrival, hence the arrival port is hardly capable of repositioning operations without information of contents of shipments.

However, the recent market study by Langley (2016) represents global 3PLs might relieve the geographical challenge on information by providing various services on a worldwide scale. According to the research, shippers more rely on 3PL for international trades, expressed in 60% of shippers outsourcing global transportation through 3PL, 66% for warehousing, and 48 % for freight forwarding. Hence, many services of 3PL have been internationalizing and expending over national borders, for example, UPS, FedEx, DHL and Penske Logistics. Whereas, the author distinguished freight forwarders from the large global 3PLs, as termed by regional full-service providers. The current situation has been reflected in Figure 2.10 with the global 3PL accessible to the full range of information in a maritime logistics chain.

This limited information accessibility can be interpreted with different levels of port community systems, ultimately aiming for the situation every actor in logistics chains can communicate with one another and exchange proper information at a single point regardless of geographical locations. Currently, the third level of port community systems has been developed in enabling port-related actors to transfer documents in electronic forms. Whereas, information exchange in the entire logistics chains is available in the next levels of port community systems that are still being researched and developed. Details of port community systems are covered in Section 5.2.
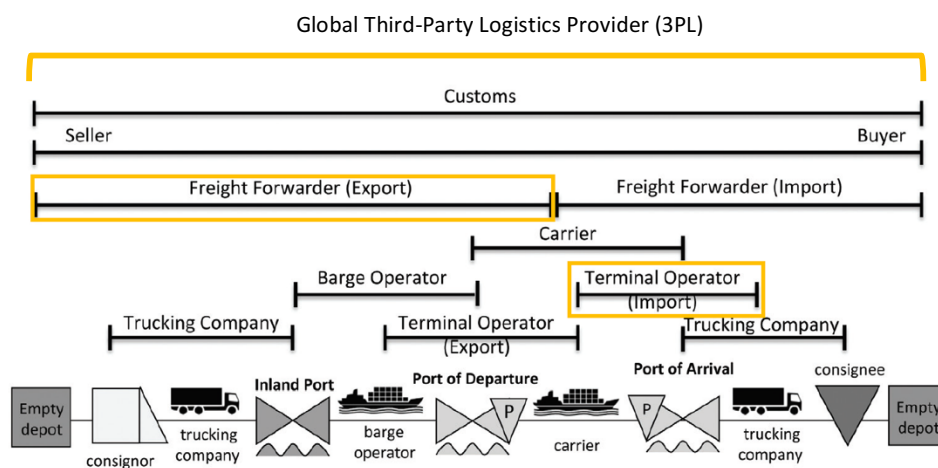

Figure 2.10 Data visibility in a logistics chain (Adopted from Klievink et al., 2012)

This project envisions ports' T&T systems in the PI in accordance with the recent trends of ports in maritime logistics. On behalf of the trends, potential VAS, namely composition and decomposition operations, are the primary object of observation in PI ports' T&T systems. Hence, the operational changes at ports will especially affect the contents of tracking information that is exchanged in logistics chains. That is, PI ports require alterations on information architecture with different informational involvement levels of actors as well as different ownership and locations on databases.

2.3 Physical Internet

The idea of PI has been herein elaborated from its foundation. The three main PI components in this research have been analyzed in the light of their new visions compared to existing logistics systems. Concerning the significant issues in freight logistics, potential changes in loading units have been highlighted. More importantly, the primary source, Modulushca project, has been profoundly reviewed as the preceding project of this research.

2.3.1 Physical Internet Foundations

As known from the word itself, the PI is based on metaphor to reshape existing logistics system with the characteristics of the internet. In this section, the author elaborates on the foundation of PI to explore analogies between the internet and logistics by matching their components, as expressed through different terminologies.

Montreuil et al. (2012) define PI as a logistics system that is capable of being accessed by all stakeholders in a logistics chain at a global scale. The authors also suggest a framework of PI foundations representing PI's building blocks and their relationships in several layers as seen in Figure 2.11.

At the core of a PI system, there are fundamental goals of efficiency and sustainability in economy, environment, and society. As mentioned with specific monetary and emissions figures in Section 1.1, logistics systems have negatively impacted the economy, environment, and society (Montreuil et al., 2012). Although all aspects are intertwined with one another, each can be led by relatively dominant factors. Depending on the factors, the efficiency and sustainability can be differently interpreted to efficiently and sustainably guide physical objects. From an economic perspective, logistics wastes within a logistics chain need to be reduced to improve productivity and, consequently, the competitive positions of corporations and countries. Sustainability in logistics systems can be achieved through the minimum use of unrenewable energy and materials that contribute to environmental pollution. Work conditions within a PI can become efficient through frequently changing shifts in society. Moreover, the PI can relieve congestion by offering efficient and sustainable transport services within society.

To meet these goals, interconnectivity at the physical, operational, and digital levels is a prerequisite for the use of encapsulation, interfaces, and protocols. Physical interconnectivity stands for consistent flows of logistics entities within a logistics chain. Logistics operation processes should be bound to the business processes of PI users who provide logistics services through the PI to their logistics customers. Also, seamless flows of information within a logistics system enable every logistics entity, for instance, involved actors and logistics constituents, to be visible and help support decisions and actions.
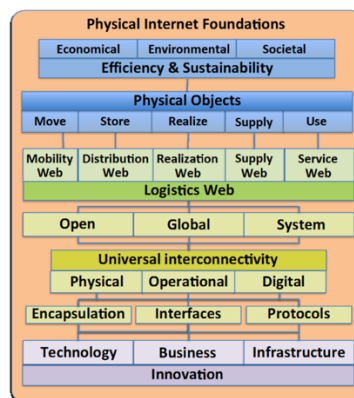

Figure 2.11 Physical internet foundations (Montreuil et al., 2012)

Three components—encapsulation, interfaces, and protocols—can be considered to be the core concepts of both interconnectivity and the overall PI environment. They can be practicable on the basis of the support of innovative technologies, business strategies, and infrastructures. Each constituent is defined and elaborated on in the context of the internet and through the metaphor, as described in the next subsection.

Metaphor

In computer networks, a computer from one network can transfer data to another computer in a different network. The computers connected to neighbor networks are called routers. Routers are composed of various layers of protocols: application, presentation, session, transport, network, data link, and physical layers.

In the transmission of data, the data passes through the protocols while becoming enveloped with additional data. Once arriving at the destination computer, the data moves back up the protocols by being stripped off a layer one-by-one. In different protocol layers, the data has other names, for example, *data* in the first three layers, *segment* in the transport layer, *packet* in the network layer, *frame* in the data link layer, and *bits* in the last tier—the physical layer.

In logistics systems, a consignor can send his or her shipments to a consignee via logistics nodes. Applying this transmission mechanism in a PI, routers transpose to the logistics nodes, π-nodes in the PI, where all shipment operations, such as loading, sorting, handling, composing, and decomposing, can occur (Sarrai et al., 2014). Moreover, the nodes are interlinked with other logistics nodes concerning the transport of shipments toward a final destination. Similar to the data in computer networks, the shipments are encapsulated in standardized modular containers in the PI, π-containers, within the logistics nodes. Table 2.3 summarizes the analogies between the internet and PI networks.

Table 2.3 Analogies between the internet and PI networks (Sarrai et al., 2014)

Network	Internet	Physical Internet
Transport unit	Packet	π-container
Node	Router	π-nodes
	Host	Consignor/ consignee
Arc	Wire/ wireless connection	Transport services

On the basis of the metaphor mentioned above, three critical components of PI can be well acknowledged. Encapsulation is one of the fundamental functions of a PI with standardized modular containers. Similar to data in computer networks, various types of π-containers can be chosen with proper composition and decomposition procedures in π-nodes.

2.3.2 Novel Visions in Physical Internet

This subsection determines and elaborates four foundations that might differentiate the PI from conventional logistics systems: (1) global open logistics Web, (2) encapsulation, and (3) interfaces, and (4) protocol.

Global open logistics Web

PI has defined a terminology of logistics Web—a collection of interconnected actors, entities, and networks, offering logistics services by being differentiated from digital web platform (Montreuil et al., 2012). More importantly, the logistics Web includes the core idea of the open system in PI. That is, the open logistics Web allows freights can be handled in the efficient manner by exploiting various

logistics services without restrictions of geography and capacities of a single logistics center. As a result, the freights can arrive at the final destination in an optimal network, including their production, storage, deployment in markets to transport.

According to logistics services that the logistics Web offers, the Web can be classified into four categories (Montreuil, Rougès, and Cimon et al., 2012):

- Mobility Web: providing transportation modes with multimodal capacities.
- Distribution Web: offering storage locations, for example warehouses and distribution centers.
- Realization Web: embeds manufacturing capacities
- Supply Web: procuring materials for manufacturing and transport

Encapsulation (Modular containers)

Important to this project, Montreuil et al. (2015) devise three modular containers as part of the LIBCHIP project (transport, handling, and packaging containers) based on their previous research on dimensional and functional specifications on logistic entities (Montreuil, 2011 and Montreuil et al., 2010).

The modular containers enable goods to be wrapped in packing, handling, and transport containers in sequence. Packaging containers (P-containers) directly enclose and protect the physical objects in the innermost composition. In turn, the P-containers or goods can be covered by handling containers (H-containers, or π-boxes), designed for use in handling and operations within the PI. Hence, the design of H-containers is suitable to apply π-handlers, for example, conveying systems or lifts. Lastly, the outermost containers, called transport containers or T-containers, are functionally similar to shipping containers currently used. Although the purposes of both containers are the same regarding easiness to carry and stability from external disturbances, T-containers are devised with more restrict and diverse dimensional standards than existing shipping containers.

Each container's specifications are covered in Table 2.4.

Table 2.4 Types of modular containers (Adopted from Krommenacker et al., 2016)

Tier of modular container	Specifications
Transport container (T-container)	External dimensions should comply with unitary dimension specifications – 1.2m, 2.4m, 3.6m, 4.8m, 6m or 12m. The widths and heights of containers need to be either 1.2m or 2.4m.
Handling container (H-container)	External modular dimensions need to be 50%, 40%, 30%, 20%, or 10% of 1.2m.
Packaging container (P-container)	There are no precise dimensional specifications for these containers, but they should be light and thin.

Interfaces

On the contrary, interfaces in PI are relatively more complicated rather than those of the internet. Data transfer only demands wire or wireless connections to bind different computers by being expressed in arcs in computer networks. Meanwhile, the PI system needs to consider both physical interfaces and information and communication (I&C) interfaces to provide transport services. Montreuil et al. (2012) distinguish physical interfaces from I&C interfaces as seen in Table 2.5.

Table 2.5 PI interfaces (Adopted from Montreuil et al., 2012)

Types of interface	Level of interface	Interface
Physical (operational) interfaces	Low	Complementary physical fixtures that allow π-containers to interlock with one another, and to be suspended to storage structure.
	High	Logistics π-nodes that is available for smooth logistics services (e.g. transfer from unimodal to multimodal transportations) by appropriately allocating freights within PI.
Information & communication (I&C) interfaces	Low	Smart tags on π-containers capable of identification, routing, traceability, conditioning of each modular containers.
	High	Digital middleware platforms that provide an open market for logistics services in PI by connecting human and PI's components.

Protocols

In computer networks, there is a collection of agreements on the procedures of transmitting data called the communication protocol. When the data passes through all protocol stacks for the transmission, as mentioned above, each layer can encapsulate the data by using different protocols, depending on its functionalities. A PI can have logistics networks through collaborative agreements between a variety of actors in logistics chains. PI protocols ensure not only the integration of logistics entities but also their performance in π-networks. Furthermore, they are dedicated to managing the resilience and reliability of π-networks.

2.3.3 Overview on PI Components

PI consists of three primary types of components: (1) π-container, (2) π-nodes, and (3) π-movers. In a nutshell, modular containers will be main loading units handled either by π-nodes consisting of locations, facilities, and diverse systems or by π-movers. Table xxx briefly represents the key types of PI's elements and parts of the elements related to repositioning operations in this project have been elaborated in more detail.

PI's components in this project require interoperations with other components. Although parts of elements in PI have been devised only, in theory, logistics facilities already used in the current systems have enough capabilities to substitute PI's components before full implementation of PI. However, it can be still worthy to analyze related PI's elements in repositioning operations because potential operators and authorities in PI ports can premeditate what they need for their new roles in PI environment. As a result, ports can have a better change to become a first mover of PI in maritime logistics.

More importantly to repositioning operations, several elements in PI have been elaborated except for three main building blocks of this project (i.e., modular containers, open interface, global protocol): π-conveyor, π-sorter, π-composer, and π-store. The necessary elements in repositioning operations in ports can be clarified based on the current processes for repositioning operations in distribution centers and research on PI initiatives (Wu, 2013; Montreuil et al., 2010).

Table 2.6 Key PI components (Montreuil et al., 2010)

Main category	Sub-category	Component	Description
π-container			Main loading units composed of packaging, handling, and transport containers
π-node		π-transits	π-nodes for transferring π-carriers from inbound to outbound π-vehicles
		π-switch	π-nodes for transferring π-containers by a singular π-mover
		π-bridge	π-nodes for transferring π-containers by multiple π-movers
		π-sorter	π-nodes for classifying π-containers in terms of exit points or specific order
		π-composer	π-nodes for designing composition of π-containers in accordance with a 3D layout
		π-store	π-nodes for storing π-containers during promised time, related to their stack orders and locations
		π-gateway	π-nodes for receiving and sending π-containers by reaching a private network
		π-hub	π-nodes for transferring π-containers from incoming to outgoing π-movers
π-movers	π-vehicle	• π-boat • π-locomotive • π-plane • π-lift • π-robot • π-truck	π-movers capable of being self-propelled to transport π-containers
	π-carrier	• π-trailer • π-tug • π-wagon	π-movers requiring the help of π-vehicles to be pushed or pulled
	π-conveyor		π-movers enabling for smooth flows of π-containers

PI Conveyor

π-conveyors enable modular containers continuously to flow by equipping rollers or belts to support them. In contrast with existing conveyors used in the current industries, π-conveyors were designed in compliance with standards of modular containers. Hence, π-conveyors may not have belts or rollers because of the interlocking functionality of the containers.

PI Sorter

π-sorters are specialized in sorting modular containers from one or the number of entry points and transporting them to a specific exit point for efficient movements of modular containers in operations. π-sorters can be built in matrix style by taking advantages from the modular dimensionality of π-containers.

In repositioning operations, π-sorters can be utilized when PI ports classify modular containers according to their next destinations and time window to leave port terminals as well as whether the containers need to be stored.

PI Composer

In-line with palletizers and de-palletizers, π-composers are in charge of creating composite π-containers. The composite π-containers may consist of sets of Packaging containers or Handling containers called to a Handling container or Transport container in the modular context. However, π-composers may differ from the current palletizers and de-palletizers in that π-composers are explicitly designed for π-containers capable of snapping with one another and unsnapping its smaller group of π-containers.

π-composers are a prerequisite in repositioning operations in PI ports as performing critical functions in the operations, that is fragmentation and defragmentation on modular containers.

PI Store

π-stores allows efficient storages by maximizing benefits of modularity on π-containers. That is, π-stores can stack π-containers stably or snap them into a grid by exploiting embedded fixtures on π-containers. Therefore, π-stores allows their users to manage π-containers individually, not as stock-keeping units (SKU) in the current logistics systems by reflecting time windows to be delivered.

Existing ports often embed storage yards for shipping containers where π-containers can also be stacked in case ports expands their roles by repositioning operations.

2.3.4 New Modularity on Physical Internet containers

This subsection is dedicated to identify novel points of modular containers in comparison with the current encapsulation in freight logistics. The project is based on the term modularity was used in reference to containers to depict that they are capable of being disassembled into several modules depending on different functionalities (Baldwin & Clark, 2002).

Conventional Encapsulation

Levinson (2013) elaborates on the origin of containers and the idea of containerization in his work. Back in the early 1950s, freights were handled piece-by-piece when loaded or unloaded to and from trains or trucks. With developments of transportation by trains, trucks where goods were encapsulated became the unit loads of trains. That is, there was no reason to unload goods from trucks to trains any more. Starting with the usage of the railcars, the usage of containers was proliferated because it led to efficiency in the freight transport process, requiring less manual activity than ever.

Despites their advantages, containers designed without standards cannot be interoperable with logistics facilities devised for different types of containers. To maximize the benefits of the containerization, standards for containers were formally set by the International Standards Organization (ISO) in the 1960s in terms of size, strength, and durability requirements. Currently, 20 or 40-foot containers are commonly used, even though some exceptional dimensions are used in different countries.

Goods in current logistics chains have went through several times of encapsulation by using diverse loading units. Figure 2.12 represents a possible encapsulation process on goods in five tiers whose details have been followed behind (Montreuil et al., 2015).
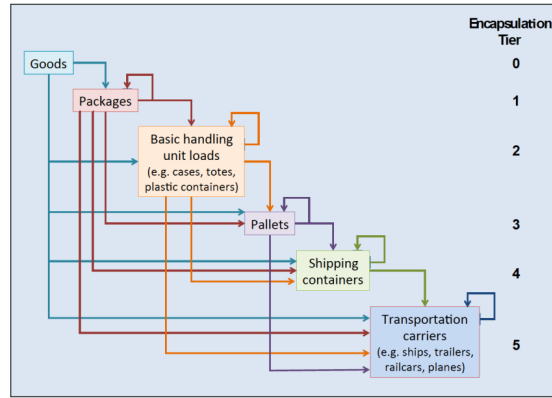
Figure 2.12 Current encapsulation process (Montreuil et al., 2015)

(1) Tier 1 (goods packaging): most goods in the first encapsulation tier have been placed in the basic selling units to customers.
(2) Tier 2 (basic handling unit loads): packaged goods in the fist tier are bundled into a basic handling unit, such as totes, cardboard boxes, containers.
(3) Tier 3 (palletizing): the basic handling units can be stabilized in their tridimensional packaging through pallets. In current freight logistics, pallets are considered as the most innovative invention for easy of handling multiple goods, boxes, other loading units.
(4) Tier 4 (Shipping containers): diverse types of loading units from previous tiers can be composed into shipping containers. The shipping containers, mostly 20 or 40-foot, protect their contents in harsh environmental conditions, such as ice, rain, and storms.
(5) Tier 5 (transportation carriers): a variety of transportation modes deal with the final encapsulation by loading goods so as to deliver them towards destinations.

It is noticeable there is no restrict standard on loading units in encapsulation tier. That is, goods can use different loading units in the encapsulation process, hence they have the level of encapsulation. For example, some goods can be directly loaded into transportation carriers as seen in Figure 2.13 (i.e. undergoing tier 0 and tier 5). Figure 2.14 depicts this variety possibility on encapsulation by a tangle of arrows across throughout the five tiers.

Figure 2.13 Example of encapsulation from Tier 0 to Tier 5 (Montreuil et al., 2015)

Encapsulation in Physical Internet
Lin et al. (2014) validated that the modular containers have positive impacts regarding the net space utilization. The result of a mathematical modeling research is that modular containers increase net space utilization compared, even though space utilization falls in container level. This is because the lower utilization in the container level can be compensated by the high utilization of items within

containers. As a result, modular containers can be used to transport shipments more efficiently than before.

The PI proposed an encapsulation process on goods by means of modular containers in Figure 2.14 corresponding to that of the current. Contrast to the current encapsulation, each modular container should comply with the sequence in encapsulation tiers from 1 to 3. That is, packaging containers are only allowed to be placed in handling containers then transport containers, whereas packages in the current encapsulation can skip some encapsulation stages to be loaded into shipping containers.
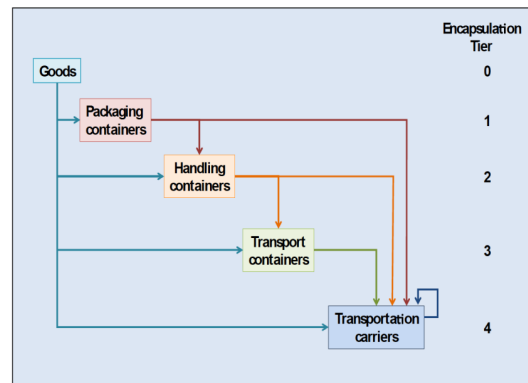
Figure 2.14 Current encapsulation process (Montreuil et al., 2015)

There are no precise dimensional specifications for these containers, but they should be light and thin.

(1) Tier 1 (packaging container): the first tier of encapsulation in PI is barely changed from the current. However, packaging containers should have marginal waste space and be light. And they should be loaded into either handling containers or transportation carriers under the reinforced modular handling process in PI.

(2) Tier 2 (handling container): handling containers (H-containers) are functionally in-line with the basic unit loads in the third tier of the current encapsulation. Contrast to the basic units, handling containers have dimensions uniformly scaled down from the next loading unit—transport containers. Additionally, handling containers can be stabilized by interlocking with one another without the help of pallets. Figure 2.15 virtually visualizes a bundle of handling containers.

(3) Tier 3 (transport container): transport containers (T-containers) are transposed to shipping containers in the fourth tier in the current encapsulation. Although both units have a similar function in protecting their contents from the external environment, T-containers can be structured in a variety of dimensions in compliance with PI's vision—sustainable, economical, and interconnected logistics.

(4) the basic handling units can be stabilized in their tridimensional packaging through pallets. In current freight logistics, pallets are considered as the most innovative invention for easy of handling multiple goods, boxes, other loading units.

(5) Tier 4 (transportation carriers): this tier is at the same level of the fifth tier in the current encapsulation.
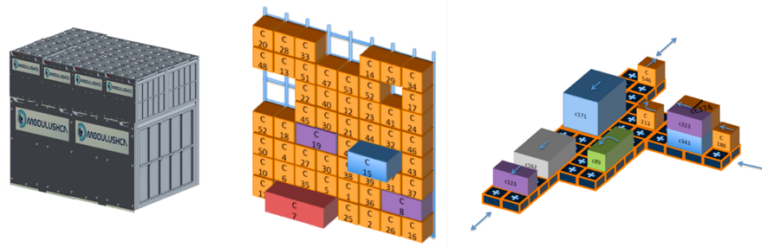
Figure 2.15 Interlocked handling containers as loading units, and their uses in handling processes (Adopted from Montreuil et al., 2015; Montreuil et al., 2010)

Comparison between the Current & PI encapsulation

The author in this project visualized both current and PI encapsulation with actual and conceptually designed loading units for a toothpaste. Figure 2.16 shows different loading units in all encapsulation tiers both in the current and PI. The potential composition of handling containers can be seen in Figure 2.15.
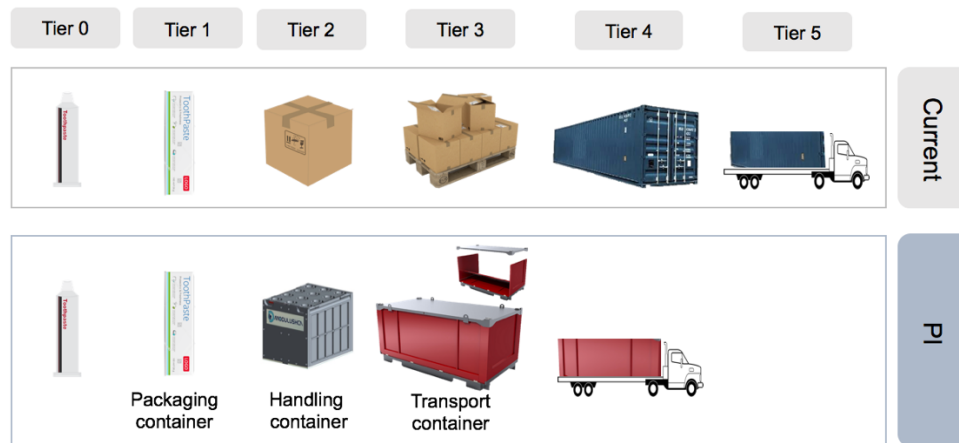

Figure 2.16 Comparison between the current and PI encapsulation based on realistic loading units (Adopted from Montreuil et al., 2015; Montreuil et al., 2010; Landschützer et al., 2015)

The PI indicates that the standards for containers that are currently used need to be tightened at the international level with a variety of dimensions. Previous research on the PI expect these restrictive but delicate standards to enable goods to fit containers with minimal storage space (Montreuil, 2011; Montreuil et al., 2010).

In the research, the term modularity was used in reference to containers to depict that they are capable of being disassembled into several modules depending on different functionalities (Baldwin & Clark, 2002). That is, π-containers can be divided into smaller units of several dimensions so smaller containers can be placed inside bigger ones (Montreuil, 2011; Montreuil et al., 2010). Research on modular containers has been done concerning the impacts of modularization, implementation design, and application.

2.3.5 Further Research on Modular Containers

As the first step of the realization of the PI initiative, the Modulushca project explored the possibility of interconnected logistics with a prototype of modular containers (i.e., handling containers). In the three-year project, researchers applied PI visions to practical cases of postal and fast-moving consumer goods in Europe (Modulushca, 2017). In the project, modular containers called M-boxes were designed with a focus on the lack of interoperability of subsystems, especially concerning packaging, pallets,

and transportation equipment. The authors consider M-boxes to solve the misfit issues of subsystems in terms of sizes and structural capabilities on the basis of standardized sizes and interlocking features.

The Modulushca project was guided by a simplified variation of the open logistics interconnection (OLI) model inspired by the open system interconnection (OSI) model and TCP/IP in the IT field. Similar to the OSI reference model, the OLI model conceptualizes logistics services within a PI through the use of seven layers: (1) the physical layer, (2) the link layer, (3) the network layer, (4) the routing layer, (5) the shipping layer, (6) the encapsulation layer, and (7) the logistics web layer (Montreuil et al., 2012).

The Modulushca project is primarily structured with the network and routing layers based on physical operations in the physical and link layers. The overall architecture of these three layers is described with business cases in Figure 2.17.
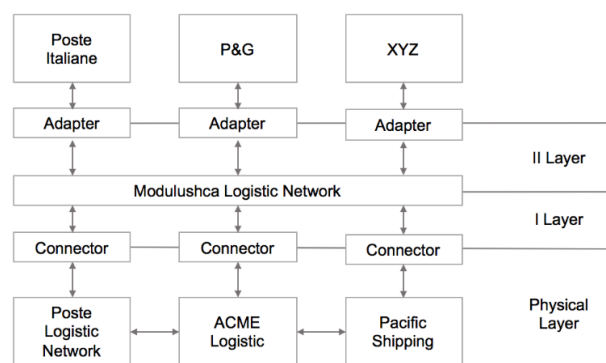

Figure 2.17 Vision of Modulushca architecture (Tretola, 2013)

The network layer, namely the I layer in the project, is a point where M-boxes are handled and transported in interfacing with existing logistics systems through connectors. Then, the M-boxes can be bundled depending on their next destination in the II layer of the routing layer. In the routing layer, adapters allow information in the semantic form to be complied with a specific actor's IT system (i.e., private IS) to be translated to the general language of Modulushca. Applying this architecture to postal logistics, a single item is handled with the management of the T&T systems in the first layer. Then the second level is supported by TMS and/or WMS to route consolidated postal items.

This project has been profoundly referred to as the Modulushca project for several reasons. First, the Modulushca project concentrated on the encapsulation of diverse visions of PI, as in this project. In addition, the Modulushca project is one of few preceding research studies with a focus on information flows about modular containers. Hence, the results of the project can be used as the important inputs of this project, particularly regarding the content of information and data accessibility regarding modular containers. Main results are herein briefly explained but details on how this project has adjusted Modulushca is covered with a potential use case in Chapter 5.

The work in Modulushca defined the Modulushca Common Data Model which classifies logistics information into four: M-box or public data, network flow, shipment flow, and business flow (Tretola, Biggi, & Verdino, 2015). The contents of information are elaborated on in each category in Table 2.7.

Table 2.7 Types of information of a logistics chain (Tretola, Biggi, & Verdino, 2015)

Types of information	Contents of information
M-box (Public) data	Unique Universal ID (UUID), size, weight, fragility, perishability, special environment(s)
Network flow	Global Identification Number for Consignment (GINC), destination address
Shipment flow	Global Shipment Identification Number (GSIN), sender identity, receiver identity, source address, description of goods, value, time window
Business flow	Invoice, acknowledge, missing time, Estimated Arrival Time (EAT)

With further research on the Modulushca project, actors can be granted differing levels of access to the four types of information about M-boxes, as seen in Figure 2.18. In the figure, the different extents of openness are depicted by the concentric layers of the information. M-box data is open data for the public, and it is accessible directly from the smart tags attached to the M-boxes. Business flow data is the most confidential data. It is only allowed to be disclosed to manufacturers and retailers (Barbarino, 2015). Therefore, the more inward actors that can access information, the more access they can have. That is, access to a type of information is granted to other data in the outer layers. For example, actors with access to business data are authorized to access all data.

The color code in Modulushca project has been used for describing the current and desired systems of ports in this project.
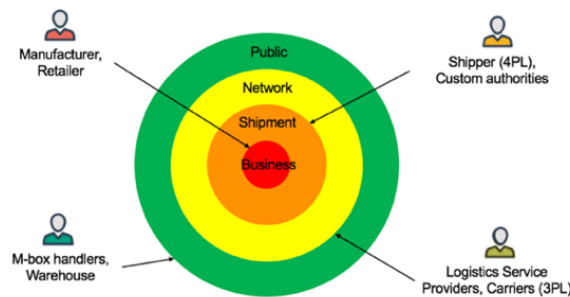

Figure 2.18 Data accessibility depending on the roles of actors (Barbarino, 2015)

Based on this research, Krommenacker et al. (2016) show how modular containers can be implemented along with existing handling processes. In this project, it can be useful for describing the PI's operating process in terms of the visibility of modular containers and other logistic entities. They point out that the process of container encapsulation (i.e., composition and decomposition) is the key element of the PI. The authors virtually represent the handling process in π-hubs as shown in Figure 2.19. The process is composed of three phases: unloading, preparation of composition or decomposition, and loading. Moreover, the authors devise a virtualization of container (VoC) framework to control container composition and decomposition processes by attaching sensors to each container. In the framework, each container can be tracked in terms of its location, container category, and identifier through the sensors. Then the information can be shared in the composite container level by a wireless sensor network (WSN).
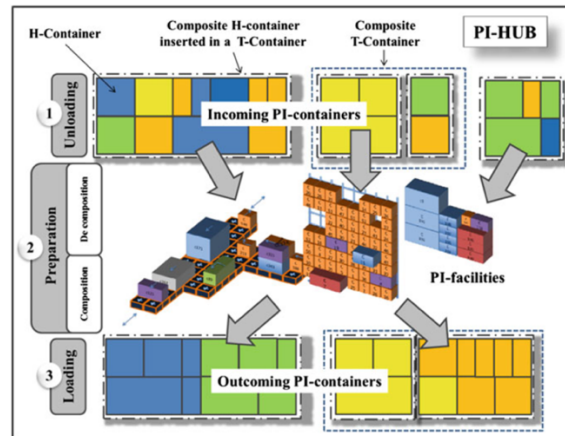
Figure 2.19 Potential PI containers treatment (Krommenacker et al., 2016)

While Sallez et al. (2016) research the advanced functionality of modular containers—activeness—communication between different modular containers can be referred for this project. The authors visualize an information sharing mechanism from goods, P-containers, an H-containers, to T-containers to lead to activeness in the PI system. Activeness means that π-container act in a conative manner by notifying current conditions itself compared to normality. It can be achieved through communication between modular containers. Therefore, the kinds of information in communications can be a guideline of information flows in this project.

3

Research Methodology

The methodology in this project is twofold: research methods and data collection. The methods are described along with the three phases in a primary research method, V-Model. That is, which research methods have been applied for each stage in V-Model. In brief, the first and third phases in V-Model have been guided by RAMI 4.0, whereas the requirement engineering helps to structure the second step. Additionally, a method applied in preliminary conceptual design has been briefly covered as parts of the third phase in V-Model. Lastly, this chapter has explained methods used for collecting data for this project.

3.1 V-Model

V-Model can be divided into left and right phases by system implementation being placed in the vertex of the model (Sage et al., 2000). On the left side, a system is conceptually developed in decomposing requirements from the high-level to the functional and physical level. The system is virtually designed—System architecture—based on the requirements elicited from the second phase. After developing the system, the system is integrated for testing and evaluation, and eventually operation and maintenance. As already mentioned in introduction, the first three steps in V-Model fall within this project scope. The author has explained the three phases in the light of this project as follows.

(1) Concept development: the first phase of this project is used to identify and represent a current system as the baseline for the next two steps. This project analyzes the status quo of modern ports and their TOS in the light of the current issues on loading units and visibility of shipment. That is, the analysis allows the second phase to identify design spaces in modern ports.

(2) Requirement engineering: the second phase aims at eliciting requirements to transform the current system into the desired system. The requirements include potential functions or behaviors of the desired system that need to be fulfilled to implement it. This project aligns characteristics of the three PI's elements in the context of ports to identify their possible functions in PI ports. It is expected the functions allow PI ports to be differentiated from modern ports.

(3) System architecture: this phase proposes a conceptual design of the desired system based on works in the two previous steps. Explicitly, this stage can be divided into preliminary conceptual design and system architecting. In the preliminary conceptual model, possible design options are discussed, and a prototype can be developed if necessary. The surviving alternatives can be designed in more detail within system architecting. The development of the prototype is beyond of the project scope. However, design alternatives found in the previous two steps can be discussed in-line with PI's visions to reflect a design choice into a conceptual

design of PI ports. The conceptual model in this project deals with the PI's components by emphasizing their uses in ports' T&T system as well as logistics operations.

3.1.1 RAMI 4.0

As the first complementary research method, RAMI 4.0 has been adjusted for the first and third stages in V-Model. Three dimensions are firstly elaborated to determine which coordinates are suitable to this project. RAMI 4.0 is composed of three coordinates as follows:

- Layers

  A layer-based approach is a pervasive approach that is used in reference models to analyze a system with diverse criteria. In RAMI 4.0, the layers in the horizontal axis are business visions, functional process, information, communication and integration mechanism, and physical assets within industry 4.0 systems. With this axis, the entire systems can be split into fractions, enabling the central aspect of each layer to be investigated in close detail. Figure 3.1 briefly describes purposes of each layers.
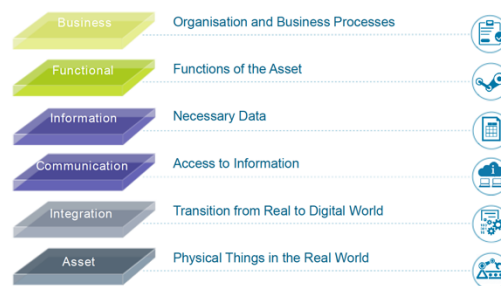

Figure 3.1 Layers in RAMI 4.0 (Krommenacker et al., 2016)

- Lifecycle & Value Stream

  RAMI 4.0 can also reflect the dependencies between materials depending on different steps in lifecycles or value chains of manufacturing. Each phase of the life cycle or value chain might require different materials and interoperability between the materials.

- Hierarchy Layer

  This layer breaks downs a system into smaller systems in a hierarchical structure. The systems can be allocated in the structure according to functions and responsibilities in different levels. This layer represents these functions from the work-piece level to the connected world, reaching beyond the boundaries of a manufacturing system or factory. Figure 3.2 emphasizes the difference on interconnectivity by comparing the industry 3.0 and industry 4.0.
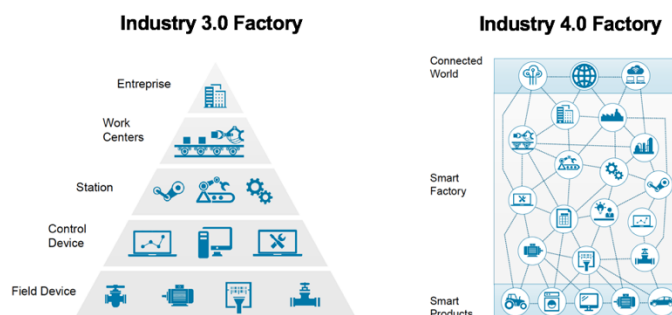
Figure 3.2 Comparison between industry 3.0 and industry 4.0 on interconnectivity

The author has determined the two axes in RAMI 4.0 (i.e., the layers and hierarchy layer) are more relevant to this project than the lifecycle and value stream layer. This project will be committed to conceptualizing a PI system in the early stage of implementation. However, the lifecycle and value stream layer helps a system to be designed across the entire lifecycle, which is beyond of the project scope.

Adjusted RAMI 4.0

This project has aligned the two dimensions in RAMI 4.0 with the context of T&T system in ports. For this, this project has been heavily based on the work of Fleischmann et al. (2016) that reinterpreted RAMI 4.0 in a conditioning monitoring system. Furthermore, literature on LIS reviewed in Chapter 2 has been referred to divide a logistics system into several sub-systems in the hierarchy layer depending on functions.

- Assumption

  This project perceives that ports' T&T systems can be implemented as web platforms, enabling ports to communicate with their external clients about tracking and tracing services based on the research by Lee et al. (2002). That is, this front-end business application is an interfacing point between the systems' client and systems

- Layers

  The author of this project focuses on the business, function, information, and asset layers to analyze and suggest information flows both in the current and PI logistics system. The communication and integration layers are beyond of the scope in this project because they have more to do with technologies that combine and transmit information from the asset layer. Pulling in different directions, these two layers are dedicated to exploring technical enablers for information flows, not information flows themselves. Research by Li et al. (2016) might be in-line with these two layers. Furthermore, it is expected that technical enablers of the communication and integration layers are hardly changed in the transition from current logistics systems to PI systems. This is because current logistics systems are already applied with diverse IoTs, although differences might remain over the extent of automation and intelligence in PI environments.

- Hierarchy Layer

  As already described the nature of LIS in Section 1.3.2, all information flows are interdependent regardless of LISs they belong to. That is, this project has formulated information flows in the viewpoint of T&T system of ports by considering interactions with external LISs.
  Considering the nature of LISs, this project breaks down a port logistics system into three hierarchical levels: (1) field of ports, (2) T&T system in TOS, (3) external LISs. It is noticeable the lowest layer comprises tangible elements in the actual port, whereas the rest two layers in LIS(s).

  The author additionally used four modules along with the three hierarchical levels in order to clarify their functions: perception, processing, human-machine interface (HMI), and interconnection modules. The first level is dedicated to perceiving physical logistics entities and their operations in the field of ports. T&T system in port is available to generate tracking and tracing information and communicate with their clients, described as processing and HMI

modules respectively. Lastly, external LISs can be interconnected with T&T system in port for information exchange.

Matching two different coordinates, four layers of RAMI 4.0 have been defined in the context of T&T system in ports, as seen in Figure 3.3.
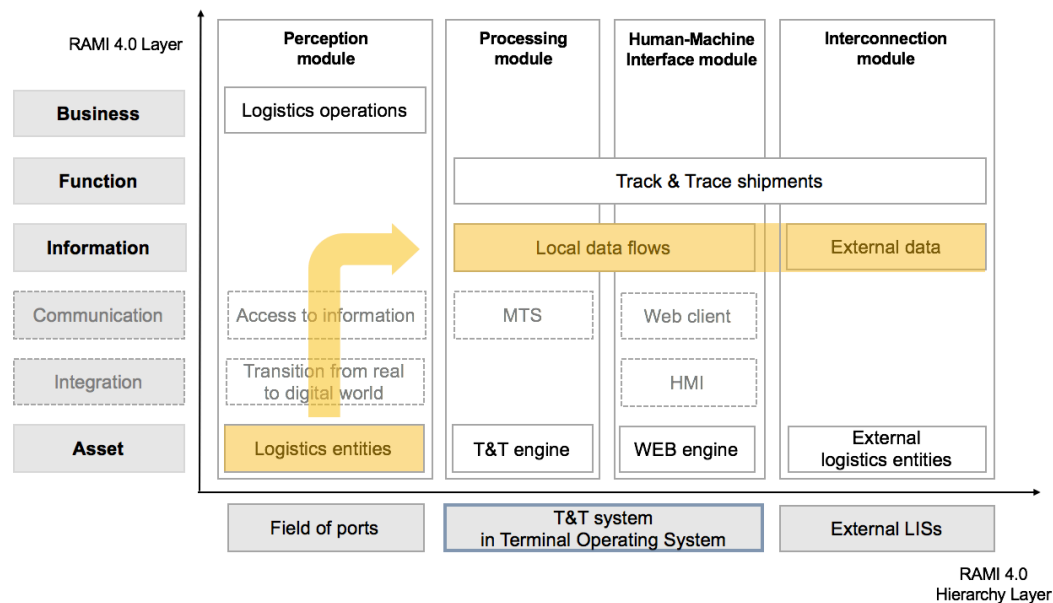

Figure 3.3 Adjusted Reference Architecture Model for T&T system in this project

(Adapted from Fleischmann et al., 2016)

(1) Asset Layer: this layer is designed to clarify logistics entities regarding their characteristics and the relationships between them. RAMI 4.0 defines physical things as parts of manufacturing machine, products, human. Therefore, the physical things are transposed to logistics entities in this project, including loading units, shipments, parts of LISs.
(2) Information Layer: information flows on logistics entities are the main subjects of this layer. Thus, the flows from one entity to the others will be elaborated on.
(3) Function Layer: this layer shows internal functions in T&T system for tracking and tracing loading units along with interactions with external LISs.
(4) Business Layer: this layer represents business visions through logistics operational processes. The operational processes comprise of diverse handling and transportation of loading units.

The asset layer offers fundamental logistics entities to track and trace modular containers for the T&T system in ports. The logistics entities include not only tracking and tracing objects (i.e., modular containers) but also sub-systems of T&T system in ports and external LISs. That is, this project starts from the asset layer to clarify logistics entities for the rest layers either on modern ports or on PI ports. The sequence of the four layers will be the asset, information, function, and business layer.

Design Tools

The methodology in this project is twofold: research methods and data collection. This section has introduced the research methods under the primary research method, V-Model. That is, which research methods were applied for each stage in V-Model? In brief, the first and third phases in V-Model have been guided by RAMI 4.0, whereas the requirement engineering helps to structure the second step. Additionally, this chapter has covered methods used for collecting data for this project.
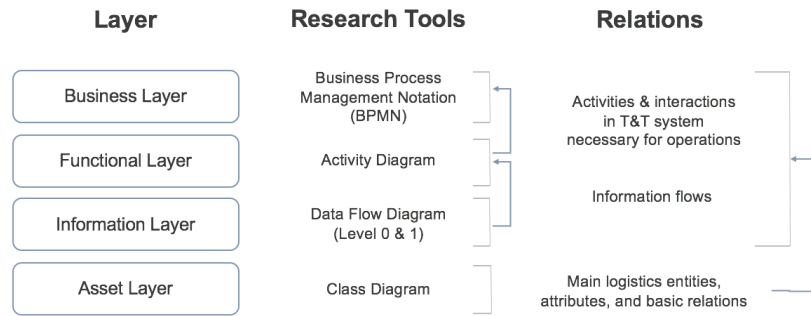
Figure 3.4 Summary of research tools & relationship

- Object-Oriented Modeling Languages

OOM is a prevalent modeling method for software development. It enables system components to be perceived as individual objects (Martin & Odell, 1998). This way of thinking helps to define the attributes, operations, rules, and relationships of the objects so semantic gaps between systems and real fields can be decreased. Based on this idea, various standard languages had been developed for different purposes. Among them, the author of this project has principally applied two languages: unified modeling language (UML) and data flow diagram (DFD).

UML was originally motivated by the same purpose as BPMN, namely system representation, but it is dedicated to information systems. That is, UML has been used in software design with a focus on system internals rather than external interactions in physical operations, as in BPMN. Although UML is comprised of many diagrams to represent diverse aspects of information systems, the author of this project applies activity diagram and class diagram according to the functional and asset layers in the RAMI 4.0 model. Critical to information flows in this project, DFD is used for the information layer in this project because there is no analogous diagram in UML. Details on each diagram follows.

(1) Class Diagram: a class diagram is the most popular illustration of UML as a graphical table contents of systems (Fowler & Scott, 1999). It represents the kinds of objects in a system as the form of classes that can embrace each object's properties and operations, termed features. Moreover, this diagram can show the relationships between the classes based on the way objects in the real world are connected.
In this project, any logistic element relevant to the functions of a port's T&T system can be illustrated as a class in the diagram, including operational means, operation, and actors in a logistics chain. Also, each class of a port's T&T system can have attributes, operations, and signifying characteristics and behaviors of the class. Based on the features, the informational relationships between classes can be depicted.

(2) Data Flow Diagram: the function layer illustrated by UML AD represents parts of information flows within a T&T system because the system's activities can be related to data sources and database systems. However, it is still difficult to recognize information flows at a glance through UML AD. Hence, the author of this project has applied data flow DFD to highlight information flows in the T&T systems of ports by synthetically considering the relationships between logistics entities from both operational and informational viewpoints. That is, the DFD in this project functions as the glue between different design tools: BPNM, UML AD, and class diagram. That is,

it shows how the physical assets described in the class diagram are bound by information flows in the T&T system to perform logistics operations.

DFD literally means that it is dedicated to clarifying where data comes from, where it data goes, and how it is stored. The DFD is classified into two levels, level 0 and level 1. The level 0 DFD, also known as a context diagram, is a high-level map to explain the context surrounding the system. In the level 1 DFD, information flows are explicitly described based on the context from the level 0 DFD. This project has applied Gane and Saron's DFD, commonly used to describe information systems ("Data Flow Diagram," 2017).

(3) Activity Diagram: an activity diagram might seem similar to a BPMN in that it describes the procedural logic and workflow patterns of systems. However, the author of this project focuses on the fact that an activity diagram mainly deals with internal functionalities used in information systems (Cozgarea et al., 2008). Therefore, this diagram can help to clarify the functions of T&T systems in ports, along with their operational flows, as shown in BPMN. Primary elements are briefly summarized in Figure 3.5.
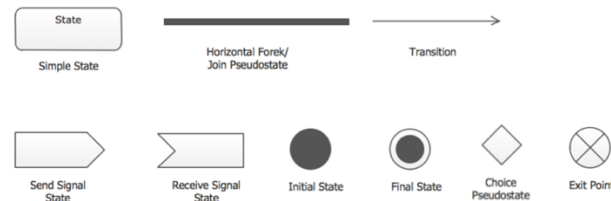

Figure 3.5 Primary elements of activity diagram ("UML Activity Diagram, Design Elements", n.d.)

- Business Process Management Notation

BPMN is the most widely used universal language to describe how systems are operated, namely business processes, along with their environments. In spite of its name, BPMN is devised for diverse types of processes in many fields, such as engineering and manufacturing (Bock et al., 2014). By using standardized grammar and graphics, the BPMN simplifies the business processes from a holistic view of the environment and external systems (Object Management Group, 2010). Main elements are briefly summarized in Figure 3.6.

This project considers port operations as parts of the entire logistics process. Hence the operations of ports can be understood with actors and logistics entities that are external to ports but still involved in the same logistics chains as ports.
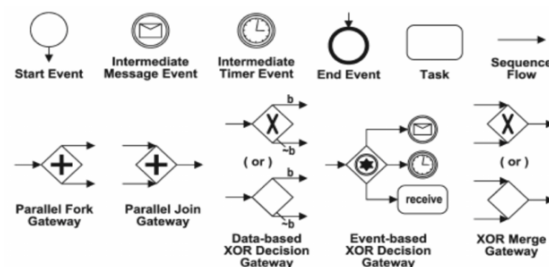

Figure 3.6 Primary elements of BPMN (Quyang et al., 2009)

Literature applied UML to explain port-related operations are covered in Appendix C.

3.1.2 Use-case-based Requirement Engineering

Gathering and analyzing the requirements of the desired system is one of the important phases of conceptualizing the system as the second sub-process in a system engineering process, V-Model in this project. To structure the phase, this project has been based on IEEE Standard for application and management of the system engineering process called IEEE Std. 1220-2005. In-line with the system engineering process, the standard provides three viewpoints on requirement analysis: operational, functional, and design perspectives (Ptack, 1998).

From the operation perspective, operational scenarios can clarify the anticipated uses of a system along with required interactions. To function properly in the scenarios, the system might need to interact with other systems, platforms, products, and human works. The functional view focuses more on the system's functionalities than interactions in the operational view. Moreover, this view helps to ensure the system performs at proper performance level. Lastly, the design view is dedicated to defining desirable design characteristics, such as texture, size, color, weight, and buoyancy.

The operational and functional viewpoints are applicable to this project to explore the potential uses of PI components in ports logistics operations when supported by the functionalities of T&T systems. Existing literature on the PI is mainly about its elements from a design point of view. Therefore, this view is out of the project scope. The two points of view can be comprised in use case, one of the methods with which to elicit and analyze requirements with the representation of the interaction between actors and the desired system (Cockburn, 2000). The use cases have been denoted in a use case diagram based on textual descriptions (i.e., scenario) (Lübke et al., 2008). Therefore, the author of this project can illustrate a potential use case of PI elements in an operational scenario. Based on the scenario, a use case diagram can show the anticipated functions of a T&T system at a PI port. As a result, the author of this project can exploit the requirements implied in the use case diagram with the scenario for a tentative design of PI ports.

3.1.3 Preliminary Conceptual Design

The preliminary conceptual design is a sub-phase in the third stage in V-Model (i.e., system architecture) that helps to discuss alternatives on plan and to eliminate unfeasible options before the beginning of modeling (Sage et al., 2000). In this research, system integration has been mainly concerned to determine the best option to integrate the T&T system in PI ports to the open interface in-line with PI visions. In order to clarify the decision, a multiple attribute utility theory has been applied to quantify results of SWOT analysis on alternatives according to four attributes generally used when selecting information system architecture (Pearlson, Saunders & Galletta, 2016).

The SWOT analysis on alternatives apparently represent the best suitable design, but the multiple attribute utility theory still allows the final decision to be explicit. Therefore, its fundamental concept is herein described. In theory, a set of alternative is assumed as $A = (a, b, c \dots)$ that a set of attributes can be each defined in $(X_1, X_2, \dots, X_n)$. Consequently, attributes of alternative a in A is corresponding to $X_1(a), X_2(a), \dots, X_n(a)$ in n-dimensional attribute space. Utility on the alternative a can be formulated by a utility function as follows:

$$U[(X_1, X_2, \dots, X_n) = f\{U_1[X_1(a)], \dots, U_n[X_n(a)]\}$$

For total utility on a single alternative a, U_i that is a utility function over the single X_1 attribute is formulated with f by aggregating the values of the single attribute utility functions:

$$U(a_i) = U_1(a_i) + U_2(a_i) + \cdots, + U_n(a_1) = (x+a)^n = \sum_{j=1}^{n} U_j(a_i)$$

3.2. Data Collection

Qualitative research methods have been exploited to gather data for this project. This project can be defined as an exploration research in that it envisions information flows of the future logistics system. In exploration research, qualitative methods can give insight and knowledge into a little known research field, transposed into PI in this project (Ellram, 1996). This project mainly used three methods of data collection for qualitative research: (1) document analysis, (2) interview, and (3) case study. Each method is elaborated in more detail behind.

3.2.1 Document Analysis

Document analysis encompasses a broad range of methods devoted to analyze and interpret the documents as significant data sources. Variety types of records are available for this method, including not only texts, but also sounds, videos, photos, and any materials capable of giving relevant messages. This project has mainly used research articles from Montreuil who has introduced PI and moreover existing publications of international physical internet conference (IPIC) are also referred. Furthermore, videos on the physical internet and Modulushca project help to understand their idea (Modulushca project, 2014a, 2014b; TEDxTalks, 2013).

3.2.2 Case study

Case studies are one of classic qualitative studies capable of understanding dynamics situations within single settings (Eisenhardt, 1989). Although the number of cases for generalizations are under dispute, a single case is still used to investigate a well-formulated concept which includes a formerly inaccessible phenomenon (Ellram, 1996). This project has exploited case studies for the second phase in V-model (i.e., requirement engineering) to set a maritime logistics chain by reflecting practical perspectives. Through the setting in the case, this project testified the idea of three PI elements, is relatively well defined in theory but have never been implemented. In-line with repositioning operations, this project explored case studies on PCL and their details have been covered in section 5.1.1.

3.2.3 Interview

Interviews are used to collect data interactively through a one-on-one meeting. They mainly help to interpret meanings of a phenomenon on the research subjects and to obtain experts' opinions about a research process in which the subjects are engaged. This project has reflected results of two interviews each with Dr. Wout Hofman, and MSc. Gerwin Zomer. Dr. Wout Hofman has been involved in the iCargo project to develop an IT architecture on intelligent cargo transportation. MSc. Gerwin Zomer is currently coordinating several European projects about international logistics as one of the project directors in TNO. Although both interviews were unstructured starting from an open-question, the one with Dr.Wout Hofman helps to obtain basic knowledge freight logistics in IT perspective at the beginning of this research. On the other hand, in the interview with Zomer, the conceptual model on PI ports has been discussed and their feasibility. Contents of meetings are attached in Appendix A and B.

4

Analysis of Current Logistics Systems in Ports

In this chapter, the author analyzes the current state of logistics systems in port terminals by aligning with the adjusted RAMI 4.0 in the project. The current model on modern ports is elaborated with four layers of the adjusted RAMI 4.0 in the sequence of the asset, information, function, and business layer. The four layers represent logistics assets, information flows, functions of the assets, and operational processes in modern ports in the light of tracking and tracing their inbounding shipments. Each layer has been illustrated by an appropriate design tool as mentioned in Chapter 3. Existing literature has been used as the primary source to acknowledge LISs as well as general operational processes in maritime logistics. The detail reference has been listed in every figures below.

4.1 Asset Layer

The asset layer has illustrated critical logistics entities and their relations necessary for tracking and tracing containers in T&T system. The objects are depicted by an individual class with properties, termed attributes, and operations that stand for characteristics and behaviors of the class. Classes in the asset layer might contain contents of information that should be exchanged to track and trace containers. Additionally, visibility on attributes and operations in classes can represent information accessibility in the viewpoint of ports.

A lot of works in literature have given insights on primary logistics entities in terms of tracking and tracing shipments in the viewpoint of modern ports. The literature has been already covered in Section 2.1 and 2.2. In particular, existing literature applied UML to depict operations of port terminals or vessels (Tang et al., 2016; Guolei et al., 2013) has been used as the baseline of the class diagram in this layer. More importantly, primary attributes and operations on classes of shipping container and its manifesto have been based on Modulushca project (Tretola, Biggi, & Verdino, 2015; Barbarino, 2015). See Appendix C.

As the chief object to be tracked and traced, shipping containers embed public data on containers mostly through bill of landing with or without barcode (Kärkkäinen et al., 2004). In the class diagram in Figure 4.1, ports are accessible to the public data, such as container identifier number, dimension, specifications for handling, as marked with public visibility symbol, "+." In contrast, attributes on goods encapsulated in shipping containers cannot be retrieved by ports with limited accessibility,

represented as the private symbol, "-." Besides the public data on shipping containers, manifest of containers can deliver the network and shipment data on a container as elaborated in Section 2.3.5. However, ports are still limited to access the shipment data by being considered as carriers who do not need to know shipping details, for example, final destination and delivery time window. Hence, the shipment data is described with protected visibility symbol, "#."

On the basis of the manifest of containers, the T&T system track, and trace shipping containers along container-handling operations, which described by the classes of track and trace in ports and operation.

Port operators have direct contact with shipping companies and inland carriers at the beginning and end of each process. Shipping companies have vessels to convey inbound shipments to ports, whereas inland transport operators have responsibility for discharging outbound shipments to hinterlands through proper transport methods. They also use manifesto on containers generated by LSP in the same logistics chain with ports. In the diagram, the class of logistician binds all actors into a class with essential attributes and operations.

As another critical entity of observation in a T&T system, ports consist of supra-structures capable of physical operations, such as unloading, loading, sorting, storage, and transport. Changes in supra-structure statuses need to be tracked and traced in the system because they are intertwined with shipments along with the physical operations that influence their conditions.
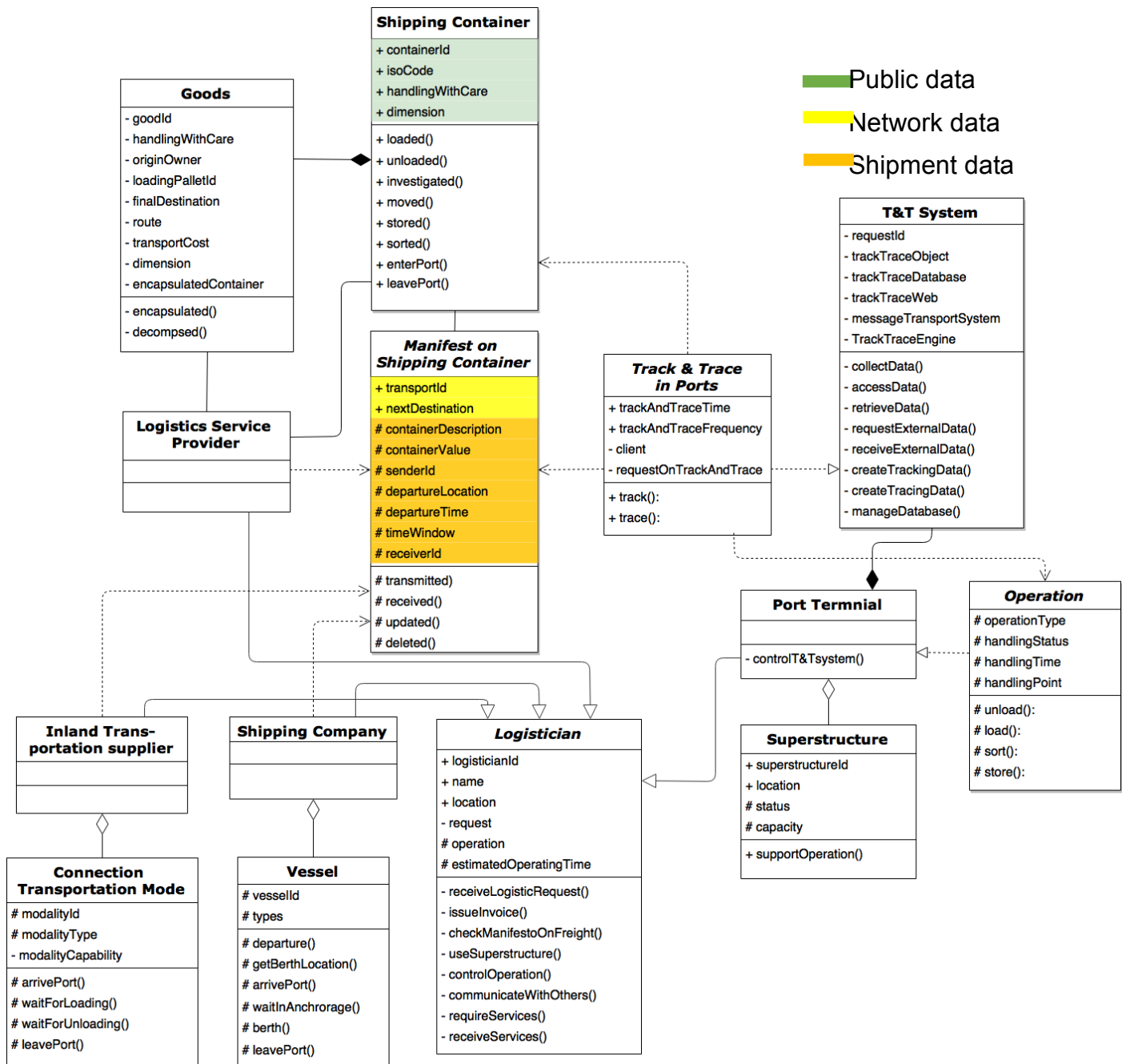
Figure 4.1 Class diagram on current ports

Note. The class diagram on ports has been based from the work by Tang et al., (2016) (Appendix C) and Guolei et al., (2013). Main attributes and operations on classes of shipping container and its manifesto have been adopted from Modulushca project (Tretola, Biggi, & Verdino, 2015; Barbarino, 2015).

In summary, this asset layer visualizes modern ports have used to handle shipping containers as their main loading unit. This visualization is meaningful in that the loading unit is the primary concern to be improved to relieve the current issues in freights in this project: inefficient space utilization on loading units and the lack of visibility on their contents.

In the context of four layers in the RAMI 4.0, the asset layer has clarified primary logistics entities in modern ports which are necessary to track and trace shipments. The logistics entities can be used as inputs in the upper layers in the adjusted RAMI 4.0 to describe information, function, and business of modern ports. As for the next layer, this layer also offers possible data based on attributes and operations in each class of logistics entities.

4.2. Information Layer

The attributes and operations of assets can be transformed into digital sources that T&T system of ports is available through integration and communication layers in RAMI 4.0. The information layer illustrates the information with flows in the viewpoint of ports. The information flows reflect interdependencies between the T&T system of ports and different logistics entities. Additionally, this information layer has been based on an internal process of T&T system that devised from the literature on components of T&T system (Lee et al., 2002). The process is vital in helping to represent how input data turn into output data within T&T system of ports. However, the information layer is chiefly concerned with data storage and flows of information by simplifying the process of T&T system.

In the context diagram, the T&T system in ports has been perceived as the primary system, whereas it is one of the logistics entities in the class diagram in the asset layer. This change in viewpoint allows this project to illustrate information flows in the ports' perspective. Beside the T&T system in ports, the context diagram consists of six external logistics entities as described in Figure 4.2.
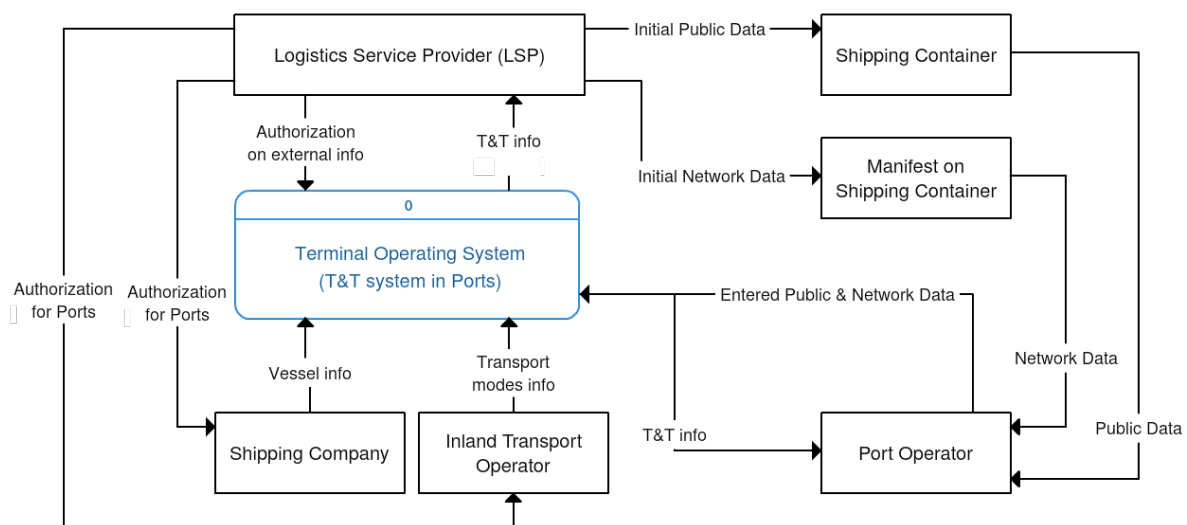

Figure 4.2 Context diagram on current ports' T&T system (Level 0 data flow diagram)

The description on the context diagram has been omitted because the level DFD 1 encompasses its contents by adding data storage and detailed information flows. That is, data flows in the level 0 DFD remain at the next level (i.e., the level 1 DFD) as an essential frame for the data diagram. That is, ultimate input and output information on each external entities are equal at both levels. However, the level 1 DFD in Figure 4.3 elaborates information flows with five steps of a functional process: (1) authorization on external data, (2) receive original container and external data, (3) track container-handling operations, (4)generate T&T information, and (5) provide T&T information.

Before collecting data from external entities, port terminals can receive authorization to access the information. Then the T&T system will be capable of gathering diverse information from external

objects. First of all, LSP offers a port operator with container information through shipping containers and e-manifest that each contains public data and network data. The port operators (i.e., ports employees, in reality) make an entry of shipping containers into the T&T system in checking whether inbound containers are in concordance with the e-manifest from LSP. All information is kept in the different database within T&T system of the port terminals, called to container, vessel and inland transportation respectively.
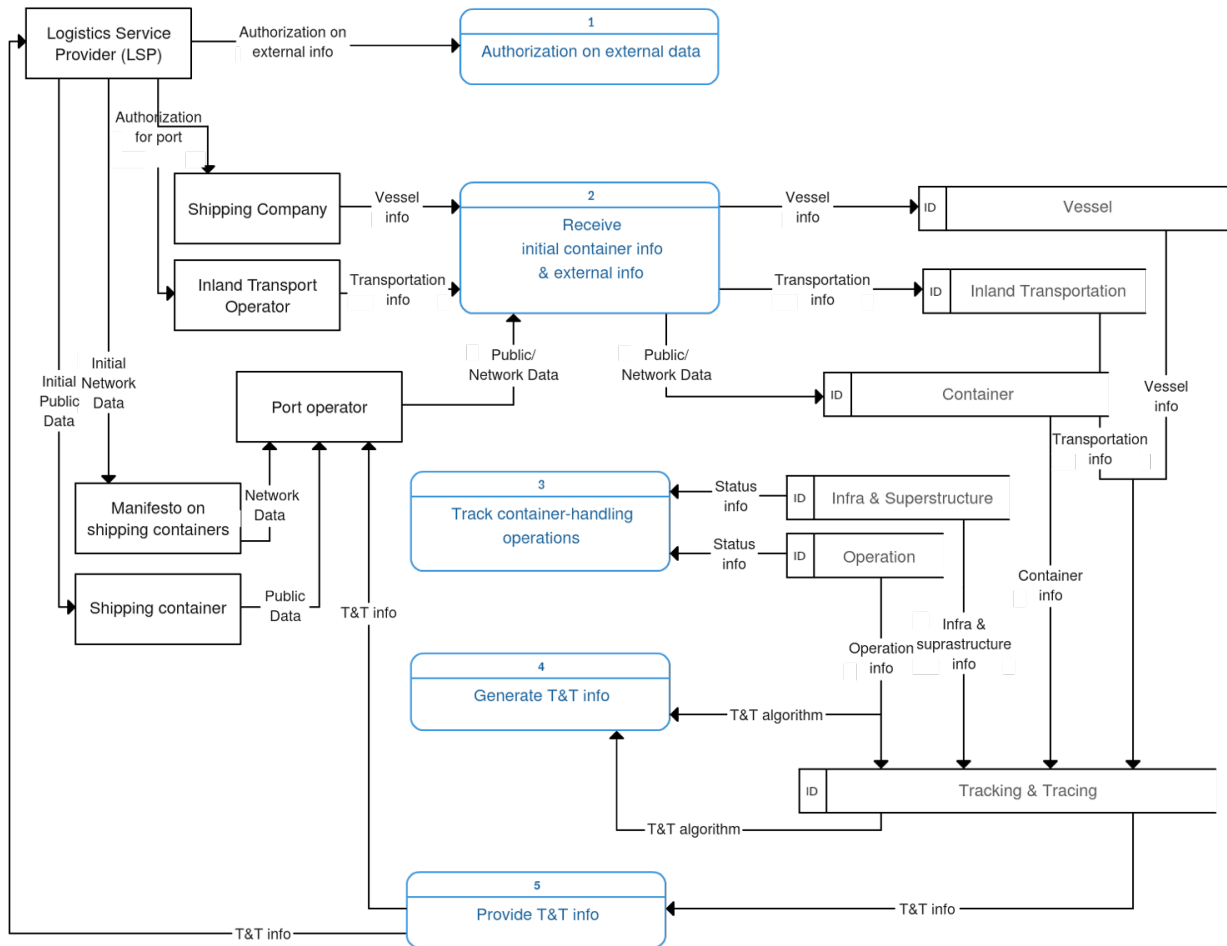

Figure 4.3 Data flow diagram on current ports' T&T system (Level 1 data flow diagram)

By using external data, port terminals track containers along with their operation-facilitating infrastructures and supra-structures. Statuses on the operation, infrastructure, supra-structures come over from each database. Then the T&T system implements embedded algorithms to create T&T information by employing all the information about shipments. Lastly, it provides the T&T information to the port operators and logistics service providers.

To conclude this subsection, this information layer represents the sequence of communication between T&T system in ports and information sources for tracking and tracing shipping containers. LSP is the first and primary information source for the T&T system for the public and network data on inbounding shipments, and the authorization to external information. The information flows are a collection of inputs and outputs of the T&T system. However, it is difficult to identify how they have been made with this layer. Therefore, the next function layer helps to clarify the procedure in more technical viewpoint.

4.3 Function Layer

The function layer represents functional flows of the T&T system for tracking and tracing shipments. That is, this layer helps to clarify how information flows of the T&T system are formulated with technical aspect. Although the functional flows are still abstract with the helicopter view, this layer provides more details on internal activities of the T&T system than those of the information layer. Furthermore, this layer includes interactions with outside logistics entities mainly from LSP, shipping company, and in-land transport supplier. With reference the adjusted RAMI 4.0, the functional flows are established with additional logistics entities in external LISs as well as T&T engine and a web platform in ports' T&T system. This foundation of the functional flows has been described in the asset layer in the RAMI 4.0.

The information layer has heavily based on literature by Lee et al. (2002) that elaborated components of T&T systems and their functionalities. In this layer, functions of the components are interlinked with one another by sequence orders, whereas the work by Lee et al. represents each component's activities as a static component diagram (Lee et al., 2002). The current method of information exchange has been reflected by literature on PCS (Keretho, 2011; e-Compliance, 2016) and the market analysis on T&T service (Kärkkäinen et al., 2004; National Academies of Sciences, Engineering, and Medicine, 2011).

The activity diagram in Figure 4.4 categorizes activities of T&T system into three swim lanes: (1) Track (2) Trace, and (3) interface according to primary logistics entities described as T&T engine and web engine in the asset layer in the adjusted RAMI 4.0. The track lane is dedicated to identifying and generating tracking data on containers, while the trace lane is to providing tracing data by classifying tracking data into terminated or non-terminated data compared to the present point. Both activities, marked with in the diagram, are composed of sub-activities, hence details on their activities are separately elaborated in the right side in Figure 4.4.

Original information on containers (i.e., manifest on containers in Figure 4.4) from LSP is an initial input data of T&T system in ports. On the basis of the initial information, tracking engine can generate tracking data, represented as activities in "generate tracking data by tracking engine." To create tracking data, external data from shipping companies and inland transport suppliers might be required. Hence LSP can offer ports to authorization on the additional data if necessary. Then, processed tracking data is either newly added, updated, or deleted in the tracking database, which will be retrieved according to LSP's request on tracking data on a container. Whereas, some requests of LSP can call tracing engine capable of accessing tracking data to determine the tracking data whether terminated or non-terminated under operation statuses.

Notably, the T&T system in modern ports exchanges information with external actors in a bilateral manner, whose details will be elaborated in Section 6.1.1. In the T&T system of ports, LSP is the main actor who provides information on containers that need to be unloaded into ports (i.e., manifest on containers in Figure 4.4) and requires containers' status afterward. With authorization from LSP, the T&T system in ports can receive information on vessel and inland transportation each from shipping companies and inland transportation suppliers with separate reciprocal communication.

Through this function layer, the informational role of ports in modern maritime logistics has been clear along with functions of the T&T system. In short, the modern ports generate tracking and tracing information limited on shipping containers and transfer them to LSPs. The T&T system is parts of a logistics system of modern ports, therefore their information role is dependent on logistics services. The next layer will represent why the T&T system has the information role through operation processes in modern ports.
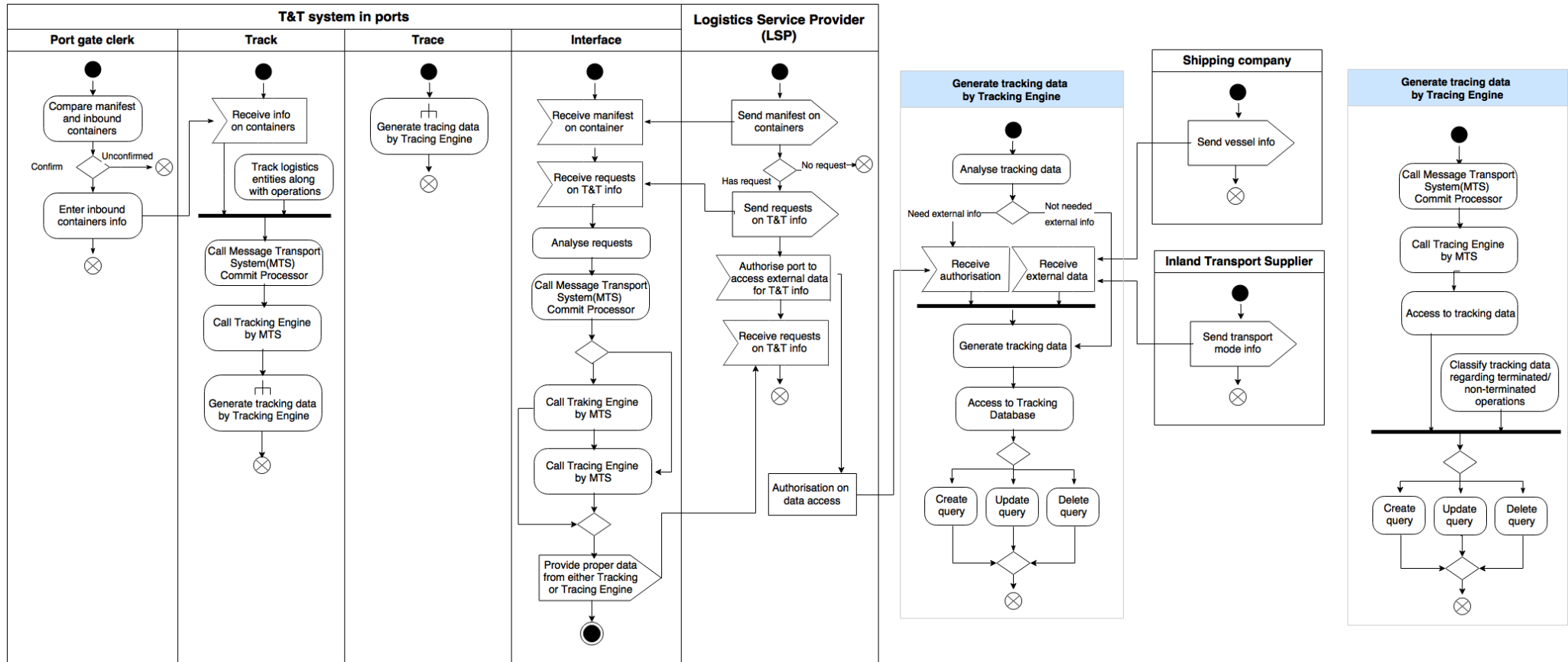
Figure 4.4 BPMN on T&T system function in current state

Note. The components of T&T system have heavily based on *A Study on the Track & Trace System for e-Logistics*, by Lee et al., 2002. Contents of information from different actors in maritime logistics have been based on *Enhancing visibility in international supply chains: the data pipeline concept*, by Klevink et al., 2012. The current way of information exchange has been adopted from literature on PCS (Keretho, 2011; e-Compliance, 2016) and the market analysis on T&T service (Kärkkäinen et al., 2004; National Academies of Sciences, Engineering, and Medicine, 2011).

4.4 Business Layer

Most port terminals deal with transshipping containers by linking sea and land in the current maritime logistics. In the business layer, their physical operations are emphasized over organizational procedures, such as ordering process, contract, and customer management. As already covered in the adjusted RAMI 4.0, the business layer matches to the field of ports in the hierarchy layer.

Even though the extent of capability on VAS is different depending on the port, port operations in the project can be generalized by a standard view based on much literature. (Brinkmann, 2011; Gharehgozli et al., 2014; Kemme, 2013; Meersmans, 2002; Cheng et al., 2005; Wu, 2013). Therefore, it was possible to complete the necessary activities in compliance with the project scope as follows (Li et al., 2015):

- Loading and discharging shipments
- Internal transportation
- Storing shipments

The general operation of ports does not include the core VAS in the project (i.e., container encapsulation and decomposition). Thus, an inland logistics center is described as the actor that is in charge of the VAS through transshipping shipments by inland transport operators. The operational role mainly for transshipping shipping containers helps to understand the function layer with limited information roles of modern ports.

In BPMN, three swim lanes are used to present a port, an inland transportation operator, and an inland logistics center (Figure 4.5). Although port operations can be triggered by an arriving vessel, the detailed operations of shipping companies are beyond the scope of this project.

With the event of vessel arrival, the port can start its operations. Internal operations in the port can be roughly classified into three phases: loading and discharging shipments, internal transportation, and storing shipments. This categorization helps provide an overview of the operations that are shown in Figure 4.1 with different colored lines. Details about the activities and usages of logistics entities are visualized in the literature on port layout and facilities. After leaving the port, inland transport operators are in charge of transporting shipments to the next destination, which is an inland logistics center in this project, by employing appropriate transportation modes. Although the inland logistics center is not the main concern in this project, its operations are included in the BPMN. It stems from the fact that inland logistics centers are currently used to provide stripping and stuffing operations for containers, which is the critical VAL in this project. Thus, the BPMN broadly deals with not only operations of a port terminal, but also those of an inland logistics center.

In brief, this business layer visualizes the primary operational role in modern ports as a gate where shipments are passed by in the form of shipping containers. That is, modern ports handle shipping containers in the single level of loading units in their operations.
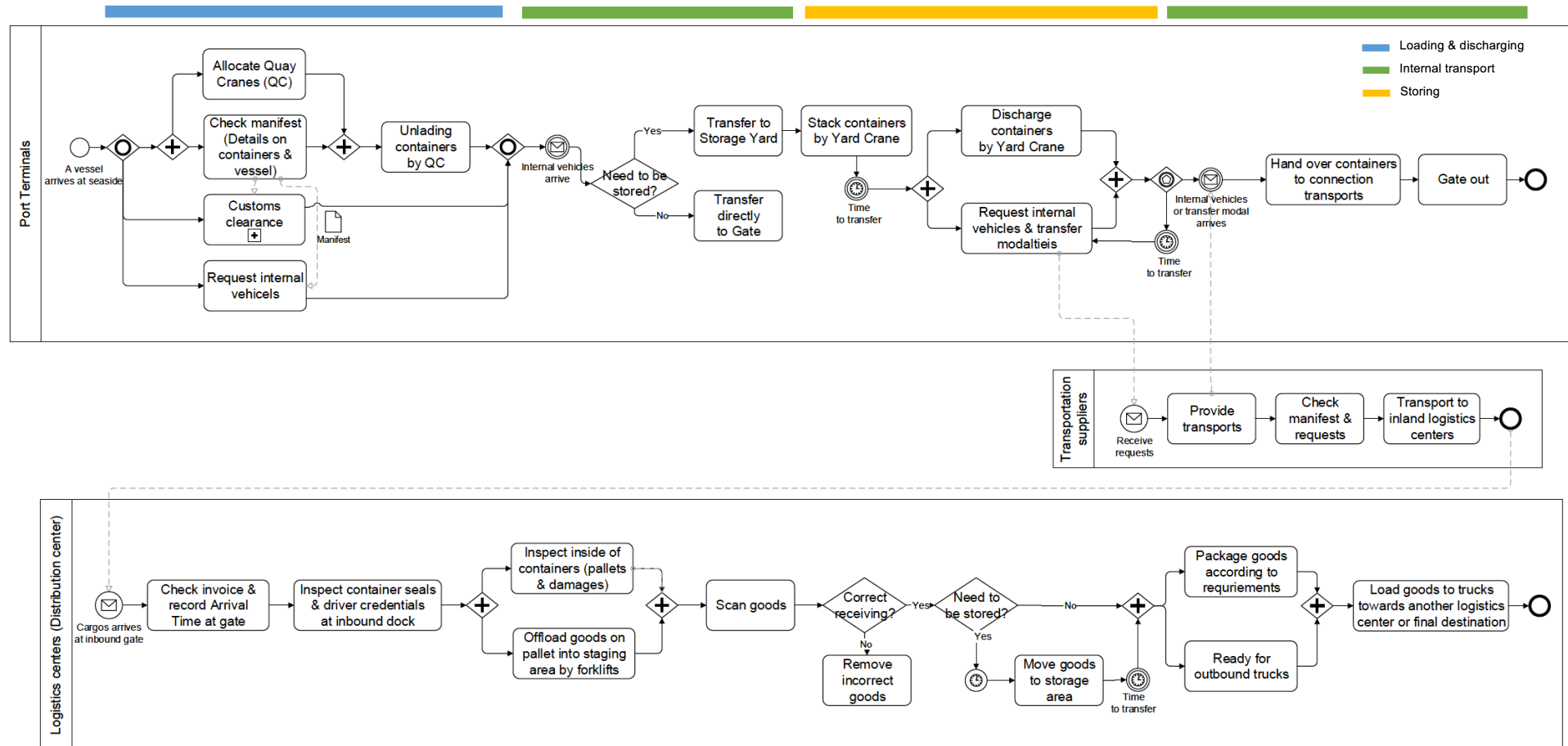
Figure 4.5 BPMN on general ports' operation in current state

Note. The swimlane on port terminals has been adopted from literature on port operations (Brinkmann, 2011; Gharehgozli et al., 2014; Kemme, 2013; Meersmans, 2002; Cheng et al., 2005). Operations of logistics centers have been confirmed in *Cargo consolidation in intermodal container transport*, by Wu, 2013. The literature on a freight logistics process have been referred (Stefansson & Woxenius, 2007; Tseng, Yue, Taylor, 2005).

4.5 Salient Implication

This chapter has covered the first step to resolve the current issues in freights: (1) inefficient space utilization on transport units, and (2) lack of visibility information on shipments. Corresponding to the conceptual development in V-Model, Chapter 4 analyzes modern ports by means of the adjusted RAMI 4.0. This section summarizes its findings in light of the first research question: How the current state of the T&T system in modern ports can be presented in the design framework?

Revisiting the research question, its sub-questions are listed as follows:

1.1 Which design framework can represent ports both in logistics operations and T&T system?
1.2 Which logistic entities are important in T&T systems of modern ports?
1.3 Which informational flows and activities in the T&T systems are required?
1.4 What is the primary operational process of modern ports?

The sub-question 1.1 has been covered with the adjusted RAMI 4.0 in Section 3.1.1. This section summarizes the finding in four layers by matching with the rest of questions. The question 1.2 is related to the asset layer, whereas the information and function layer with the question 1.3. Lastly, the question 1.4 can be linked with the business layer. Then design spaces in modern ports are briefly covered with the potentials of the three PI's components, that is modular containers, the open interface web, and global protocols.

4.5.1 Asset Layer

This layer has defined fundamental logistics entities used for tracking and tracing shipments from the viewpoint of modern ports. The most critical point in this layer is current ports offer logistics services to a single level of the loading unit, shipping containers. The shipping containers are primary objects to be tracked and traced for the T&T system in ports. Manifests of the shipping containers are also significant as they include the network data, such as identifier number of transport and the next destination. Beside shipping containers and their manifests, actors are even considered as the logistics entities in the asset layer. Modern ports closely are associated with LSP, shipping company, and inland transport suppliers.

4.5.2 Information & Function Layer

The information and function layers have represented information and activity flows in the T&T system of ports by considering informational interactions with external logistics entities. Contract to the asset layer, the two layers proposed interrelations between logistics entities under the functional sequence of the T&T system. By the two layers, it was clarified modern ports are only accessible to public and network data of containers, which cannot represent internal contents of the containers as well as details shipping information of them. Consequently, the T&T system is capable of tracking and tracing only the single level of loading units, shipping containers. Notably, the T&T system bilaterally communicate with external LISs, in particular those of LSP, shipping companies, and inland transport suppliers.

4.5.3 Business Layer

The business layer has described that the central operational role of modern ports is to transship shipping containers from the sea to the land. In the operation process, modern ports only handle the shipping containers from the entrance to the exit. Therefore, this layer offers the reason why the T&T system has the limited visibility on contents of shipping containers.

4.5.4 Improvement Points in Modern Ports

Modern ports have a plenty of room for improvement to solve the issues of freight logistics in this project— inefficient space utilization on transport units. First, the improvement points that captured by the current analysis on port logistics systems are summarized and detailed explanation follows behind.

- Operational services in ports within maritime logistics
- Additional information in the T&T system of ports
- Arrangement between actors about information accessibility
- The way of information exchange between the T&T system in ports and external LISs

Currently, ports cannot do anything with their position in maritime logistics. However, the inefficiency of transport units is expected to have a significant leverage on ports due to the increasing container flows for international trades. That is, the more ports deal with shipping containers that have space, the more the inefficiency can be accumulated in requiring unnecessary usage of resources, such as more unloading operations by quay cranes, more area in the storage yard, and more transport by internal vehicles in ports. In-line with trends in maritime logistics, ports have potentials to cope with the inefficient space usage in transport units for not only their benefits but also for the entire maritime logistics chains. In the light of PI, modern ports can have a new operational process by exploiting three-tiered loading units (i.e., modular containers). The typical VAS, which highly uses the modularity in freights, is composition and decomposition of shipments. Currently, the logistics center receives shipments in the form of goods or small boxes that contain the goods by unloading them from a shipping container. Then the goods or small boxes are handled by the internal transportation modes of the logistics centers with pallets.

Besides limited their operational role in maritime logistics chains, ports are confronted by another challenge to resolve the issue on inefficient space usage in transport units: lack of visibility information on containers. At present, ports are only accessible to public and network data of containers, which cannot represent internal contents of the containers as well as details shipping information about them. The accessibility of information should be arranged in a negotiation table with actors who are potential information sources.

Besides limited information accessibility, there is still room for improvement in the way of information exchange in the modern ports. Although EDI has been available to port-related actors (i.e., ports, shipping companies, and inland transport suppliers), most cases in ports use manually entered information on containers based on their manifest. Also, modern ports rely on the bilateral information exchange when they communicate with shipping companies and in-land transport suppliers under the authorization of LIS.

To conclude, modern ports should extend the range of their operations in order to contribute to the current issues on loading units. The ports cannot perform the new operations due to the limited information accessibility. That is, ports should explicitly perceive which contents of information they need and with whom they need to negotiate to receive the information. Lastly, ports can improve the bilateral communication by integrating the T&T system of ports with other LISs in different way.

In the following chapter, requirements on the three PI' components are clarified. That is, how the three PI's elements should function in PI ports for points of improvement in modern ports? The next chapter will help to bridge the gap between modern ports to PI ports with the requirements

5

Requirements for PI ports

This section particularizes how can the three PI's components fill the room for improvement in modern ports. That is requirements to transform current ports into PI ports. This project has applied two phases in the requirement engineering process (i.e., requirement elicitation, and requirement analysis) to gather and analyze the requirements on PI ports as mentioned in Section 3.1.2. A use case is used to elicit requirements on PI ports by representing expecting functions of the primary PI components. Additionally, the requirements on each PI component has been highlighted one by one in the step of requirement analysis.

This Chapter is structured with the two phases of requirement engineering. Moreover, it has identified limitations of the use case before reflecting them into a tentative design of PI ports, which is covered in Chapter 6. The boundaries are derived from assumptions of the use case, and furthermore, the points of improvement in modern ports are traced whether all points are covered using the three PI elements.

5.1 Use-Case based Requirement Elicitation

In the section, a use case can be explained in two ways: use case scenario and use case diagram. The author emphasizes operational uses of modular containers in the use case scenario. On the other hand, the use case diagram represents functions of T&T system in ports with the focus on the necessary contents of information and informational roles of other actors. As foundation of the use case scenario, a practical case in PCL has been firstly introduced. Then the core problems in this project have been clarified again in the context of the case before formulating the use case of PI ports.

5.1.1. Practical Case study on PCL

The modularity on loading units is the fundamental idea in (de)composition operations in helping shipments to be placed into appropriate units. The arrangement in loading units ultimately leads efficient handling and transport of shipments within logistics chains. PCL has a variety of successful cases that show the modularity on loading units is available for ports in contrast with uses of the single loading unit. In particular, this project is based on the case of Teesport due to potential applicability of modular containers in their fundamental VAS, repositioning operations.

Teesport in PCL
The concept of PCL and its best practice cases have been intensely researched to generate a plausible use-case based on PI's components in this project. This is because ports in the context of PCL are

highly willing to seek new opportunities to boost their competitiveness within maritime logistics chains. Also, repositioning operations are subject to one of the main interesting VAL for ports as already covered in Section 2.1.4. Thus, this project supposes ports in line with PCL are interested in the application of PI's components as a potential first-mover towards PI within maritime logistics.

There are various best practice cases of PCL in the UK where most containers, namely 70% of importing containers, are handled by deep-sea containers ports in the South and East of England. Whereas distributing operations are dominantly centered in West Midlands, which controls 43% of the total (Bisogno et al., 2015). This logistics pattern implies transport imbalance that might lead the decline of the regional port industry as well as ports congestions and transport costs.

This project more focuses on the case of Teesport where container throughputs have visibly increased with the help of PCL. Figure 5.1 displays the success of Teesport with rankings of containers throughput in top 15 UK ports over the last decade (Monios & Wilmsmeier, 2014). Once ensuring the increase of container throughputs, the next challenge in Teesport will be inherent visibility limitations on containers in operations. Hence, this project suggests the use of PI's components and relevant information flows for repositioning operations as a potential solution on the visibility limits. Detailed application of PCL in Teesport has been covered in Section 5.2.
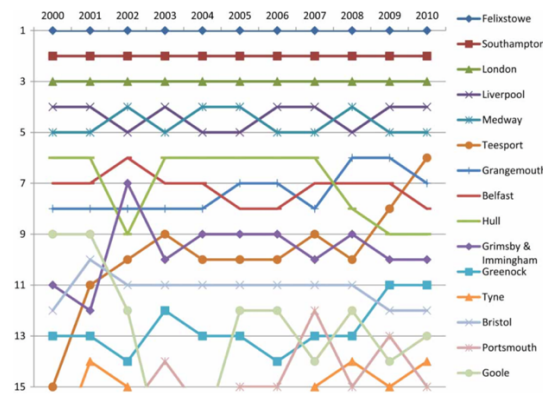

Figure 5.1 Container throughput rankings of UK ports (Bisogno et al., 2015 adapted from DfT, 2011)

Tesco Distribution Center in Teesport

As a successful case of PCL, the port of Tees has overcome geographical limits in Northeast England. The location might not be preferable by shipping companies because of the longer travel time compared to southern ports (Song & Panayides, 2015). To attract shipping lines, PD ports—the owner of Teesport—focused on the trend of large retailers that are willing to move distribution operations to near the ports (Falkner, 2006). Therefore, Teesport invested £300 million in facilities used for distribution center-related activities (Jones & Robinson, 2012). As a result of the first movement in port-based distribution, Tesco—one of the UK's major retailers—opened their distribution center in an entry of Teesport, resulting in additional shipping flows to the port.

As a part of the strategy to simplify supply chains, Tesco places more weight on the distribution centers of Teesport based on the port's capability as a feeder. In other words, Teesport is capable of offering diverse networks through roads, rails, and sea and can reach cities scattered in all directions (PD Ports, n.d.).

Applying the same method as Mason et al. (Mason, Pettit & Beresford, n.d.), the advantages of the distribution center in Teesport can be emphasized by an assumption without the distribution. Figure 5.2 illustrates two cases, one that equips the distribution center within Teesport and another that does not. Focusing on the shipment flows toward Tesco retail stores near Teesport, shipments can be

transported directly using distribution operations at the distribution center in Teesport. On the contrary, if Tesco did not open the port-centric distribution center in Teesport, the neighboring retail stores were fed by another distribution center, Doncaster, as seen in Case 2 in Figure 5.2. In the latter case, shipments are likely to take much time, be costly, and cause high CO_2 emissions.
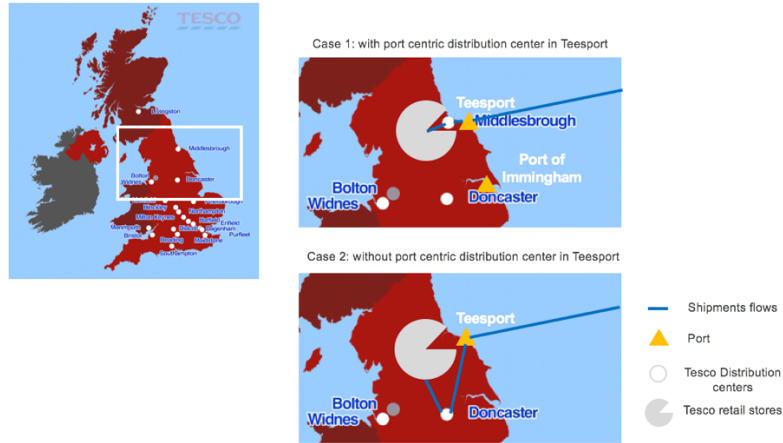

Figure 5.2 Concept of port-centric distribution for use case
(Adapted from Tesco Distribution Centres, 2017)

5.1.2 Problem Alignment

This section aligns the two main concerns on freights (i.e., waste of space in loading units and the invisibility of shipments) with the context of ports. The problem statements with the viewpoint of ports can be an explicit ground of following use case scenario and diagram on PI ports.

The problem statements in Table 5.1 and 5.2 are based on actors as in the practical case of Tesco. Briefly explaining, international manufactures send their products to Tesco via the destination port (i.e., Teesport) with helps of freight forwarders and LSP. A crucial point in the case is Teesport offers repositioning operations and Tesco can directly receive products from Teesport. The problems have been explained with related actors, their impacts, and successful solution with the PI's components of this project.

Table 5.1 Empty space in containers

Problem	**Container Empty Space** Shipping containers arrived at Teesport are not in the best use of space as represented with empty space in the containers. This is because contents of the containers have been formed in different shapes depending on freight forwarders.
Related actors	Tesco, Manufacturers, and Final customer of Tesco
Impacts	The empty space in containers might: • increase transport lead time • increase transport costs by affecting efficiency in resource utilization, such as inland transportation modes, vessels, and storage space • lead adverse effect on the environment consistent to inefficient uses of resources in logistics chains

	• rise final price of final products and decrease market competitiveness of manufacturers
Successful solution	Logisticians introduce modular containers aiming for efficient utilization of space in containers. In this project, ports in the context of PCL reduce the empty space of containers by means of modular containers.

Table 5.2 Lack of data in repositioning operations

Problem	**The Lack of visibility on contents of shipping containers** Teesport cannot know contents of shipping containers that have been generated or owned by manufacturers, freight forwarders, and LSP.
Related actors	Teesport, Manufacturers, Tesco, and Freight forwarders, LSP
Impacts	The lack of data on contents of shipping containers precludes ports from performing repositioning operations. As a result, all expecting benefits in PCL cannot be achieved in Teesport.
Successful solution	Teesport is authorized to access to external data, namely information on shipments from manufacturers, freight forwarders, and LSP under prior consent—termed global protocol in PI. Information sharing between ports and other actors is available through open interface web which is a single point for all actors in logistics chains.

5.1.3 Use-Case Scenario

The use-case scenario visualizes potential uses of the three PI's elements in Teesport which described as successful solutions above. Frist of all, the primary precondition should be acknowledged for better understanding the use-case scenario. Then the use case scenario describes the logistics chain and relationships between actors in more detail. Lastly, the use of modular containers in the repositioning operations in Teesport is illustrated.

Primary Pre-Condition

The use case supposes that the port of destination, Teesport, is the first logistics point at which to apply modular containers in a logistics chain to emphasize the roles of modular containers in the use case. That is logistics points ahead of Teesport encapsulate shipments in their particular ways without adopting modular containers, for instance using smaller boxes. Then Teesport can decompose the shipments from previous logistics points to rearrange them with the use of modular containers by leading the efficiency in space utilization, handling operations, and modular tracking and tracing.

Even though the actual implementation of PI might aim to widely distribute modular containers to logisticians in logistics networks in the world, this case is limited to a single logistics chain. Therefore, the use case can represent the roles of modular containers with a restriction on the usage of the containers for some logisticians.

Although techniques to identify the public data on containers are out of scope in this project, this use case assumes all tiers of modular containers embed smart tags to reduce ambiguity in information flows. That is, containers are capable of providing the public data directly to PI ports.

Teesport capable of repositioning operations with modular containers

A clothes manufacturing company, Todag whose factory is placed in Shanghai, have a supply contract with a British grocery and merchandise retailer, Tesco. As an existing partnership between Tesco and

PD ports, the owner of Teesport, Todag needs to transport their clothes via Teesport where containers can be rearranged before leaving for retail stores of Tesco. Under the same condition of contract with Todag, TeiVei Corp. plans to supply its TV sets from a factory in Hong Kong via the port of Hong Kong and Teesport.

The manufacturers forwards products by using their usual logistics network mediated by LSP, therefore Todag corp. used to exploit the port of Shanghai through inland transport suppliers and freight forwarders, named as X in Figure 5.3. Whereas, TV sets made by TeiVei corp. are transferred to the port of Hong Kong through logisticians Y. Although the manufacturers utilize different port of departure, their products are coming into the same port of destination, Teesport.
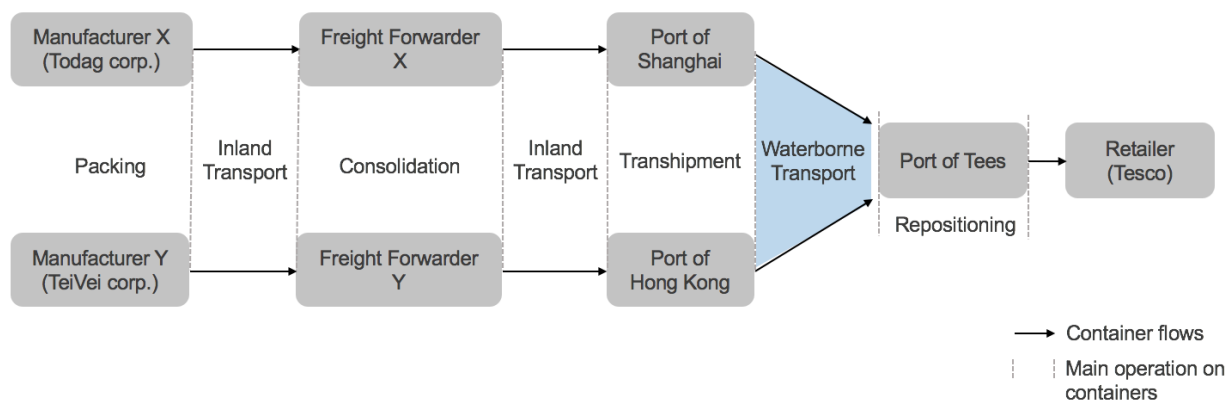

Figure 5.3 Overall logistics chain of the use case

Especially in this use case, it is assumed that the orders on clothes and TV sets are to restock one of Tesco Superstore in a town of Billingham, 14 miles from Teesport. That is, shipments are supposed to be transported to the same final destination in Billingham.
However, time windows on the shipments are diverse according to the level of stocks and characteristics of goods. In the use case, the Tesco Superstore still have enough stocks on T-shirts expecting to be out of stocks within 20 days. Whereas, the store requests faster shipping for TV sets and swimsuits due to the low stocks of TV sets and closing of seasonal sales on swimsuits.

In the use case, two primary shipping containers are transported from the port of Shanghai and Hong Kong to Teesport, as presented in "inbound containers" in Figure 5.4. Teesport strips the shipping containers to make them into smaller units which are not modular containers, but they are smaller than shipping containers. The smaller containers are packed by logisticians in logistics centers before arriving at Teesport, and they are distinctly marked in black boxes, whereas modular containers are shown in colored boxes: yellow and green.

Before encapsulating the smaller containers in modular containers, Teesport sorts them under the same next destination and time window. Considering Tesco's requests on time window, the T-shirts that were separately packed in two smaller containers in a shipping container from Shanghai can be newly grouped into a new H-container that is marked in yellow. Teesport can store H-containers until they reaching a minimum dispatch unit, along with other containers that have the same destination and time window.

Due to the decomposing operations on shipping containers, it is also possible to assemble shipments that are placed in different shipping containers. In this use case, TV sets and swimsuits bound to the same destination and time window can be encapsulated in the same H-containers for the

best use of space, as depicted by the green boxes. In the same manner, other shipments that are supposed to be delivered to Tesco Superstore in Burham can be put into the same group in case they have the same transport information regarding next destination and time window. This situation is shown by the dummy shipments in blue boxes in Figure 5.4. Lastly, Teesport can compose all grouped H-containers into a singular T-container according to the best use of space.
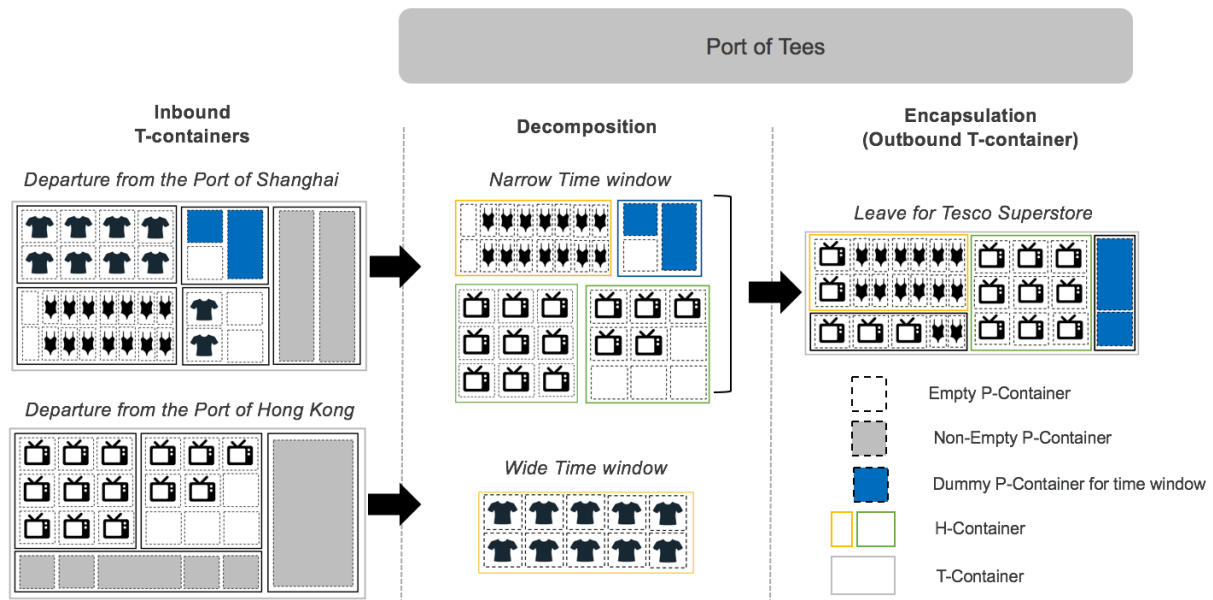

Figure 5.4 Potential use case of modular containers in repositioning operation

5.1.4 Use-Case Diagram of T&T system in PI Ports

The use case diagram represents what Teesport's operators can do with the T&T system and more importantly, what contents of information need for repositioning operations. The use case scenario is heavily referred to come up with the functionalities and contents of information along with operations in PI ports.

In Figure 5.5, the port terminal operator in Teesport has been marked in blue as the main user in T&T system. At first, the T&T systems in PI ports can gain visibility of two inbound containers from the ports of Shanghai and Hong Kong by accessing their public, network, and shipment data in the open interface web platform. This information access is preapproved by the manufacturers, namely Todag and TeiVei Corp. in the use case, and two LSPs for each manufacturer's logistics network. After repositioning operations based on the public, network, and shipment data, the T&T system can be used to identify updates in packaging with the use of modular containers. The modular containers might have different packing lists, next destinations, and time windows. Hence, these changes in network and shipment data should be shared with LSPs through the open interface web.

With the modular containers, the system can T&T containers and consider them in separate modules, that is, in three different tiers: P-containers, H-containers, and T-containers. Moreover, tracking and tracing data about the modular containers can be provided in the open web platform mainly for LSPs, inland transport suppliers, and consignees with a different levels of information access.
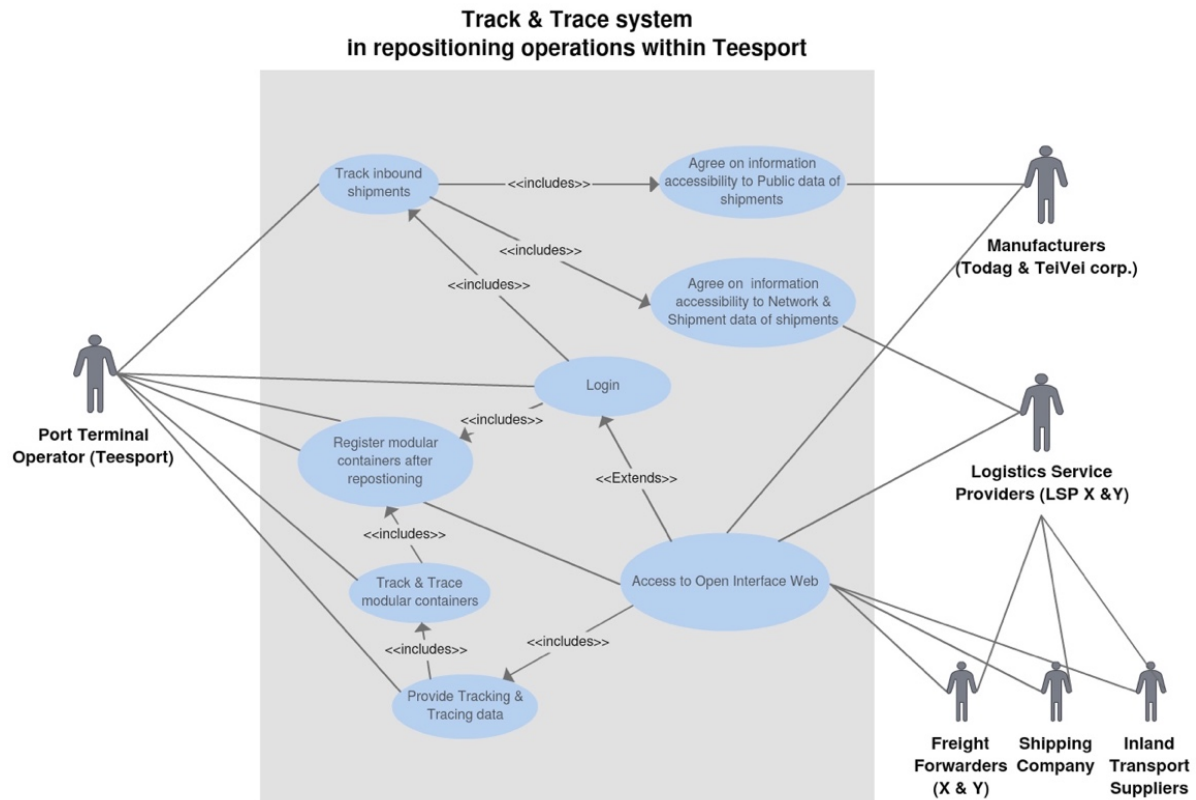
**Track & Trace system
in repositioning operations within Teesport**

Figure 5.5 Use case diagram on T&T system in Teesport

5.1.5 Use-Case Description

The use-case description summarizes the use case scenario and diagram by synthesizing them into a context. The use-case description is composed of three essential: (1) Precondition, (2) Success guarantee, and (2) Trigger (A, 2010). Preconditions stand for states that a system must have to begin a use case. Core precondition is already covered before the use case scenario, but implied conditions are elaborated in this use case description. Success guarantees describe the system's state with its successful run based on main actors' interests in the use case. Lastly, potential events start the use case are covered as Trigger (Cockburn, 2000).

Use Case:
Teesport's Track &Trace (T&T) system in repositioning operations with the help of PI's components

Stakeholders and Concerns:

Table H.4 Potential users of the PI's open interface and their primary interest
(Adapted from Heaver et al., 2000)

Potential users of PI open interface	Name in the use case scenario	Main concern
Consignor & Consignee	TeiVei and Todag manufacturing corp. & Tesco	• Minimization of total logistics service and time cost • Reliable T&T information on shipping items
LSP & Freight Forwarder	LSP X and Y & Freight Forwarder X and Y	• Maximization of profit • Customer satisfaction • Advanced visibility of shipments

Primary actor: Teesport operators

Precondition:

1. Teesport is capable of encapsulating shipments in more efficient way by equipping diverse types of modular containers and strategies as the first mover in application of modular containers in the logistics chain.
2. The modular containers used by Teesport bear a smart tag regardless of their levels, therefore all levels of containers – Packaging, Handling, and Transport containers – have their own smart tags.
3. With modular containers embedding smart tags, Teesport can track and trace the containers not only within the port, but also in other logistics centers after leaving from Teesport.
4. Critical to this use case, actors in the logistics chain have gone through prior consent on the extent of information accessibility according to their relationships in the chain.
5. Through prior consent between LSP and their partners, Teesport is accessible to shipment information by the level of "Shipment data" including Public and Network data in Modulushca Common Data Model.
6. To share the external, Teesport has registered in an open interface web platform that other actors are also involved.

Success guarantee:

- Teesport benefits from modular containers by increasing space utilization in each loading units.
- T&T system in Teesport is capable of providing T&T information on modular containers with item-centric visibility after repositioning operations.
- T&T system in Teesport is accessible to information on contents of containers (i.e., the public, network, and shipment data) through PI open interface web.

Trigger:

- Teesport operator has asked for information on inbound containers for repositioning operations.
- Requests for T&T information on modular containers have been transmitted from the open interface web to T&T system in Teesport.

5.2 Use-Case-Based Requirement Analysis

Although the use case scenario and diagram on Teesport have implied requirements on the major PI elements, it is difficult to grasp explicit requirements from a story. Therefore, this section examines functionalities of each PI component to clarify how the elements should behave in the PI ports.

5.2.1 Operation: Modular Container

Modular containers should be distributed in logistics chains to suit operational purposes. The use case scenario shows Teesport should be capable of handling and transporting all levels of modular containers to perform repositioning operations. That is, packaging, handling, and transport containers.

Under the scenario assumption, uses of modular containers in a downstream logistics chain has been mainly visualized in Figure 5.6. This possible distribution will be important to represent operational and informational dependencies between a destination port, transposed to Teesport, and other logisticians in the downstream chain.
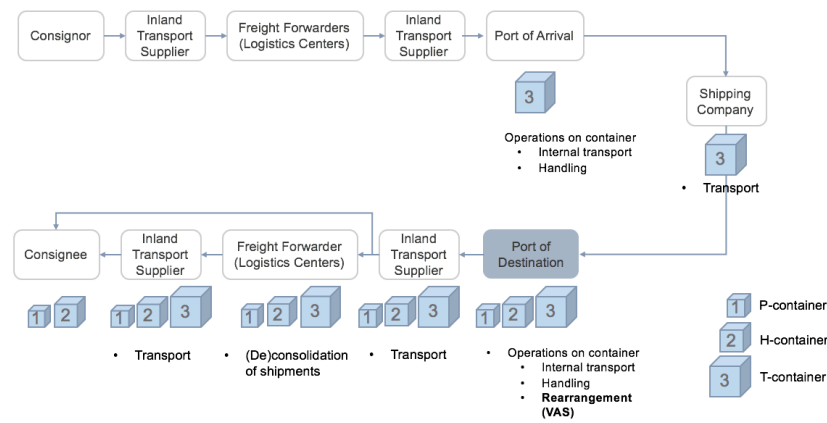

Figure 5.6 Potential handling units on modular containers according to actors' roles

The containers from the PI port can be transported to logistics centers or they can be directly to the final consignee after the reconsolidation service is provided. If logistics legs are not required between the port of destination and the consignee, then the port can hand over the shipments in the form of T-containers, H-containers or P-container to the inland transport supplier. Thus, the consignee can receive P-containers or H-containers each from H-container and T-container. Although an outbound container is depicted as T-container in the scenario, outbound loading units can be flexible with different levels of modular containers.

5.2.2 Open Interface Platform

One of the crucial differences between traditional ports and PI port is the use of an open interface platform. The open web platform plays the role of an intercommunication channel through which actors in a logistics chain can exchange information. In the platform, PI port should perceive exactly which information about modular containers should be shared, herein called "contents of information." That is, contents of information associated with the repositioning operations from the viewpoint of ports.

As seen in the use case diagram, Teesport need to receive not only the public and network data on modular containers, but also their shipment data. The shipment data in the Modulushca data model includes identity of sender and receiver, source address, description of goods, value, time window.

Particularly, the next destination and time window are significant in repositioning operations in PI Ports.

Although four categories in the Modulushca data model were designed for only H-containers within the scope of the Modulushca project, they can be stretched to all three tiers of containers in this project, including P-containers and T-containers. Hence, each tier of modular containers can have four types of information in this project, as illustrated in Figure 5.7. This extended information model helps to discuss information accessibility on each container tier in the next section.
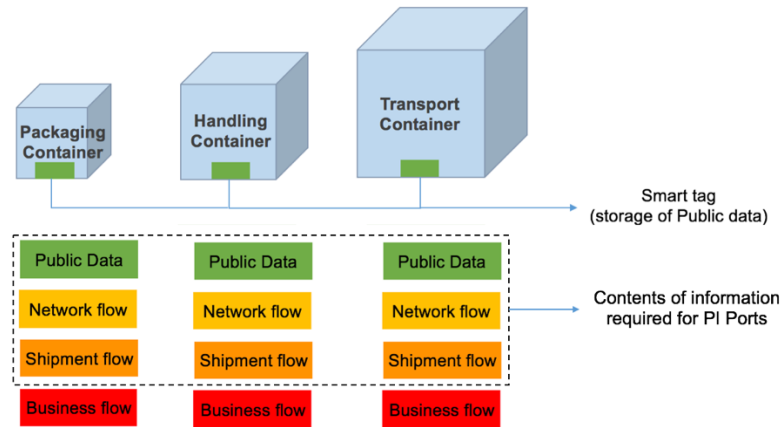

Figure 5.7 Data model aligned with three tiers modular containers
(Adapted from Tretola, Biggi, & Verdino, 2015)

5.2.3 Standard Protocol

The operational change of Teesport requires additional information in its T&T system as described in the use case scenario and diagram. As discussed above, the PI port should be accessible the shipment data of all tiers of modular containers as well as their public and network data. For the additional information, the PI port should rearrange the extent availability of information with port-related actors. Standard protocol suggests explicit information accessibility on three levels of modular containers by analyzing who are in power as information sources.

First of all, the author has redefined port-related actors by adapting Modulushca data model as explained in Section 2.3.4. The model has been built with general supply chains without considering the characteristics of maritime logistics and its actors. Therefore, the actors had to be aligned with the context of maritime logistics. The new classification on actors includes four categories: carrier, VAS provider, LSP, and the ultimate customers of logistics services (the customers). Carriers have a responsibility to transport modular containers from one destination to another in compliance with the requests of consignors, freight forwarders, 3PLs, or 4PLs. For the carriage of containers, they can handle them, such as loading, unloading, sorting, and storage. In a logistics chain, inland transport suppliers and shipping companies that are also considered to be carriers. Carriers not only physically transport containers but also add value, as mentioned in Section 2.3.5. The logisticians involved in the operations of consolidating, de-consolidating, or reconsolidating containers can be called VAS providers with potential leverages on containers. This project considers freight forwarders in logistics centers and port terminal operators to be VAS providers. Even though LSP might carry out VAS operations, they assign the operations to VAS providers in this context under contract with them. Thus, they are qualified to know the statuses of both container transport and operations.

On the basis of the potential handling units covered in Figure 5.5, the categorized actors can be matched to the available information depending on different modular tiers, as seen in Table 5.3. The

final customers and LSPs can access all data, regardless of the various tiers of modular containers. That is, they are authorized to receive all information about modular containers. Carriers have relatively limited accessibility, but each carrier can be granted access to different tiered containers according to their positions in maritime logistics. Inland transport suppliers in the downstream logistics chain can be fed by the PI port in diverse levels of modular containers. Depending on the level, network data can be accessible either in T-container, H-containers, or P-containers. For example, if the PI port hands over shipments in P-containers then inland transport suppliers should know the network data of the P-containers. Critical to this project, ports are allowed to access shipment data on three modular containers. They are not limited to network data as in the original Modulushca data model.

Table 5.3 Data accessibility depending on roles of actors with modular containers

(Adapted from Tretola, Biggi, & Verdino, 2015)

Container Tier	Final Customer	Carrier		VAS Provider	LSP
	Consignor/ Consignee	Inland transport supplier	Shipping company	Freight forwarder/ PI Port	3PL/ 4PL
1. Packaging Container	- Public - Network - Shipment - Business	- Public - (Network)	- Public	- Public - Network - Shipment	- Public - Network - Shipment - Business
2. Handling Container	- Public - Network - Shipment - Business	- Public - (Network)	- Public	- Public - Network - Shipment	- Public - Network - Shipment - Business
3. Transport Container	- Public - Network - Shipment - Business	- Public - Network	- Public - Network	- Public - Network - Shipment	- Public - Network - Shipment - Business

However, PI ports may not know with whom they need to collaborate to achieve the information access about modular containers. Therefore, data sources about the three types of information in the Modulushca data model are traced based on literature on current logistics systems. The literature reveals that public data has been created by a consignor, whereas the LSP takes charge of network and shipment flow as an intermediary in the current logistics chain (Kärkkäinen et al., 2004; Klievink et al., 2012).

Concerning PI ports, the public data of P-containers is created by an original consignor, LSP, or freight forwarder while that of H-containers and T-containers can be changed through the handling operations of VASs providers (mainly PI ports with repositioning operations). Through the operations of PI ports, data on the network and shipment flows of modular containers can be rearranged as well.

Table 5.4 summarizes each data source based on the three types of information, allowing for comparisons between current ports and PI ports.

Table 5.4 Types of information of a logistics chain & their data sources
(Adapted from Tretola, Biggi, & Verdino, 2015; Kärkkäinen et al., 2004; Klievink et al., 2012)

Tier of Modular Container	Types of Information	Data Source of T&T System in Ports	
		Current Ports	PI Ports
Packaging container	Public data	LSP	Consignor
	Network flow		LSP/ Freight forwarders
	Shipment flow		
Handling container	Public data		LSP/ Freight forwarders/ PI ports
	Network flow		
	Shipment flow		
Transport container	Public data		
	Network flow		
	Shipment flow		

5.3 Limitations of Use Case

There are several limitations in this use case from emphasizing leverages of the three PI's components in the perspective of ports. Frist of all, this use case is set in a single logistics chain with the focus on the specific destination port—Teesport. As a result, the case has been simplified in considering only two consignors in the chain however, more actors can be involved in real maritime logistics chains. Also, the use case cannot show diverse outbound loading units within the limited background. That is, the outbound unit is described as a T-containers but it can be P-containers and H-containers.

The use case supposes only Teesport, namely the destination port, is capable of exploiting modular containers within the chain. With this assumption, the use case can highlight benefits from modular containers within the limited location. If the use case assumes other logisticians can use modular containers, advantages of using the containers could seem scattered throughout the whole logistic chain. Additionally, the assumption reflects the trend in maritime logistics that downstream operations close to final consignees is regarded as a promising business. In this context of the use case, a destination port is adjacent to the downstream compared to a departure port. However, it is quite different from ultimate PI's vision aiming for introducing modular containers throughout logistics centers.

Besides limitations from assumptions, the use case has not precisely described the last point of improvement in modern ports. In Chapter 4, the analysis of the current port logistics systems has concluded the room for improvement:

- Operational services in ports within maritime logistics
- Additional information in the T&T system of ports
- Arrangement between actors about information accessibility
- The way of information exchange between the T&T system in ports and external LISs

The first three points of improvement have been covered with requirements on the three PI's elements respectively. That is, modular containers in the use case allow the PI ports to perform the new VAS, repositioning operations. For the new operational service, the necessary contents of information and accessibility have been mentioned as requirements of the open interface and global protocol. However, the use case diagram did not precisely suggest the way that the T&T system in PI

ports interacts with the open interface. This is because the existing literature on PI has not clarified the method of system integration. Therefore, this project will discuss the optimal method of system integration in accordance with PI's vision.

5.4 Salient Implication

This chapter has elicited and analyzed requirements on the three PI components in PI ports. As the second phase in V-Model, the chapter applied a use-case approach into requirement engineering. Its main findings can be summarized by answering the second research question: Which requirements should be considered for the T&T systems of PI ports?

The question consists of three sub-questions as follows:

2.1 What are operational and informational use case of the PI's components in PI ports?
2.2 What are requirements on the three PI's components in PI ports?
2.3 What are limitations of the use case considered in a design of PI ports?

The three sub-questions can be answered each following sections.

5.4.1 Use-Case of Major PI Components

The use case shows that the potential effects on the usage of three PI's components can be synergized with those of decomposing and composing VASs by PCL. The use case has been twofold: (1) use case scenario and (2) use case diagram. The operational applications of modular containers are covered in the use case scenario. While the use case diagram describes functions of T&T system in PI port, requires interactions with other actors due to information exchange.

The use case scenario verifies modular containers allow loading units in the PI port to have a marginal waste of space through repositioning operations. The scenario has illustrated a procedure of repositioning operations that the PI port decomposes inbounding T-containers to recompose their contents into H-containers by considering the next destination and transport time window. Although this advantage in space utilization had been predictable only with the idea of modular containers, the benefit is visible in the use case established under the plausible scenario.

The use case diagram shows possible functions of T&T system for the PI port: (1) access to the open interface, (2) track inbound shipments, (3) register modular containers after repositioning (4) track and trace modular containers and (5) provide tracking and tracing data. These are fundamental functions of T&T system based on the repositioning operations in the use case scenario. More importantly, the use case diagram represents the PI port should be accessible not only the public and network data but also to the network data for repositioning operations.

5.4.2 Requirements on Major PI Components

Requirements on each PI element has been analyzed in more detail because it is difficult to capture them from the use case described in a story. The requirements are herein summarized with the three PI elements: modular containers, open interface, and global protocol.

- Modular Containers: PI ports should have physical accessibility on all three tiers of modular containers to perform repositioning operations. In repositioning operations, PI ports need to determine appropriate modular containers for the best use of space. Also, the next destination and delivery time window should be taken into account.

- Open Interface Web: PI ports need to be accessible to the public, network, and shipment data on modular containers in the open interface web. These contents of information are prerequisites to perform repositioning operations.
- Global Protocol: PI ports have to induce port-related actors to provide their information into the open interface web. Especially, consignors, VAS providers, and LSP can be significant information sources for PI ports in connection with repositioning operations. Consignors provide the public data on P-containers whose network and shipment data can be generated and updated LSP and VAS providers. The public, network, and shipment data on H-containers and T-containers can be accessible to LSP, VAS providers including PI ports.

5.4.3 Limitations of Use Case

Limitations of the use case can be summarized into three:

- Limited involvement of actors in a single logistics chain
- Limited cases on outbound loading units in a single logistics chain
- Distribution of modular containers limited to PI ports
- Ambiguity on system integration between the T&T system in PI port and the open interface

These limitations can be a foundation of the preliminary conceptual design ahead of a design of PI ports.

6

Conceptual Design of PI Ports

The ultimate goal of this chapter is to suggest a conceptual design on PI ports utilizing the adjusted RAMI 4.0. For the purpose, this chapter is composed of three sub-sections: (1) preliminary conceptual model, (2) design on PI ports, and (3) significant milestones ahead of PI ports. In the first section, limitations of use cases from chapter 5 have been first explored to reflect them into the design in-line with PI's visions. Then, the conceptual model of PI ports is covered in the second section. Lastly, the third part has suggested critical factors that might impact on the feasibility of PI ports for the further consideration.

6.1 Preliminary Conceptual Design

As briefly mentioned in Section 3.1, the preliminary conceptual design helps to eliminate unacceptable design alternatives, also called design spaces (Sage et al., 2000). In the light of the limitations of the use case, requirements on the way of system integration are still missing in the existing PI research. Recent research in PI has described the open interface as an enabler connecting physical objects with one another through Internet—World Wide Web (Montreuil, 2010). However, the PI has hardly suggested a particular information architecture for the open interface, that is how T&T system in ports can be interconnected with external LISs in maritime logistics? On the other hand, lots of research on port community system (PCS) have been suggesting alternatives on system integration. This project can explore the alternatives on PCS because it also aims for integrating LISs of port-related actors in-line with PI's vision.

6.1.1 Design Choice on System Integration

Firstly, the concept of PCS and the current system integration is analyzed. Three alternatives are discussed in the context of a port whose T&T system need to be interoperable with PI open interface. Then the optimal design alternative is decided with the help of simplified utility theory. Lastly, technical details on the design choice are covered to be used in building a conceptual design on PI ports.

Port Community System
The open interface web in PI corresponds to Port community system (PCS) that has been adopted from a single window by aiming for an advanced information exchange between actors in maritime logistics. The single window system has a single-entry point (i.e., electric platform) that manages the standardized information and documents of every activity, such as export, import, and transit. The concept of single window has been applied to relatively limited coverage, maritime logistics chains

with ports as the center. In a PCS, ports and port-related actors can access the electronic data interchange (EDI) information on transportation, logistics processes, and commercial in an easy and efficient way ("Port Community Systems," 2014). Moreover, all operational information about freights is electronically handled. Therefore, PCS can offer its system users tracking and tracing services for their freights, along with the entire logistics chain. Customs declaration has been the main concern in literature on PCS to reduce the amount of paperwork involved. However, this project more focuses on visibility of freights for the new business in ports, repositioning operation.

A roadmap on PCS has divided the PCS in five stages according to the the United Nations Network of Experts for Paperless Trade and Transport in Asia and the Pacific (UNNExT, 2015). Going into detail, PCS can be described in five levels according to the time for emerging and potential benefits. The higher the level of PCS, the more time it takes to be implement and the more values the level have. Each level of PCS is explained as follows behind and the PCS roadmap is illustrated in Figure 6.1 (Keretho, 2011).

- Level 1 (Paperless Customs Declaration System): in the first level of PCS, EDI is available for customs declaration, submission of loading list on containers, and customs payments.
- Level 2 (Integration with Regulatory bodies): extending the first level of PCS, this level of PCS corporates with additional government bodies' information systems enabling for uses of EDI information on permits and certificates by Customs Department.
- Level 3 (PCS in major seaports and airports): in the third level of PCS, actors involved in sea/ airport logistics chains can exchange EDI information with one another for efficient operations. Notably, many countries have been developed this level of PCS exploring an opportunity to transform them into the fourth PCS. For example, Portbase in Port of Rotterdam, Dakosy in Port of Hamburg, and Portic in Port of Barcelona.
- Level 4 (An Integrated National Logistics Platform): the range of actors in information exchange is extended into importers and exporters within a country.
- Level 5 (A Regional Information-Exchange System): the fifth level of PCS is capable of supporting EDI information exchange across different continents.
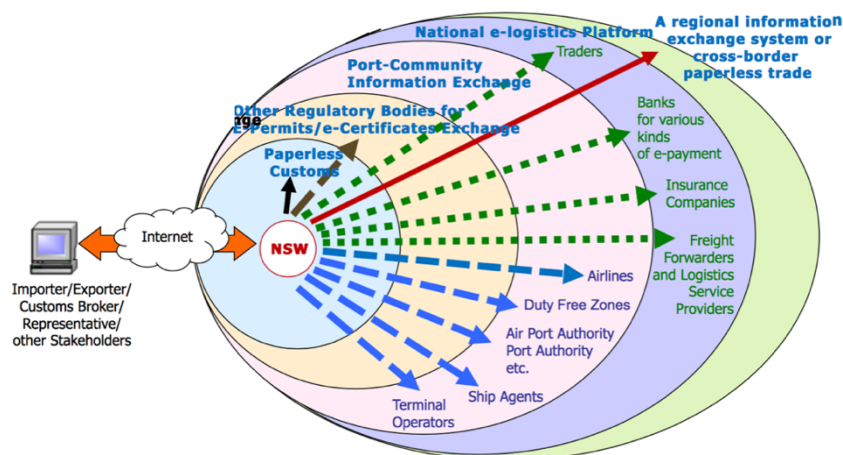

Figure 6.1 Port Community System roadmap (Keretho, 2011)

In the roadmap, the open interface web in PI can match with the last stage of PCS—regional information exchange system. The PCS is available for information exchange at global level in accordance with a vision of PI that pursues a universal interconnected logistics system.

Design Alternatives on Information System Integration
As a part of the Seventh Framework Program (FP7) funded by the European commission, the project of e-compliance proposed comprehensive analysis on integration between PCS in four categories. Other literature also suggested alternatives, normally bilateral information model, centralized and decentralized model (Kersten, 2011; Sonderegger, 2010). However, this section has mainly covered works in e-compliance that encompasses the alternatives from other literature with keen insight.

According to e-compliance, there are four design alternatives in integration of PCSs: (1) bilateral message exchange (2) full reciprocal system integration (3) multilateral message exchange, and (4) central PCS as seen in Figure 6.2 (e-Compliance, 2016). The first design—bilateral message exchange—based on the least integration possible. In this arm's length integration, different two systems can share specific data or messages. More attractively, this bilateral design can be expanded by linking with the number of PCSs through a central platform on a national or Europe scale, which is described as the third design—multilateral message exchange. The system designed for the multilateral message exchange can collect proper data from data servers in each PCS into a central platform, that is each PCS is decentralized.

In the second design, full bilateral system integration, two PCSs share a single information system with the help of the same interface. Although this type of integration is highly desired in enabling two PCSs to reflect their local specifics into the integrated system, however, it might be challenging to align various local regulations into the single system in practical cases. In-line with the second design, a central PCS in the fourth model provides a united front-end interface of PCS (i.e., a single web platform) for the number of PCSs while keeping their own PCS for locally-specific functions.
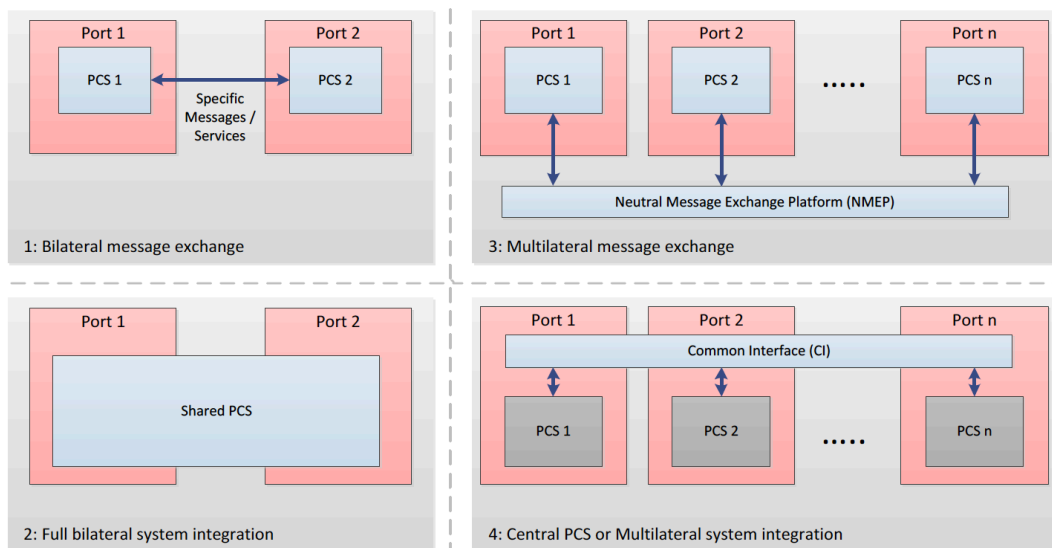
Figure 6.2 Four types of PCS integration (e-Compliance, 2016)

Design Decision on Information System Integration in PI
The T&T system in modern ports has communicated with external PCSs in the bilateral manner—the first design alternative. The activity diagram covered in Section 4.1.3 describes the bilateral information exchange between ports and LSP, shipping company, and inland transport supplier.

Interviewees in the e-Compliance project (2016) pointed out the lack of market power of actors who might benefit from the PCS. This is reason why PCSs in Europe are scarcely integrated today. This project proposed the new business on repositioning operation for ports by means of PI that will

increase their market power in maritime logistics. For this, this section has suggested the optimal way to share information between T&T system in ports and the PI open interface. Except for the first alternative (i.e., status quo), the rest design alternatives are simply compared with four criteria, commonly used when selecting information system architecture (Pearlson, Saunders & Galletta, 2016):

(1) Adaptability: the possibility that an information system is implemented with marginal impacts on existing business principles and operations.
(2) Scalability: the ability for an information system to adopt to increased or decreased. In the context of PI, the scalability can signify the capacity for a number of LISs at global scale.
(3) Security: an extent a potential information system can maintain its assets safely. Commonly, centralized systems that store and execute data in a mainframe computer are considered more secure than decentralized systems. This is because the decentralized systems consist of diverse servers to interconnect with one another, and every server should be protected in the context of security.
(4) Expected investment: potential initial costs to integrate LISs. Although there are more profound financial criteria based on cost-benefit analysis, this is beyond of the scope in this project.

Three design alternatives have been evaluated through these criteria based on SWOT analysis in e-compliance (Appendix D).

- Alternative 1: Full bilateral system integration

  The full bilateral system integration is barely suitable for the integration between T&T system of ports and the PI open interface web due to its limits on scalability. Under the vision, interconnectivity, PI envisions integration not only with a single LIS, but also various LISs throughout maritime logistics chains.

  Besides the scalability, it might be technically easy to integrate existing two systems in reciprocal manner. However, at the same time, a strong contractual agreement should be preceded between two system operators, which can hinder the integration.
  The number of systems to be integrated is two, hence the implementation costs will be relatively low. Additionally, the system can be easily secure as it is centralized for two systems and exclusive to other LISs.

- Alternative 2: Multilateral message exchange

  The multilateral message exchange can be the optimal solution for system integration in PI among all alternatives. Contrast to the full bilateral system, it is scalable only needed to add another arm's length link for a new system. In the same platform, users should follow its rules without any changes in the rules and message structures, when new users join. That is, needless reinvent the wheel.

  The system security is one of threats in that one security compromise applies to the entire system in compliance with the security rule. Various links should be considered under the appropriate level of security compromise. As for initial investment, existing LISs are reusable, whereas implementation on links between the the neutral platform and actors can cost.

- Alternative 3: Multilateral system integration

  The multilateral system integration is the most proximate to a single window system out of three alternatives. All users in the system exploit a single front-end web which is scalable and

include a lot of information from users. As a result, the system can easily lead economy of scale by interconnecting actors in global market, such as large importers, freight forwarders, and transport suppliers. However, the integration is barely feasible at global scale because potential risks and complexities in the platform. Users can be exposed to the great security risks on their data and privacy. Therefore, users should have a lot of trust for the platform and other actors to adopt the system. In addition, the development of the platform will be costly to encompass all users.

- Summary of Design Choice

Although each design alternative has been reviewed through the four criteria, the design choice can be still not explicit without quantitative evaluation. Hence, this project simply has applied multiple attribute utility theory to quantify results of evaluation (Sage et al., 2000). In the multiple attribute utility, alternatives are prioritized by a final score accumulated performance score on a set of attributes or evaluators.

Applying a basic idea of multi-attribute utility theory, four attributes (i.e., adaptability, scalability, security, and investment) in this project can be assigned by three levels of performance: low, moderate, and high. The three levels of performance can change into scores 0, 0.5, and 1 respectively. Then, the scores on each design alternatives can be added up easily to be compared. Table 6.1 shows the evaluation results and the final design decision highlighted in grey—multilateral message exchange.

Table 6.1 Performance scores on four criteria and the design choice
based on the accumulated score

Criteria	Full bilateral system integration	Multilateral message exchange	Multilateral system integration
Adaptability	Moderate (0.5)	High (1)	Low (0)
Scalability	Low (0)	High (1)	High (1)
Security	High (1)	Moderate (0.5)	Low (0)
Investment	Low (1)	Moderate (0.5)	High (0)
Final score	2.5	3	1

Note. The three design alternatives are from the project of e-Compliance (2015), and our evaluators are from Pearlson, Saunders & Galletta (2016).

Application Program Interface for the Design Choice
The project has suggested the PI open interface web plays role of the neural message exchange platform where the T&T system in ports can interchange information with various actors. For the interchange, it is essential to embed technologies on links between the platform and other LISs.

Aydogdu et al. (2015) elaborates how an application program interface (API), which has been used to interlink different systems, can be applied for integration of PCSs (Aydogdu et al., 2015). Based on the work, the author in the project visualized the implementation of API in the PI open interface as seen in Figure 6.3.

In the design choice, actors involved in maritime logistics have their own LIS which mainly consists of database, API, and a graphical user interface (GUI). Independently, the actor might run a front-end system for their clients, mostly in the form of website, and they can manage their data in local databases. Then, they can access to GUI of the PI open interface to interchange necessary data through the API.
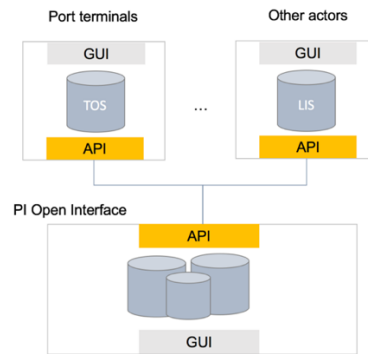
Figure 6.3 Integration between T&T system in ports and the PI open interface in technical viewpoint (Adopted from Aydogdu et al., 2015; Keceli, 2011)

6.1.2 Design Assumptions

Design assumptions help to complement four limitations on the use case in a design of PI ports by aligning them with PI's visions. Each limitation can be matched with the following design assumptions:

- In the design, PI ports are placed in an open maritime logistics market at global scale, hence their inbound T-containers can be from a number of international customers.
- Outbound loading units of PI ports can be either P-containers, H-containers, or T-containers.
- In the beginning of the logistics chains, three tiers of modular containers are deployed, therefore inbound T-containers are encapsulated with H-containers and P-containers.
- T&T system of PI ports is integrated with the PI open interface under the design choice on multilateral information exchange.

Beside the design assumptions on limitations, several pre-conditions in the use case can still remain as additional design assumptions.

- Modular containers embed smart tags capable of providing the public data to PI ports
- PI ports reach agreement on their information accessibility from other logisticians involved in the maritime logistics chain.
- To share the external, all logisticians in the design have registered in an open interface web platform.

6.2 Design on PI ports

A conceptual design on PI ports is established by reflecting use-case-based requirements on the three PI's elements and design assumptions. The conceptual model on PI ports is elaborated with four layers in the adjusted RAMI 4.0, as in the current port systems. The same design tools in the existing systems have been applied in each layer of the PI ports' design with the sequence of the asset, information, function, and business layer. The author has explained each layer with the focus on differences from that of the current port systems as covered in Chapter 4.

6.2.1 Asset Layer

This asset layer represents PI ports interacts with more logistics entities than the current port logistics systems due to the three PI elements. Primary classes are elaborated to emphasize the differences from those in the present port logistics systems as covered in Section 4.1.

Briefly explaining the background of this asset layer, the layer is heavily based on the previous chapter to depict the primary logistics entities from the use case. Their requirements on each element on PI also help to describe not only relationships between entities but also the visibility of attributes or operations on classes. The existing literature on PI gave insights on attributes and operations of the PI elements (Montreuil et al., 2012; 2010; 2015). As for the design choice, the literature on API has been used to represent attributes and operations on the components of the interface in more detail (Kao et al., 2015; Jacobson, Brail & Woods, 2012).

As a noticeable difference from the asset layer of the current systems, three levels of containers appear in the context of PI ports as separate objects, but they all inherit an abstract class called container. See Figure 6.4. Aggregation associations allow containers to show their asset hierarchy. P-containers can belong to H-containers, and H-containers can belong to T-containers in the same manner. Their information can be transferred by the class of manifest as in the current systems. But one different thing is attributes, transposed to network data in the Modulushca mode, are designed with a symbol of public visibility, "+." This is the reflection of information accessibility in connection with the open interface web and global protocol.

The class of (de)consolidate containers newly added in this class diagram to highlight the repositioning   operations in PI ports. As one of the operations, this class is linked with the class of operation under aggregation associations. Also, the repositioning operation is tracked and traced by PI ports shown in the association with the class of Track & Trace in ports.

This class diagram includes most actors in each class contrast to the current class diagram that three actors are depicted, such as LSP, inland transportation supplier, and shipping company. The is because final customers VAS providers defined in Section 5.2.3 become significant information suppliers for PI ports because of the change in their operation.

The appearance of classes, related to the open interface, might be another reason why this class diagram encompasses most of the actors in maritime logistics. PI envisions interconnections between physical objects through Internet (Montreuil, 2010) that is, all port-related actors can access the open platform for sharing their information.

In the current port systems, actors bilaterally communicate with each other through manifest on shipping containers. On the other hand, the open interface web can be integrated with other LISs, including the T&T system in PI ports in a multilateral manner. This asset layer describes the integration with three classes: open logistics interface, application program interface (API), and open logistics database server. The class of API helps to give authentication for other LISs and enables them to access appropriate information through the association with the class of database server.

In brief, this asset layer captures increased interactions in operations and information exchange within PI ports. The three classes on modular containers have represented PI ports have physical accessibility on all tiers of them. Moreover, the class of manifest has shown the public, network, and shipment data are available for PI ports. The open interface web is associated with classes of API and database server in compliance with the design decision on system integration for multilateral message exchange. Through API, most actors in maritime logistics can communicate with one another and access to the database for achieving the necessary information. The repositioning operation also falls

within the object to be tracked and traced, consequently the tracking and tracing information is shared with the open interface web.

Packaging Container

+ encapsulated()

Handling Container

+ encapsulated()
+ deconsolidated()
+ interlock()

Transportation Container

+ deconsolidated()
+ reconsolidated()

Manifest

+ transportId
+ nextDestination
+ containerDescription
+ containerValue
+ senderId
+ departureLocaion
+ departureTime
+ timeWindow
+ receiveId

+ transmitted()
+ received()
+ updated()
+ deleted()

Good

encapsulated()
decomposed()

Container

+ containerId
+ containerType
+ handlingWithCare
+ dimension

+ loaded()
+ unloaded()
+ moved()
+ investigated()
+ sorted()
+ enterPort()
+ leavePort()

T&T System

- requestId
- trackTraceObject
- trackTraceDatabase
- trackTraceWeb
- messageTransportSystem
- trackTraceEngine

- collectData()
- accessData()
- retrieveData()
- createTrackingData()
- createTracingData()
- manageDatabase()

Sensor

+ sensorId
+ attachedObjectId
+ battery
- memory

+ actuated():
+ sense():
+ convertAnaloguetoDigital():
- storgeData():
- processData():
- updateData():
- deleteData():
- transeive():

Track & Trace in Ports

+ trackAndTracetime
+ trackAndTracefrequency
- client
- requestOnTrackAndTrace

+ track():
+ trace():

(De)consolidate Containers

+ reconsolidate()
+ deconsolidate()
+ updateManifest()

Operation

operationId
handlingStatus
operationType
handlingTime
handlingPoint

+ unload():
+ load():
+ sort():
+ store():

Open Logistics Interface (Web)

+ services

- manageMember():
- getRequest():
- processService():
- provideService():

Application Program Interface (API)

+ authenticationScheme
+ functionalities
+ httpMethod
- designSchema
inputData
outputData

+ called()
+ certify()
+ deny()
- transmitInputData()
- provideOutputData()

Open Logistics Database server

- databaseId
- data
- relations
- server

- encryptData():
- selectData():
- insertData():
- updateData():
- deleteData():

Consignee

orderNumber
- informationOfGood
- informationOnConsignee

+ selectLogisticsServiceProvider()

Freight Forwarder

3PL/ 4PL

+ integrateLogisitcsChain()

Shipping Company

Port Termnial

- controlIT&Tsystem()

Hinterland Transport Operator

Distribution Center

+ provideValueAddedService():

Final consignee

+ confirmDelivery():

Logistician

+ logisticianId
+ name
+ location
- request
operation
estimatedOperatingTime

+ receiveLogisticRequest()
+ issueInvoice()
- checkManifestoOnFreight()
- useSuperstructure()
- controlOperation()
+ communicateWithOthers()
- accessToOpenLogisticsWeb()
- requireServices()
- receiveServices()

Logistics Service Customer

+ userId
# name
# request
- transportCapacity
- transportRoute
- transportTime
- finalDestinationInfo

+ accessToOpenLogisticsWeb()
+ requireTransportInfo()
- receieveTransportInfo()
+ complain()

Figure 6.4 Class diagram on PI ports

Note. The class diagram on ports has been based from the work by Tang et al., (2016) and Guolei et al., (2013). Main attributes and operations on classes of shipping container and its manifesto have been adopted from Modulushca project (Tretola, Biggi, & Verdino, 2015; Barbarino, 2015). PI components, namely modular containers, have been reflected from Montreuil et al., (2012), (2015), (2010

6.2.2 Information Layer

The information layer has been structured with two levels of DFD in the same manner in Chapter 4. Therefore, a context diagram of PI ports firstly shows information flows between T&T system of PI ports and external entities. Then a level 1 DFD elaborates the data streams along with functional processes of T&T system in PI ports.

The external entity of open interface web in this context diagram is the most significant difference from that of current systems. As seen in Figure 6.5, all information flows pass through the open interface web, and they are transferred to appropriate receivers. By contrast, external actors are bilaterally connected with T&T system of ports in the context diagram of the current systems. Detailed information flows are elaborated with the level 1 DFD to avoid overlap in explanation.
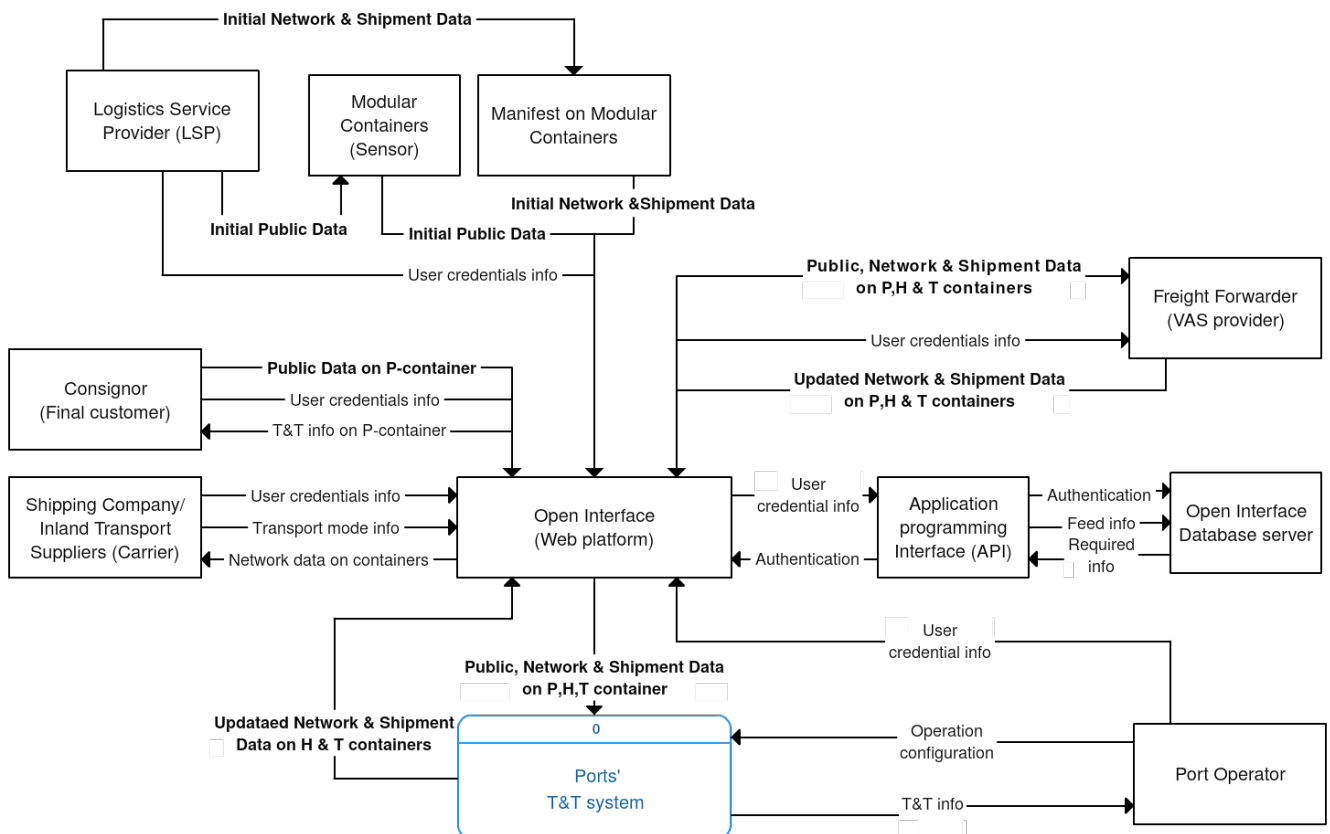
Figure 6.5 Context diagram PI ports' T&T system (Level 0 data flow diagram)

The overall functional flows in DFD (level 1) of PI ports have hardly changed from that in the current ports. Hence the level 1 DFD on PI ports has been comprised of five phases: (1) access to open interface, (2) receive original container and external data, (3) track container-handling operations, (4) generate T&T information, and (5) provide T&T information.
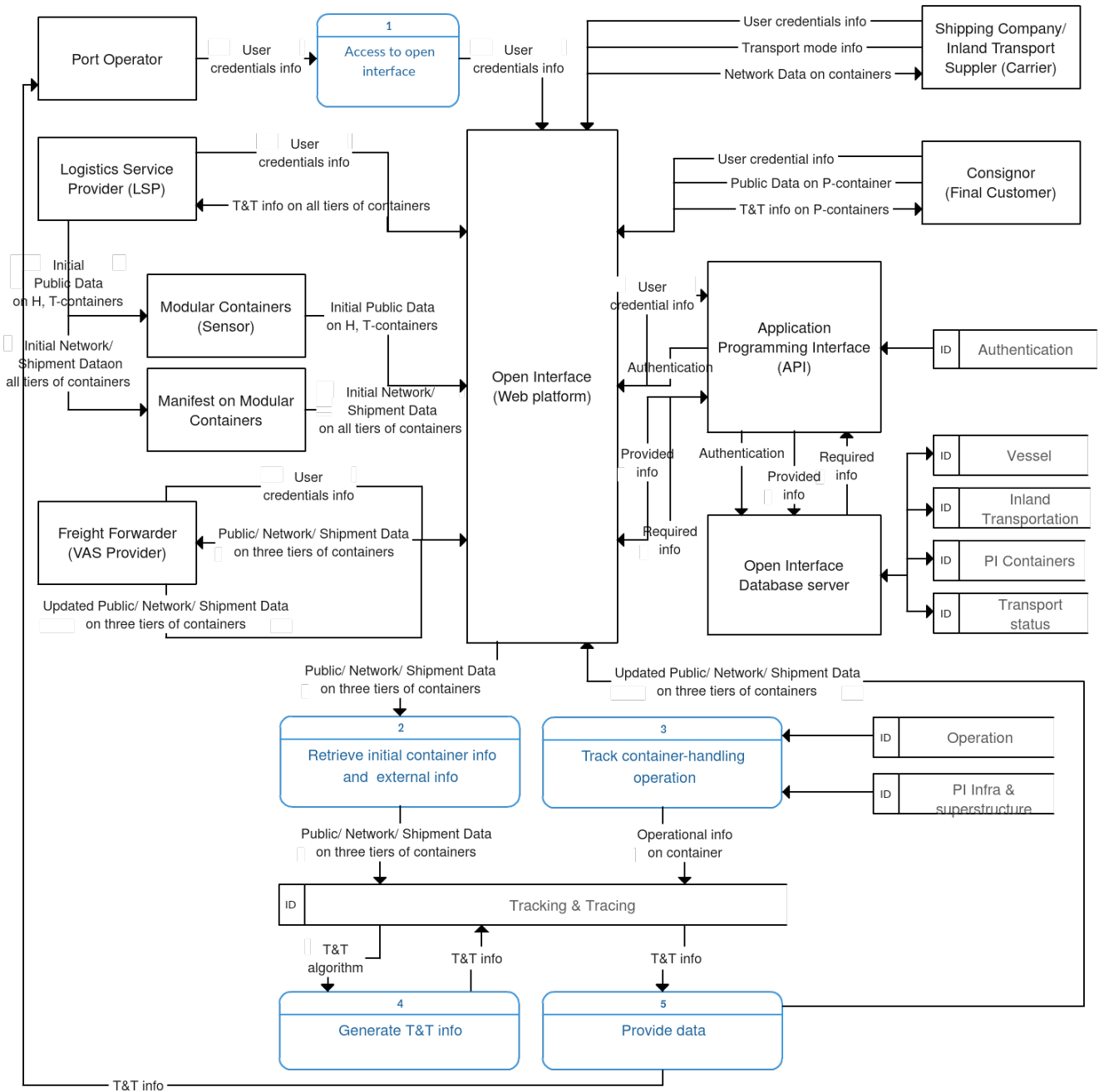
Figure 6.6 Data flow diagram of PI ports' T&T system (Level 1 data flow diagram)

Information flows in Figure 6.6 starts from access from T&T system in PI ports to open interface. Contrast to the current systems; PI ports send user credential information to the open interface for authentication and authorization on data, not to the LSP in bilateral communication manner. In the open interface, API authenticates PI ports and retrieves the public, network, and shipment data from open interface database server. The information in the database server is transferred the other way around from the database to the open interface through API.

Various actors have contributed either to generate or to update the three types of information on modular containers before being retrieved by PI ports. They provide and receive the necessary information through the open interface web facilitating API and database server. This is depicted in the DFD where all actors provide their user credential information to the open interface. As for contents of information, consignors offer the public data on P-containers that nobody is qualified to change. On

the other hand, initial public data on H-containers, and T-containers can be provided by LSP through containers as mentioned in the design. LSP also provides detailed data on the H-containers sand T-containers (i.e., initial network and shipment data) through the manifet. VAS providers, namely freight forwarders, can update the three types of information on modular containers in all tiers, except for the public data of P-containers. Besides, carriers offer transport information.

To return to the process of T&T system, the retrieved three types information can be used as inputs for tracking and tracing information along with operations. The operations on modular containers, as in the current systems, can be recorded in the database of operation, PI infrastructures, and supra-structures. But the database of operations in PI ports includes repositioning operations as well even though it is not described in the DFD.   Lastly, the T&T system generates tracking and tracing information on modular containers with the help of the T&T algorithm. The tracking and tracing information can be transmitted into the open interface for external actors.

Consignors can receive the tracking and tracing information on P-containers whereas LSP and VAS providers are accessible to all types of tracking and tracing information on all modular containers. Carriers receive network data in modular containers but they have different information flows according to the level of loading units that they take over. That is, shipping companies deal with T-containers in transshipping operations. Therefore, they are accessible the network data in the level of T-containers. However, the accessibility of inland transport suppliers is more flexible than shipping companies because they can receive various types of loading units, from P-containers, H-containers, and T-containers. That is the reason why the DFD describes the contents of information in the flows except for the level of modular containers.

In summary, this layer formulates new information flows in PI ports by adapting the three PI elements. Although the significant functional flows in the T&T system is almost same with that in the current systems, this layer shows the number of interactions on information becomes essential to the T&T system in PI ports. This is because PI ports are capable of handling all tiers of modular containers. Consequently, they are accessible to three types of information on the modular containers. These have been already discussed in requirements on the three PI's components. This information layer is meaningful in that of visualizing them in the sequence of communication between T&T system in PI ports and external information sources. However, this layer has not covered precise ways of interaction in the open interface, which will be elaborated in the next layer, functional layer.

6.2.3 Function Layer

This function layer has more significant meaning in PI ports than in the current systems by representing the integration between T&T system in PI ports and the open interface web. The alliance has been depicted with not only activities each in T&T system and the pen interface, but also interactions between two systems. Information flows are used as primary inputs in the middle of these activities and interactions. Therefore, this layer helps to understand how the information flows of PI ports work in the back-end.

The fundamental components and functionalities in T&T system are referred from literature by Lee et al. (2002). The information flows on PI ports in the previous section are used as primary sources in the function layer. More importantly, this layer has reflected the design choice (i.e., multilateral message exchange) made in Section 6.1. Literature by Aydogdu et al. (2015) give knowledge on the fundamental principle how to work API. Detailed references are mentioned as the note in Figure 6.7.
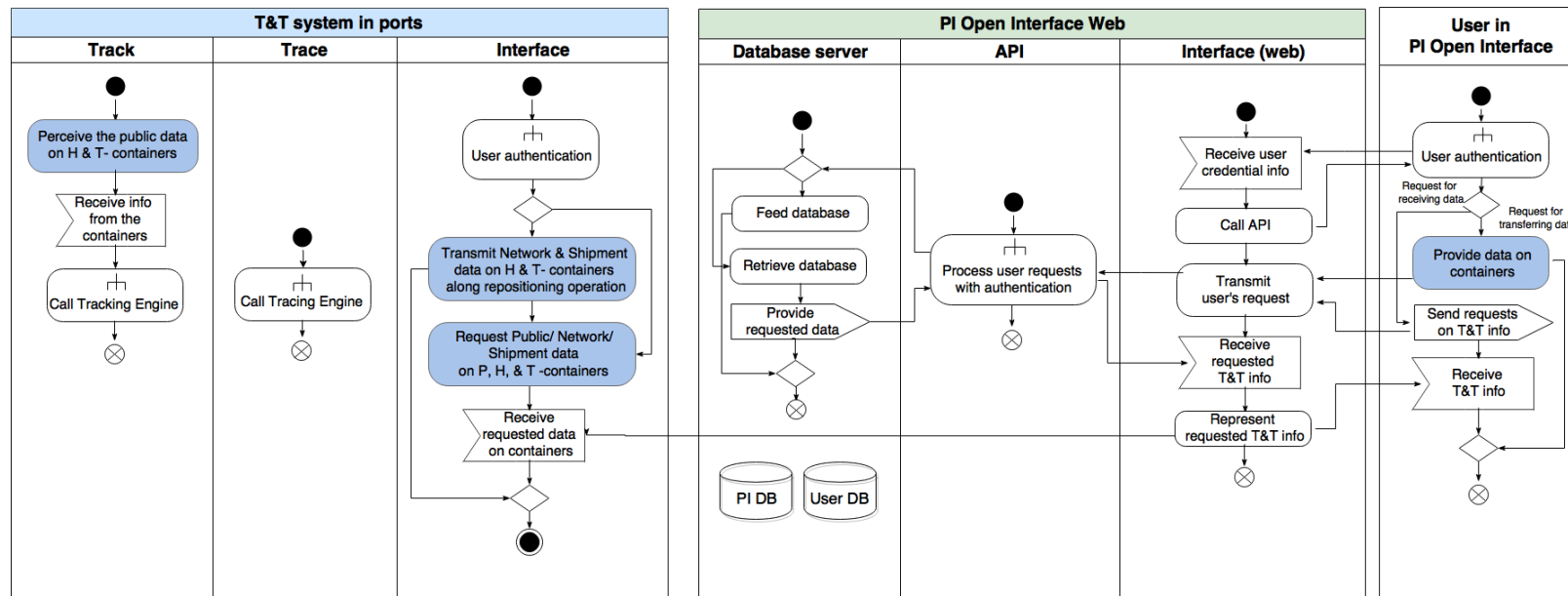
Figure 6.7 Activity diagram of T&T system in PI ports

Note. The components of T&T system have heavily based on *A Study on the Track & Trace System for e-Logistics*, by Lee et al., 2002. Contents of information from different actors in maritime logistics have been based on *Enhancing visibility in international supply chains: the data pipeline concept*, by Klevink et al., 2012. The method on information exchange in PI ports has been adopted from literature on PCS (Keretho, 2011; e-Compliance, 2016) and API working processes (Aydogdu et al., 2015). PI open interface web has been reflected from Montreuil et al., (2012), (2015), (2010).

In the activity diagram, logisticians can be considered as users of the open interface including ports. However, the diagram (Figure 6.5) here separately illustrates ports to emphasize their activities in T&T systems. As briefly explained in the information layer, all actors should go through the event of user authentication either to receive or to provide their information to the open interface.

As one of the notable differences from the current systems, the function layer on PI ports includes the open interface web. The open interface web is composed of three activities according to its primary components: (1) database server, (2) API, and (3) interface (web). To return to the requests from users, the front-end interface grasps the requests and call API to process them with authentication. By the requires, the API can feed information to the database or retrieve the appropriate information from them. The databases depicted in the information layer has been simplified in the lane of database server as PI and user database (DB). The PI DB corresponds to DB of the vessel, inland transportation, PI containers, and transport status in the information layer. The use DB is for authentication DB.

Activities of T&T system in PI ports do not change from those in the current systems. But the events, manually perceive the public data on modular containers, disappeared in the T&T system of PI ports under the design assumptions on smart tags.

Besides, the T&T system in PI ports reflects the new information flows along with repositioning operations as marked in blue in Figure 6.5. In a lane of the open interface, contents of information are abstractedly represented as "data on containers" from the viewpoint of PI ports, even though all users provide different information. Therefore, specific activities in the lane are described in Figure 6.8.
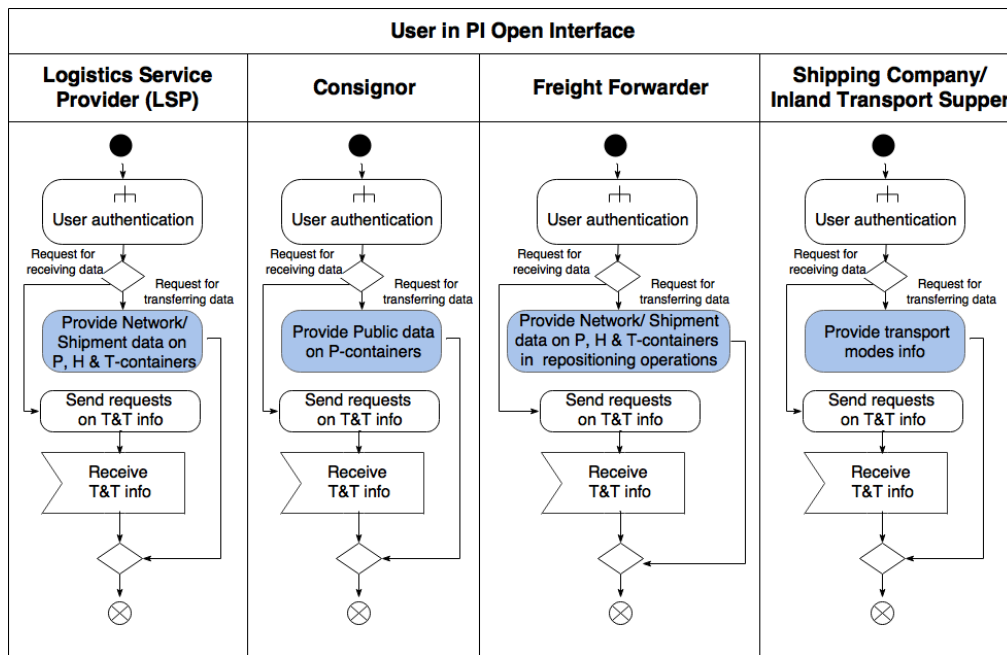

Figure 6.8 Detailed activity diagram on users in PI open interface web

The symbol of "φ" in four activities means they are composed of sub-processes, as seen in Figure 6.9. Four activities have sub-processes in this activity diagram. Two sub-processes represent the tracking and tracing engines of T&T systems, as in functional layer on the current status, whereas the remaining two processes elaborate on how users can be authenticated and how an API processes their requests with the authentication within the open interface web. A detailed explanation is omitted because they have been already covered in above.
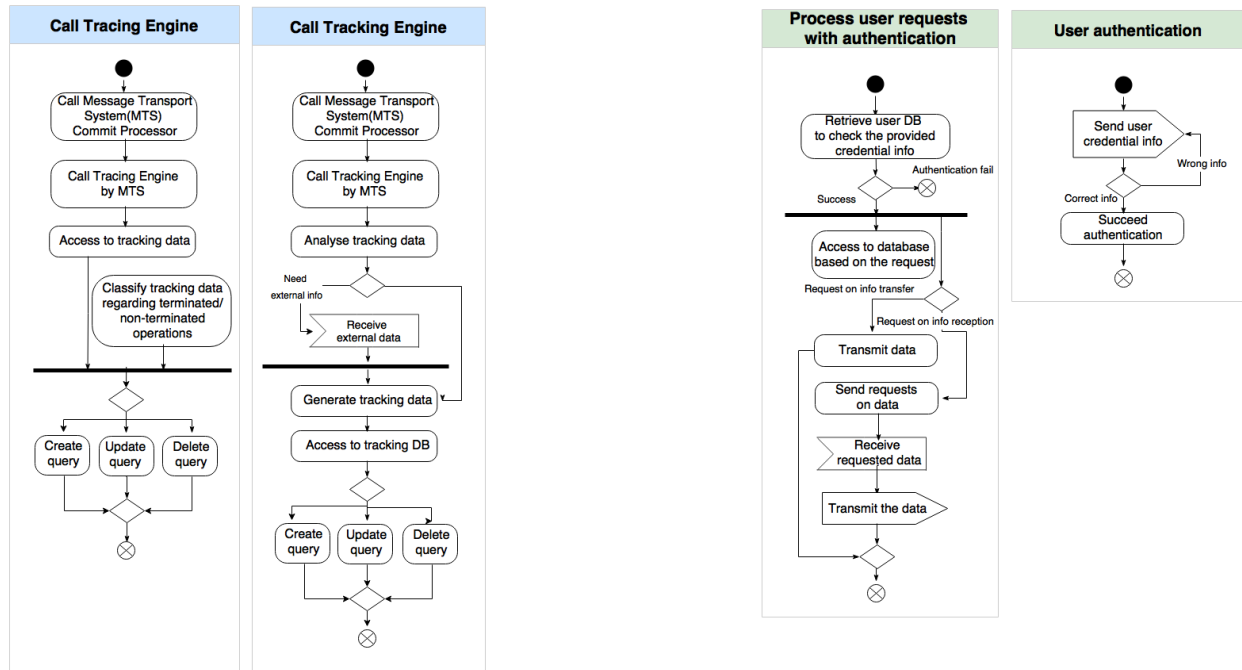
Figure 6.9 Sub-processes of activity diagram of T&T system in PI ports

To conclude this section, this function layer on PI ports has highlighted interoperability between their T&T system and the open interface web with focuses on information exchange. Contrast to reciprocal communications in current port systems; the open interface web enables all actors to exchange their information in a multilateral manner with the help of the API and database server. In short, the function layer represents which activities and interactions need to be fulfilled in the T&T system for the information flows of PI ports. In-line with the function layer, the next layer will show which operational process is feasible with the information flows.

6.2.4 Business Layer

The PI ports in this project are capable of providing VASs that involve the rearrangement of containers with the help of modular containers. As the most significant change compared to the current ports, the repositioning operations are marked with a blue box in PI ports' BPMN. See Figure 6.10. The repositioning operation is based on the current distribution centers which are mostly in charge of rearranging loading units before distributing shipments (Wu, 2013). Detailed references are mentioned in the bottom of the Figure 6.10.

Modular containers will arrive at PI ports in the transport unit of transport containers (T-containers), corresponding with shipping containers in traditional port terminals. Then ports can determine a decomposing level on modular containers. T-containers can be decomposed into handling containers that are designed for ease of handling by being enveloped in T-containers. They are called H-containers.

It is also possible to repeat decomposing operation two more times to strip the H-containers into packaging containers. The packaging containers (P-container) are directly wrapping goods. That is, PI ports deal with small container units, one or two level down from T-containers. Stripped H-containers or P-containers from T-containers can be stored in the form of H-containers or P-containers according to their transport time window. Existing yard storage can be called the second storage point, but its functionality remains unchanged—stacking T-containers. When it is time to be transported, PI ports explore the best loading unit among P-containers, H-containers, and T-containers. Contrast to the current logistics systems; outbound loading units can be not only T-containers but also P-containers and H-containers.

Another factor to notice in the BPMN is the presence of the diverse levels of modular containers (P-containers, H-containers, and T-containers) in logistics centers. Although the fundamental processes are hardly changed, modular containers can remain stable due to not only their standardized shape from containerization but also their interlocking format in a container chunk. In the swim lane of logistics centers, detailed operations have been omitted but it describes the possibility of VASs on the loading units.

Lastly, it is observable that a final consignee has become one of the stakeholders who should be taken into account. Logistics legs in a logistics chain can shorten because PI ports have absorbed some of the functionalities of logistics centers—VASs involving the rearrangement of containers. That is, containers that are leaving a destination port terminal do not need to stop by a logistics center to realign container placement and can be transported directly to the final consignee, even though there are other VASs at logistics centers in between. The ultimate consignee, as seen in the right bottom of the BPMN, can take over shipments from PI ports through transport suppliers, either in the unit of P-containers, H-containers, or even T-containers.

In brief, this business layer represents potential repositioning operation processes in PI ports by applying modular containers. In the processes, modularity of PI containers is aligned with the decomposing and recomposing operations. Hence PI ports become capable of adjusting loading units across three tiers. Furthermore, the layer briefly describes influences of the loading units on reducing logistics legs through the distribution center and ultimate customer.
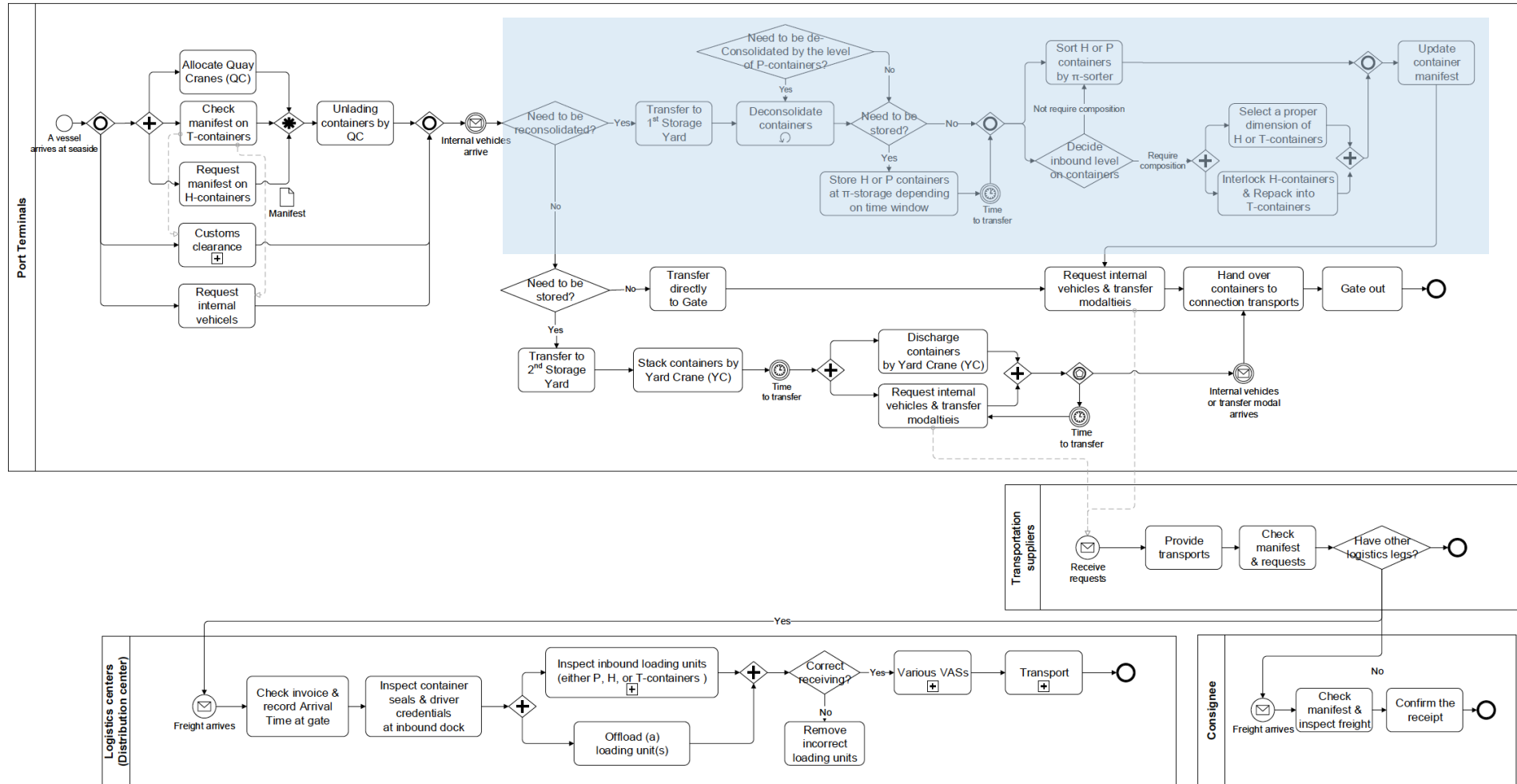
Figure 6.10 BPMN on PI ports' operations

Note. The swimlane on port terminals has been adopted from literature on port operations and logistics centers (Brinkmann, 2011; Gharehgozli et al., 2014; Kemme, 2013; Meersmans, 2002; Cheng et al., 2005; Wu, 2013). The literature on a freight logistics process have been referred (Stefansson & Woxenius, 2007; Tseng, Yue, Taylor, 2005). The potential uses of modular containers and other PI components have been reflected from Montreuil et al., (2012), (2015), (2010), Barbarino, (2015), Tretola, Biggi, & Verdino, (2015), Tretola, (2013), and Lin et al., (2014).

6.3 Major Milestones Ahead of PI ports

This section additionally points out several factors capable of increasing the feasibility of PI Ports. The PI ports still exists in conceptual model, even though the model on PI ports has been based on assumptions complemented from the limitations of the use case in this project. Within the scope of this project, three considerations are analyzed: (1) accessibility of smart sensor and (2) various incentives of different actors in PI ports (3) open interface operator.

The first point to be considered is possible uses of smart sensors in PI ports. The model assumes the smart sensors embedded on modular containers contain their public data from LSP. However, the initial public data on packaging, handling, and transport containers might be changed by repositioning operations in PI ports, while the public data of packaging containers is hardly altered. The changes on data can be directly updated through the sensors if PI ports equip identification readers. In that case updates on public data do not need to be reported to the open interface. However, different LSPs using PI ports need to unify frequency of radio of sensors and their data formats to retrieve and update the sensors through readers within PI ports. The standard issues had been already discussed in Section 2.2.3.

More fundamentally, the prior consent on information accessibility can be actualized with different actors' agreement on PI ports. Expected incentives of the actors in PI ports need to be considered in-line with their objectives in maritime logistics chains. Then problem owners in this project (i.e., port operators and port authorities) can induce cooperative movements of the actors on PI ports. Table 6.2 presents different actors' objectives in maritime logistics and their potential incentives with PI ports based on four categories of actors in this project.

Table 6.2 Model comparison between modern and PI ports
(Heaver et al., 2000; Dalmolen et al., 2012; Rodrigue, 2017; Hutchison Logistics Europe, 2016)

Category	Actors	Possible objectives	Potential incentives from PI ports
VAS provider	Port operator	• Maximize profits • Maintain customer loyalty in long-term perspective through logistics services and VAS	• Increase profits through repositioning operations • Increase market position • Increase flexibility on transshipping schedule based on extended information accessibility (e.g. the next destination and time window) • Lower congestions and short distance to distribute containers • Increase efficiency in handling and storing containers • Enable for direct delivery to final consignees • Contribute to lower total logistics services • Contribute to lower amount of emission
	(Public) Port authority	• Contribute minimizing cost	• Increase efficiency in uses of port infrastructures • Increase adjacent land utilization rate

		• Maximize cargo handling	• Contribute to increase job opportunities • Contribute to revive regional ports by collaboration with external actors
	Freight forwarder	• Maximize profits • Increase service capabilities	• Increase efficiency in uses of port infrastructures • Ease to pick-up empty containers from adjacent ports
Logistics service provider (LSP)	3PL/ 4PL	• Maximize profits • Maintain customer loyalty • Increase service capabilities	• Decrease total logistics costs in logistics chains • Attract more customers • Increase container visibility • Reduce costs for empty container movement
Carrier	Shipping company	• Maximize profits • Optimize transport utilization	• Increase space utilization in transport units • Increase efficiency in transport allocation • Lower transport costs (incl. time cost) • Contribute to lower amount of emission
	Inland transport suppliers		
Final customer	Consignor	• Minimize costs on logistics services (incl. time cost) • Secure delivery services • Minimize emissions	• Ease to track and trace items • Use logistics services at lower price • Contribute to lower amount of emission
	Consignee		

The last factor to be concerned is a potential operator of the open interface web. In conventional ports, most cases of LSP is dedicated to providing tracking and tracing information. However, there is no a representative of the open interface because the PI interface has not ever been implemented.
The PCS and single window system are in-line with the open interface web in that the systems aim for multilateral information exchange between all actors through an integrated web. Although the PCS and single window system are established upon specific scopes (i.e., port-related operations and a country), the systems can give insights on how the operator functions? International port community systems association (IPCSA) describes the operator of PCS and single window as follows ("Port Community Systems," 2014). An operator of PCS can be either public, private or public/private organization. On behalf of other actors, the PCS operator is in charge of manage exchange of

information compliance with service level agreements. A representative of the single window has legal responsibility along with operations of the system within a country or region. Under the national or regional legislation, the operator allows actors to be involved in trades of information and documents.

The iCargo project used the terminology of information service integrator (ISI) which provides informational infrastructures—access point between actors—for the open exchange of information (Dalmolen et al., 2012). More technically, the authors categorize information infrastructures of ISI into three: (1) semantic model, (2) semantic tooling, and (3) community tooling. Briefly explaining, the ISI includes a conceptual data model, namely semantic model, which defines how exchanged information needs to be interpreted and expressed in a specific business process. Additionally, the ISI embeds semantic tooling to enable the semantic model to be technically implemented, for example, data sharing interface and linked open data interface. Besides the semantic tooling, community tooling guides how to collaborate with different actors based on sets of business rules. with one of the researchers in iCargo project—Dr. Wout Hofman (personal communication, June 29, 2017), he added actors in logistics chains will take the responsibility for specific parts information that they provided in the open interface web. See Appendix E for the summary of interview.

6.4 Salient Implication

This chapter has proposed the tentative design of PI ports capable of repositioning operations with the help of the three PI's elements. The section is transposed to the third step in V-Model; therefore it has explored preliminary concepts for the design, in particular, system integration between T&T system in PI ports and the PI open interface. Moreover, design assumptions have been discussed to complement limitations of the use case. This is ultimately for making the PI ports' design to be more in-line with PI's visions. Its main findings can be summarized with answers to the third and last research question: How a conceptual design of PI ports can be presented in the design framework with three PI elements?

These are its sub-questions:

3.1 What are alternatives in the design of PI ports and which alternative is selected?
3.2 Which logistic entities are important for activities in T&T systems of PI ports?
3.3 Which informational flows in the T&T systems are required for repositioning operatio
-ns?
3.4 What is the primary operational process of PI ports?

The question 3.1 can be answered by a brief procedure of the design choice on system integration between the T&T system in PI ports and the open interface. Findings on the design of PI ports have been summarized through the rest sub-questions in the same way with Chapter 4. That is, the question 3.2 is connected with the asset layer, whereas the information and function layer with the question 3.3. The fourth and last question 1.4 is related to the business layer.

6.4.1 Decision for Design

The current port systems bilaterally exchange information with external LISs which is considered as one of the points for improvement in modern ports in this project. However, today literature on PI has not proposed an explicit way how the PI open interface web can be integrated with other LISs. This ambiguity on system integration might hinder this project from formulating information flows which are interdependent, no matter where they belong to as the nature of LISs. Especially in this project, the open interface web is one of the main information sources that should be interconnected with the T&T system in PI ports. Therefore, the author has explored several design alternatives, researched in the

context of PCS, because its vision is in-line with PI. There are three options to system integration were considered (e-Compliance, 2016):

- Full bilateral system integration
- **Multilateral message exchange**
- Multilateral system integration

Through simplified the multiple-attribute utility theory, each alternative has been evaluated with four attributes (i.e., adaptability, scalability, security, and investment) commonly used for the decision on information system architecture (Pearlson, Saunders & Galletta, 2016). As the outcome, multilateral message exchange has been decided as the design choice.

6.4.2 Asset Layer

This asset layer has represented PI ports encompass more logistics entities to perform repositioning operations in comparison with the current port systems. As noticeable entities, three tiers of modular containers appear in the context of PI ports in this layer. Moreover, manifestos of the modular containers have depicted the extended information accessibility of PI ports, that is not only the public and network data, but also the shipment data. The layer shows the T&T system in PI ports is integrated with the open interface web following multilateral information exchange model. Under the design choice, the open interface has been described with its API and database server. Additionally, the layer has highlighted repositioning operations in PI ports by describing them into a class. The class of repositioning operations is associated to classes of the T&T system and the PI open interface. The association represents the operations are tracked and traced along with modular containers by the T&T system and then the tracking and tracing information is transferred to the open interface web.

6.4.3 Information & Function Layer

The information layer has made the necessary contents of information in PI ports, mentioned in the asset layer, into a stream. In the viewpoint of PI ports, the information flows have been established by considering diverse sources on three types of information on modular containers (i.e., the public, network, and shipment data). In short, consignors can provide the public data on P-containers. Besides LSP, PI ports and freight forwarders are accessible to the public, network, and shipment data on P-containers, H-containers, and T-containers without authority to change the public data of P-containers. Carriers, such as shipping company and inland transport suppliers, are related to the network data on the modular containers, even though the accessibility on levels of modular containers are dependent on their operational roles.

For the information flows, T&T system in PI ports should include appropriate activities and interactions with the open interface web. Those events and communications have been depicted in the function layer by using the information flow as their inputs. As one of the primary findings, the layer represents multilateral information exchanges between the open interface and other LISs, including the T&T system. To summarize the transaction, the T&T system in PI ports access to the open interface with their user credential information. An API of the interface can authenticate the PI ports and authorize their informational requests by accessing to the database server. The database server can offer the public, network, and shipment data for PI ports through the API and the open interface.

6.4.4 Business Layer

The business layer has illustrated potential repositioning operation processes in PI ports that previous layers ultimately support. PI ports absorb repositioning operations from the current distribution centers with the help of the three PI's elements. In the layer, PI ports can adjust levels of loading units across

three tiers of modular containers. As a result, the business layer has shown the standardized PI containers allows outbound loading units of ports to be flexible. That is, the outbound units can be either P-containers, H-containers, or T-containers. Additionally, the layer has visualized this flexibility on loading units can make logistics legs short through the distribution center and ultimate customer.

Besides the model, the chapter has pointed out three milestones which might increase the feasibility of PI ports: (1) accessibility of smart sensor and (2) various incentives of different actors in PI ports (3) open interface operator.

7

Conclusion & Recommendation

This chapter is composed of the conclusion and recommendations. The primary research question is answered by looking back silence findings of the entire research. Additionally, recommendations can give insights for the academic field on PI and the logistics industry, especially ports. For this, the recommendations reflect both a narrow and broad viewpoint each on this research and the overall PI.

7.1 Conclusion

This research has proposed a tentative design of information flows in PI ports, embedding three PI components: (1) modular containers, (2) open interface web, and (3) global protocols. In particular, the research has explored potentials of the three PI components to resolve the current issues in freight logistics—inefficient space utilization on loading units and their invisibility in logistics chains. To testify their potentials, this project has set a use case in-line with trends in maritime logistics that imply ports tend to extend their VASs. These concerns have been synthesized in a core research question:

How can information flows on modular containers be designed with the help of the PI open interface and global protocols to improve visibility on loading units in (de)composition operations within ports?

In order for answering the main question, first of all, literature have been profoundly reviewed to obtain knowledge on maritime logistics systems, their LISs, and PI (Chapter 2). Second, a design framework for this project has been proposed by adjusting RAMI 4.0 for designing two models each for the current and PI system (Chapter 3). In the adjusted RAMI 4.0, four layers primarily helped to analysis the current port systems and to design PI ports. Four layers are dedicated to illustrating different concerns as follows:

(5) Asset Layer: major logistics entities, including loading units, shipments, parts of LISs, are described with their attributes and operations.
(6) Information Layer: information flows on logistic entities are formulated with the focus on informational interactions between two entities.
(7) Function Layer: activities in T&T system and interactions with external LISs have been elaborated by represents how the information flows have been formulated.
(8) Business Layer: various operations on handling and transport loading units in ports have been illustrated as a process.

The next three steps are highly correlated to each other because of being structured by V-Model: (1) conceptual development, (2) requirement engineering, and (3) system architecture. On the basis of two main elements (literature review and the design framework), the current port logistics systems are analyzed (Chapter 4) as parts of the first step of V-Model. In compliance with the developed RAMI

4.0, the current port systems described in four layers as mentioned above. Main findings from modern ports can be summarized with the four layers:

- Asset Layer: it was found the most critical logistics entities in modern ports are shipping containers in the light of visibility on loading units. This finding implies ports provide logistics services to a single level of the loading units. Manifests of the shipping containers are also principal objects to be tracked and traced as they contain the network data, such as identifier number of transport and the next destination. Beside shipping containers and their manifests, external actors (i.e., LSP, shipping company, and inland transport suppliers) is engaged in tracking and tracing loading units in the context of maritime logistics.
- Information Layer: the primary information flows in modern ports are associated with LSP. LSP has authorities on information of loading units under contracts with shipping companies and inland transport suppliers. Currently, present ports are accessible to the public and network data of containers that do not represent internal contents of the containers as well as their details shipping information.
- Function Layer: in order for information flows, the T&T system in modern ports corporates with LSP to be authorized to the public and network data on loading units. After being allowed by the LSP, the T& T system bilaterally communicates with shipping companies and inland transport suppliers each for information on inbound and outbound loading units.
- Business Layer: information flows, established by diverse associations between logistics entities and activities in the T&T system, ultimately support the operational role of modern ports, transshipping shipping containers from the sea to the land. This finding implies the limited operational leverage result in restrict visibility on contents of shipping containers.

These findings from modern ports concluded with points of improvement aiming for better utilization of space in loading units and their visibility:

- Operational services in ports within maritime logistics
- Additional information in the T&T system of ports
- Arrangement between actors about information accessibility
- The way of information exchange between the T&T system in ports and external LISs

Concerning requirement engineering, the specific use case, reflecting dynamics and complexities from various actors in practical situations and the nature of logistics systems, has been set to identify potentials of the three PI elements (Chapter 5). In the setting, ports are capable of repositioning their inbound shipments on the basis of standardized three levels of loading units (i.e., modular containers) with appropriate information accessible through the open interface and global protocols. Requirements on the significant PI components follows:

- Modular Containers: physically, PI ports should be accessible to all three tiers of modular containers to perform repositioning operations. In repositioning operations, PI ports should be capable of determining suitable levels of modular containers for the best use of space by considering their next destinations and delivery time windows.
- Open Interface Web: PI ports require the public, network, and shipment data on modular containers from the open interface web for their repositioning operations.
- Global Protocol: PI ports should negotiate with port-related actors who are information sources for repositioning operations. Especially, consignors, VAS providers, and LSP can be critical sources for PI ports. Consignors offer the public data on P-containers whose network and shipment data can be generated and updated LSP and VAS providers. The public, network, and

shipment data on H-containers and T-containers are available for LSP, VAS providers including PI ports.

The last phase of this research, system architecting, has started from defining design assumptions complementing limitations of the use case (Chapter 6). One significant assumption determined by analyzing is to integrate the T&T system in PI ports and the open interface in a multilateral message exchange method.
Subsequently, a tentative design of PI ports has been illustrated by means of four layers in the developed RAMI 4.0 as in the current ports logistics systems.

(9) Asset Layer: contrast to logistics systems in modern ports, three tiers of modular containers fall within the context of PI ports. Additionally, information accessibility is extended as found in manifestos of the modular containers. PI ports in settings with the capability of repositioning operations are accessible to not only the public and network data but also the shipment data. On the basis of the choice on system integration, the open interface web comprised of API and database server has been depicted as a communication channel between the T&T system and external LISs.

- Information Layer: the widespread accessibility of information in PI ports increases interactions between the T&T system and external actors. In brief, consignors can provide the public data on P-containers whereas LSP, freight forwarders and PI ports are accessible to the public, network, and shipment data on P-containers, H-containers, and T-containers without authority to change the public data of P-containers. Carriers (i.e., shipping company and inland transport suppliers) can receive the network data on the modular containers, even though the accessibility on levels of modular containers can differ.

    Notably, all information flows are reached to the open interface web for the diverse actors multilaterally to share their information. Hence, the T&T system of PI ports can accomplish repositioning operations in spite of complexities on information exchanges.

- Function Layer: information flows can be comprehended along with activities in the T&T system in PI ports. The system firstly should access the open interface with their user credential information. An API of the interface can authenticate the PI ports and authorize their requests by retrieving the database. The database server ultimately provides the public, network, and shipment data for PI ports through the API and the open interface.

- Business Layer: an operational process comprised of repositioning operation process has been described. In the repositioning operations, PI ports are capable of adjusting levels of loading units across three tiers of modular containers (i.e., P-containers, H-containers, and T-containers). The operation process visually presents the standardized modular containers allow PI ports to handle and transport shipments through appropriate loading units. As a result, PI ports are expected to have a marginal waste in loading units by obtaining the advanced visibility on them.

To conclude, the primary research question can be answered by the information layer in the conceptual design of PI ports that verifies potentials of the three PI ports to increase space utilization on the loading units and their visibility. The information flows in PI ports can be well comprehended through the developed RAMI 4.0 enabling for analyzing PI ports in various aspect along with hierarchical but interconnected logistics entities.

7.2 Recommendation

This research still contains room for improvement which might be fulfilled in future research. Limitations of this study have been covered, and consequently, recommendations are given for future studies and the overall PI world.

7.2.1 Research Limitation

The idea of PI exists in theory with difficulties to be implemented because of its massive scale and required changes in behaviors of actors, facilities, and technologies. Especially, PI is a composite concept of logistics operations and informational interconnectivity intrinsic in the operation. Hence, the PI system will be feasible only when the two aspects are thoroughly studied and explored both in theory and practical cases. Besides the limitations of the nature of PI, this section more focuses on the barriers to this research.

This research proposed the conceptual design of PI ports in settings from a single use case (i.e., repositioning operation) which is not efficient to generalize the uses of PI elements. Additionally, the single use case is mainly concerned with the three PI's components as parts of the entire PI system.

With respect to the settings in the use case, this project has verified potentials of the three PI's elements within a theoretical context without quantitative research or practical cases in reality, which might able to emphasize their possibilities.

Besides limitations on settings, this research reflected the design decision on LIS integration based on alternatives researched in the context of PCS. Although PCS has similar visions with the PI open interface, new options can exist for the PI open interface that has not studied yet.

Lastly, the developed RAMI 4.0 is dedicated to illustrating four layers except for the integration and communication layer. The two layers are beyond of scope in this research because of their strong relations with information technologies which are expected to be barely changed in the PI context. However, the two layers can still help the conceptual design to be logical by representing the way of transforming physical logistics entities into information sources.

7.2.2 Future Research

Apparently, PI still needs further research to clarify ideas for its elements. Besides research on PI itself, future research can propose an explicit design framework specialized in PI. A PI design framework helps to visualize and testify the ideas of PI in theory, and subsequently, it can be used to communicate with potential operators of PI. As a baseline of the PI design framework, the adjusted RAMI 4.0 in this research can be referred.

In parallel with the fundamental part, future research can be dedicated to investigating conceptual designs on PI components in diverse contexts. Due to difficulties in implementation, conceptual designs are suitable to present potentials of PI. The more their uses cases are accumulated, the more completed the entire conceptual design of PI become. With respect to this research, two considerations are noticeable for future conceptual designs. Firstly, the conceptual design needs to be plausible by reflecting trends of logistics fields. The viable conceptual models help to represent practical potentials of PI, and subsequently, they can be used as a blueprint for its implementation in reality. Secondly, future research should perceive the viewpoint of IT in PI is also essential in its conceptual designs. Hence, theoretical models in future research can also formulate information flows and furthermore information architecture along with PI logistics entities.

As a possible next step, quantitative methods can be applied to conceptual designs to verify potentials of PI numerically. Concerning this research, virtual simulations on PI ports can be executable to identify whether the three PI components enhance space utilization and visibility of loading units compared to the current systems. Notably, the conceptual model in the research that designed by UML and BPMN can be easily executable by existing software transforming models to computational codes. However, specific configurations of each PI's elements will be a prerequisite. For example, specific functions, performance, processing time and interoperability with other components. Therefore, further research on logistics entities, such as PI sorter, convey, and composer is required. In connection with the PI design framework, the ability of execution can be considered as determining design tools.

Lastly, future research can explore methods of integration between the open interface and external LISs. This research has been based on one of the alternatives (multilateral message exchange) devised for integrating PCSs. The field of PI can be committed to investigating further options and to determining an optimal design choice that best suits for PI visions.
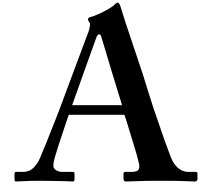
7.2.3 Prospects on PI

The concept of PI will not happen overnight. It may seem unfeasible due to the massive changes that might be required in existing infrastructures, business processes, and relations between stakeholders. However, it is obvious there is still room for improvement in the current freight logistics in spite of diverse efforts in the industry, such as containerization and the application IT. That is, the freight industry needs a transformative and intensive paradigm from the long-term perspective, which can be the PI.

A variety of research that is currently in progress has been conducted separately based on different goals. However, the research has ultimately the same goal that pursues freight logistics to be more efficient than now. The PI can provide a superordinate vision for the research to align logistics systems in each study with one another. The logistics systems can be considered as part of a whole logistics system which the PI eventually aims for. For example, projects, such as iCargo, CORE, and ARKTRANS, can be the parts of PI research with the united vision in high level.

In a gradual transition for PI, its core elements can be firstly developed and introduced into practical cases while research on others are still in progress. It is feasible to use modular containers for niche markets in the near future, for example e-commercial shipments that deal with relatively small loading units, pharmaceutical shipments that require particular condition information, and a specific city freight shipping services.

The logistics centers will define their roles depending on their capacities and ability to interconnect to other adjacent centers, named to logistics Web in PI. Then, each logistics Web can be composed of logistics networks.

Modern ports have high potential to benefit from PI due to the amount of freights they handle, relatively big freight capacities and scale. If port-related actors are aware of this potential, the implementation of PI will be accelerated. This is because some ports have been already integrated with PCSs in a national or continental level. The PI open interface can be developed by incorporating the PCSs.

A

Interview Summary

Interview summary	
Date	3. November. 2017
Interviewee	Gerwin Zomer in TNO
Duration	1 hour (11:00 am – 12:00 pm)
Structure	11:00 – 11:20: introduction of my thesis 11:20 – 12:00: answers on questions & general feedbacks
Purpose	(1) Reflecting practical freight logistics services (2) Validating the concept on PI ports design
Main findings	(1) Practical issues on inefficient space utilization of loading units (2) Potentials of Physical Internet (PI) on the current freight logistics (3) Alternative architectures in logistics information system (LIS) (4) Possible application of this project in short-term perspective

1. Practical issue on inefficient space utilization of loading units

- An idea of modularization has been applying with pallets in shipping containers in most case of freight logistics. The modularity on containers suggests two different concepts of transportation: (1) less-than-container loading (LCL) and (2) full container loading (FCL). LCL allows consignors to share loading units of a container with other consignors when they have a small volume of shipments. Hence, consignors can reduce transportation costs by distributing the total costs with others. Whereas, FCL logistics put a flat price on a container.

- However, many consignors are willing to use FCL, even if they have no full loading freights for FCL. That is, the decision of consignors can be one of the reasons on inefficient space utilization of loading units.

- There are several reasons why consignors prefer FCL:

    (1) LCL logistics can require additional costs, such as logistics service fees to LSP, port service charge, and terminal handling fees. Although LSP often charges LCL shipments at two or three times lower price than FCL, consignors might need to pay more than FCL due to additional costs for LCL.

    (2) LCL shipments require more handling services compared FCL. Therefore, it might take more time to reach the final destination.

    (3) Moreover, information on shipments can be scattered in LCL logistics throughout diverse logisticians. Contrast to LCL logistics consignors can receive freight information directly by a shipping company in FCL logistics.

2. Meaning of this project on the current issue in freight logistics

- In the modern freight logistics, the need for standardized loading units has been noticed together with the need of standardized dimensions and handling processes on the loading units. Based on these needs, diverse research on intermodal loading units (ILU) has been conducting in Europe, for example, SeaconAZ.
- In-line with this project, standardized loading units on freights can improve their space utilization by encouraging consignors in their proper choices on the loading units. Standardized loading units allow LCL shipments to be composed into FCL shipments with minimal handling services. Hence, extra costs, including time, in composition operations will be reduced. As a result, consignors can exploit LCL logistics with right loading units while LSP maximizes space utilization of the loading units.
- Modular containers in PI can be differentiated from the recent ILU in that the PI containerssuggest three loading units under a layer-based approach with standardized dimensions and functionalities. The three-tiered loading units make capable of optimizing N-to-N supply logistics chains, whereas the current research on ILU focuses on point-to-point supply logistics chains, such as between inland transport suppliers and ports.
- Furthermore, it is expected the layer-based loading units in PI can improve the visibility of loading units by level of their contents. Information of loading units in different levels is accessible, that is not only to the external loading units but also the lower levels of loading units. Therefore, it is likely to know what is inside in loading units.

3. Alternatives on information architecture in future freight logistics

- Decentralized information architecture is the alternative to centralized information architecture. The big difference between two architectures is the way of data sharing: (1) pull and (2) push. In decentralized information architecture, actors in logistics chains either require or receive information when they need the information. That is, information on shipments needs to be aggregated from diverse actors along with their operations. On the other hand, logisticians in centralized information architecture should firstly provide their data regardless of requests on the data. Once all information is gathered along with logistics operations, related actors are accessible to the information.
- The decentralized information architecture has been used in CORE project. Rules of data sharing had to be clarified in case of breaks in information flows or long latency time, whichcan occur in decentralized information architecture. The regulations of data sharing represent which actors need what kinds of information at which points of logistics chains.

4. Feasibility of this project

- PI envisions a standardized logistics system at a global scale in redefining logistics entities with new standards and functionalities. Existing logistics entities should be developed capable of interoperating with PI containers. That is, it takes a long time to implement PI to all over the world.
- In short, it seems feasible to apply three-tiered loading units into either niche logistics market or limited regional scope. For example, e-commercial shipments that deal with relatively small loading units, pharmaceutical shipments that require particular condition information, and a specific city freight shipping services.

B

Logistics Centers

Types of Logistics Centers

Although logistic centers have been sorted by various factors, the extent of covering activities in logistics, including VAS, can be related to this project as a criterion of classification. According to extent, Rimienė, and Grundey (2007) categorize logistic centers into six categories: logistics nodes, logistics centers (not the same as the provisional term used in this project), freight villages, transport terminals, distribution centers, and warehouses. This decreases their functions from the large-scale integration of transportation modes within the logistics node to storing cargo in warehouses.

Notteboom et al. (2009) add transportation modes of logistic centers as another factor of the classification. Logistics centers are divided into port terminals, rail terminals, and distribution centers. A port terminal is placed near the sea as an interface between the maritime and inland systems. In turn, rail terminals can be subdivided into transfer containers from the port terminal to inland centers by rails. Depending on functional activities, rail terminals may either substitute the activities of the port terminal or offer intermodal transportation modes. Distribution centers generally perform value-added functionalities like container decomposition, cross-docking, and warehousing.

Higgins et al. (2012) propose a standard logistic center hierarchy by synthesizing a variety of classifications for logistics centers. The hierarchy for logistic centers reflects not only their functions, value-added activities, and scales but also cargo capacities. As seen in Figure B.1, logistic centers at higher levels can offer many VASs with bigger capacity. The details about each logistics center follow.

1st Level (Warehousing & Distribution Cluster)

- **Container Yard & Warehouse:** Warehouses generally store inventories and manage them to be transferred on time and are demanded in the supply chain because they act as buffers. As another buffer, container yards are in charge of storing, maintaining, and cleaning containers that are generally located either in or near a primary port and other logistic centers.
- **Distribution Center & Inland Container Depot:** Unlike warehouses, distribution centers are more concerned with shipment flows than their storage. Distribution centers have fundamental functions, transportation, warehousing, and cross-docking. Some of them include VASs, such as information management, return processing, barcoding, and labeling. Inland container depots are similar to distribution centers in that their key emphasis is on shipment flows rather than storage. However, inland container depots take over the functions of

traditional ports, except for waterborne transportation. For example, they handle and store containers, and conduct customs inspections and clearances as VASs.

2nd Level (Freight Transportation & Distribution Cluster)

- **Intermodal Terminal:** An intermodal terminal is a facility where shipments can be consolidated and transshipped with the use of intermodal transportation for continental and local trade.
- **Inland Port:** An inland port can be perceived as an extended traditional seaport despite its inland location. Although its activities include those of facilities in the bottom layer, namely warehousing, distribution clustering, and intermodal terminal, an inland port directly deals with maritime logistics flows linked to the main port terminal. Therefore, it can lead the economy of scales to consolidate or deconsolidate shipments, as well as reduce congestion in ports.
- **Freight Village:** As the largest type of inland logistics center, a freight village has enhanced capabilities, particularly in intermodal connections and general infrastructure and equipment. There are a variety of arrangements with industrial stakeholders behind the advanced capability on the basis of joint ownership and management structures. Moreover, a freight village can reach a comparable economic scale as a main port terminal due to its large scale.

3rd Level (Mainport Terminal)

Major global ports and terminals fall under the top level of a logistics center, the gateway cluster, which stands for logistics facilities called "gateways" by Notteboom and Rodrigue (2009) and "logistics nodes" by Rimienė and Grundey (2007). International seaports are typical main port terminals where large volumes of freight are transferred and handled before transloading to other transportation modes for further transport. On top of the size of main port terminals, it is expected that they embed a full range of VASs, as well as sufficient infrastructure and supra-structure capabilities. Moreover, main port terminals play the role of actual gateways to inland intermodal transport, either by transloading outbound shipments to proper modes or by unloading shipments to let them into main port terminals in inverse cases.
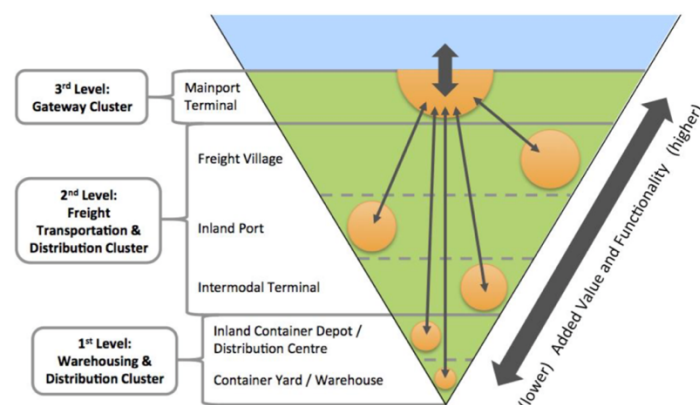

Figure B.1 Hierarchical classification on logistics centers (Higgins et al., 2012)

Even though these classifications do not cover every variation of logistics centers, it can help to relieve ambiguity in uses of the terminology by categorizing various sorts of applications into three levels.

Consistent with this classification, PI ports in the project are in the transition stage toward becoming main port terminals because they embed only parts of VASs, repositioning operations. This project expects PI elements to be used as suitable means with leading efficiency in potential VASs within ports.

C
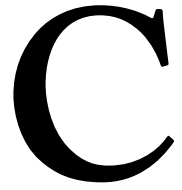
Literature on Class Diagram

Some literature depicts logistics entities with emphasis on their hierarchical relations (Bielli et al., 2006; Yun et al., 1999). Yun et al. (1999) focus on gate, container yard, and berth. Then each facility is divided again into its subsystems, for example block, yard side bay, and slot for the container yard.

Besides facilities in ports, Bielli et al. (2006) explore logistics entities in detail based on operation activities and diverse entities. The class diagram in their literature is useful because it provides an understanding of not only the logistics entities of ports themselves but also their associations to analogize information flows afterwards.
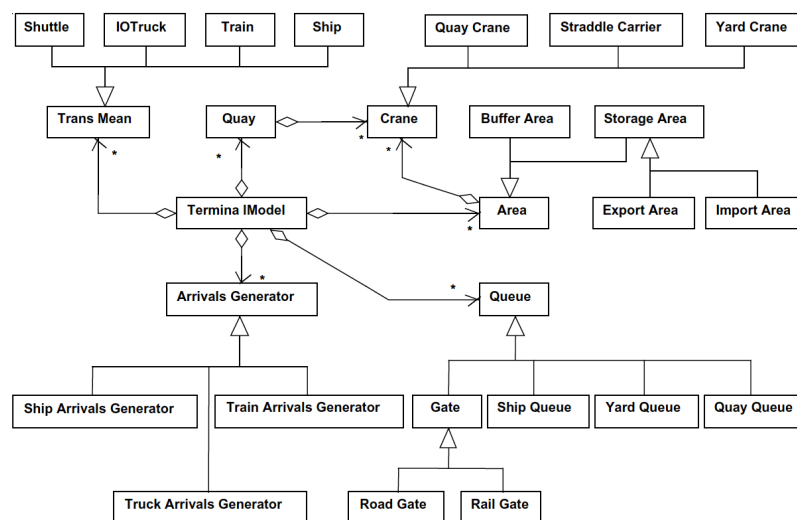
Figure C.1 Class diagram on ports (Bielli et al., 2006)

In the class diagram, five super-classes exist as the first level in the hierarchy: terminal model, area, crane, trans mean, and queue. With a port (terminal model) as the center, all logistics entities are interlinked with one another depending on their operational dependency. Table C.1 shows the meanings of each class with marks of * on super-classes.

Table C.1 Description of logistics entity class (Bielli et al., 2006)

Class	Description	Class	Description
Terminal Model*	Container terminal	YardCrane	Crane used in storage area
TransMean*	All transport means	StorageArea	Area to stack containers
Crane*	All types of cranes	BufferArea	Temporary storage area
Queue*	All types of queues	QuayQueue	Queue for quay

Quay	Quays in the terminal	YardQueue	Queue for yard
Area*	Regions in the terminal	ShipQueue	Queue for ship
Shuttle	Internal trucks	Gate	Point entering or leaving the terminal
IOTruck	Input/output trucks toward or from the terminal	RoadGate	Point trucks enter or leave the terminal
QuayCrane	Crane used in seaside	ArrivalsGenerator	Notice on arrivals to terminals

Performance of port terminal has been monitored in terms of ship anchorage (Guolei et al., 2013). For this, the authors have been devised the class diagram on ship operation system as seen in Figure C.2.
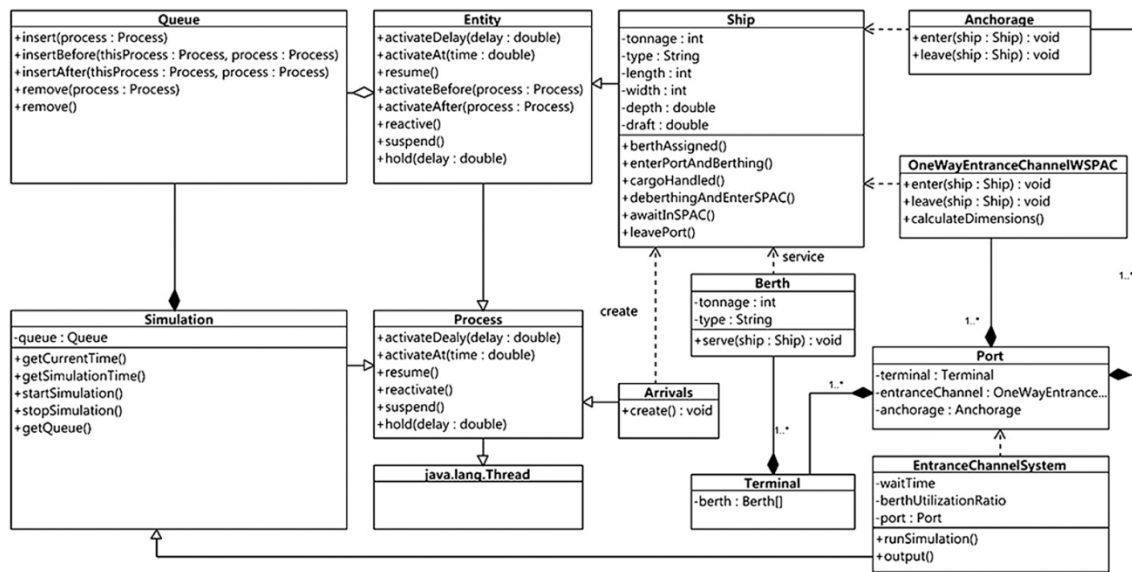
Figure G.2 Class diagram on ship operation system (Guolei et al., 2013)

In-line with research by Gueolei et al, Tang et al. (2016) designed a class diagram to explore the optimal dimension of entrance channel in ports by simulating berth operations. Consistent with this project, the class diagram elaborates classes of ship and port terminal with possible attributes and operations in more detail compared to work by Bielli et al. (2006). See Figure C.3.
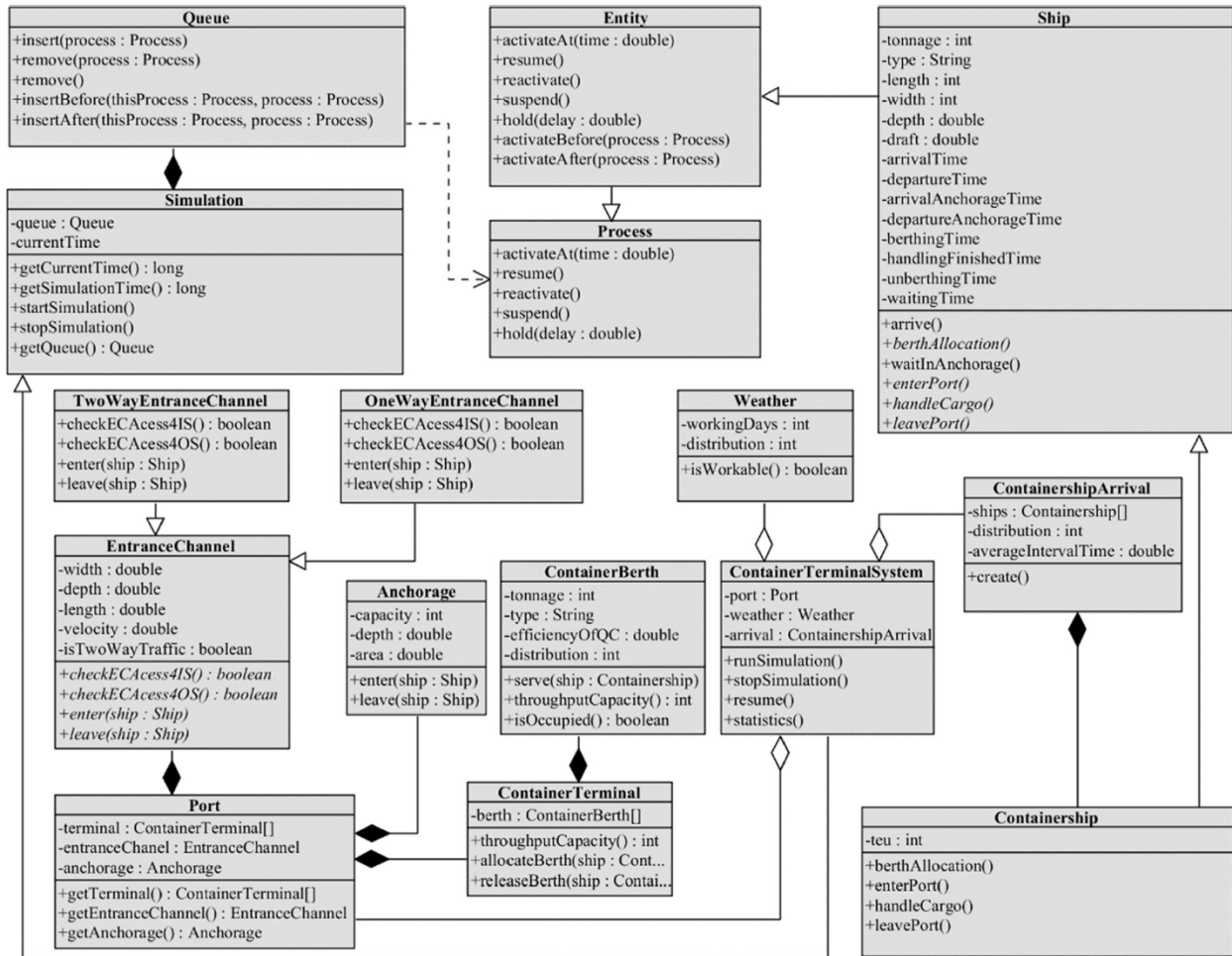
Figure C.3 Class diagram on port terminals (Tang et al., 2016)

D

SWOT Analysis on Alternatives

Strength, weakness, opportunity, and threats on three design alternatives have been referred by the e-compliance project (e-compliance, 2015).

D.1 Alternative 1: Full Bilateral System Integration

Strength	• Bilateral effort between two system operators • Long-term reduction in transaction costs • Realization of economies of scale • Control opportunity • Strong commitment • Adjustability on the needs of individual ports
Weakness	• Requires two different actors who are willing to merge their systems. One system can take the other over, as opposed to a merge of equals • Requires great deal of time, commitment, trust, preparation of procedures • Has disadvantages of centralized structure due to no physical presence on an independent system
Opportunity	• Piggybacking and collaboration between system operators • Easy exploiting of best practices among ports of merged PCS and corporation of the governance structures
Threat	• Down time of a shared platform can lead problems at both ports concurrently • Once the systems have been integrated, it would be very hard to take apart from each other • Operational changes in a system will affect the common system • Dependency between two port operators increases

D.2 Alternative 2: Multilateral Message Exchange

Strength	• Relatively easy to implement • Multiple actors are connected in the same platform and standards, which makes other actors' involvement easy • Realization of economies of scale • Individual actors should agree upon rules and message structures, hence no need to 'reinvent the wheel' • The system can accommodate a number of systems
Weakness	• The platform should to be clarified, agreed upon, financed and built first, which will need a strong commitment of the core platform users • The platform should consider the different needs of the users depending on their diverse PCS businesses • The platform needs to update not only the shifting needs of users and the technological maintenances but also legislative change
Opportunity	• Recruiting new users to extend the platform • the united technological approach would lead to collaborated business practices
Threat	• The same level of security compromise will apply to all systems under the same rules • Bad quality data provided by a system can influence operations of the entire platform • Down time of the neutral platform hinders the information exchange for all involving systems

D.3 Alternative 3: Multilateral System Integration

Strength	• Large potentials on international markets, such as large transport suppliers, importers, and freight forwarders to offer a single point of access, but allows local systems to be existed for their own legacy • Realization of economies of scale without geographical limits • Long-term reduction on transactional costs • Integration of local specifics
Weakness	• The implementation of a united front-end system is costly and complex • Requires a lot of trust of actors • Reluctant to diminish the role of local PCS • Agreements on legislator framework and jurisdiction for the single platform

	• Greater risks on data leakage and system security
Opportunity	• Further integration of documents, business practices, and procedures among the ports systems
Threat	• External political events can influence on the integrated PCS • This design is most vulnerable to privacy violations and data leaks

E

Interview Summary

Interview summary	
Date	29. June. 2017
Interviewee	Wout Hofman in TNO
Duration	1 hour (13:30 am – 14:30 pm)
Structure	13:30 – 14:10: general knowledge on logistics and IT 14:10 – 14:00: comments on the thesis topic
Purpose	(1) Understanding a general logistics process (2) Obtaining insights for PI from the current application of IT on logistics
Main findings	(1) The basic concept of Physical Internet (2) A logistics process with Internet Reference Model (3) A process on information exchange in the project of iCargo (4) The fundamental idea of federal systems (5) Requirements to apply PI into ports

The project iCargo is highly related to this research project in that iCargo explores a new logistics system with sustainability needs on logistics services. Both projects have analyzed potential roles of various actors in the new logistics system. In addition, the projects have been based on the viewpoint of information. iCargo represented an architecture of information sharing between actors. In-line with this, this project suggested potential information flows between logistics entities in PI ports.

Dr. Wout Hofman from TNO has been involving the iCargo project and he has shared a general knowledge on logistics and IT on logistics. Furthermore, he has given insights on PI ports and overall approach of this project. The summary of interview is covered in behind.

1. **Basic idea of "Physical Internet" in the logistics industry**
   - Dynamic planning with PI-boxes
   - Various physical standards on PI-boxes
   - The level of intelligence (Self-organization) of PI-boxes can be different by costs, tags, and capability of tags

2. **Five layers of a logistics chain in line with Internet Reference Model**

    (1) Supplier
- Decision Making on networks of PI-boxes with goals depending on diverse parameter, such as speed, price, and priority
- Data owners of PI-boxes

    (2) Shipment
- (De)encapsulation for network layers
- PI-boxes level

    (3) Routing networks
- Dynamic planning on routes with the use of information on capacities of logistics entities

    (4) Transportation
- Moving assets
- Road, waterway, carriers

    (5) Physical infrastructure
- Provide services in different level of QoS everyday
- Private/ public
- Hub, terminal, etc.

3. Network Analysis as remaining research area
- Analysis of decisions of each stakeholder within networks
- How to change stereotypical behaviors of stakeholders collaboratively in keeping their competitiveness within networks (Policy)

4. Exchange information process
    (1) Dynamic planning
- Decision on Quality of Service (QoS) based on information, for example, price, schedule, capabilities of logistics entities

    (2) Booking/ Ordering
- Actual selection through sharing transaction data

    (3) Visibility (T&T system)
- Visibility on logistics entities
- Different visibility objects depending on interest of client, for example, the final consignee is interested only in ETA, ATA, and time of border crossing
- Influence on planning with Resilience & Agility

5. Federation System (Logistics Open Web or Pipeline)
- Still conceptual infrastructure and needs to be established
- Challenges of openness on confidential commercial data as competitive sources
- Agreements on how to communicate with stakeholders
    - Services of stakeholders
    - Protocols

- Register (Authorization)
- Connection through Ontology and Semantics match
- Research area: incentives of stakeholders from informational cooperation or agreements

6. Ports with PI
- (de)composition activities placed in hinterland
- Conditions for Value-Added Services (i.e., composition & decomposition) in ports
    - Facilities for composition and decomposition
    - Reasoning for composition and decomposition
    - Algorithm based on data accessibility of shipments (e.g. destination and cargo flows)

7. General comments on project approach
For Information flows in PI-ports, policies between different stakeholders need to be taken into account to understand required infrastructure, data accessibility, and different types of contracts, such as (dominant, community, and bio models)

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