Visibility in Physicla 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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Abstract— This research has proposed a tentative design of information flows on PI embed three PI components: (1) modular containers, (2) open interface web, and (3) global protocols. Through the design, this research has identified potentials of the primary PI elements to resolve current issues in freight logistics (i.e., inefficient space utilization on loading units and lack of their visibility). In-line with trends of the maritime logistics, PI ports in the design exploit the major PI elements in one of the value-added services, repositioning operation. In the context of PI ports, requirements on the three PI components have been elicited and reflected in the conceptual design. The adjusted RAMI 4.0 has been applied to visualize not only information flows in PI ports but also required logistics entities, activities and interactions in Track and Trace (T&T) system, and moreover operational processes. As a result, the conceptual model proposes requirements for PI ports along with potentials of each PI element.

Keywords—Physical Internet; Container terminal ports; Port-centric logistics, Modular container; Open interface web; Global protocols; Information flow; Tracking and Tracing system

I. INTRODUCTION

Freight transport logistics is the most critical domain in transportation by allowing goods to be placed at a proper point in time. [1] Developments in the economy, manufacturing systems, and logistic networks increase the demand for freight logistics. As a result, it is expected that there will be a sharp growth in the freight logistic industry. [2]

Besides macroscopic leverages of freight logistics, several operational issues directly occur within logistic systems. [2] In this research, inefficient space utilization of loading units— container and trucks has been mainly concerned. However, there is the doubt that containers have been packing still in inefficient manners up to this day, even after 50 years from when formal regulations on standards of containers had been created by International Standards Organization (ISO). 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). [3]

Through existing research and an interview with Zomer, it was found that "insufficient standards on loading units" is one of the causes of the waste of space. [4-5] 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 problems. The PI is a globally open logistics system with advanced visions on interconnectivity in its physical, operational, and digital aspects. [2, 6-8]

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 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.

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?

II. Research Scope & Methodologies

A. Research Scope

This research project is focused on parts of the PI' components rather than all of them, which is beyond the scope of this study because of their diversity. Three main building blocks in PI have been used for a tentative use case and design of PI ports as follows [2, 6-8]:

• Modular Containers: there are three level of containers under the idea of modularity in PI—packaging, handling, and transport containers. 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. T-containers are devised with more restrict and diverse dimensional standards than existing shipping containers.

• Open interface web: The open interface web is regarded as an enabler of a potential application of modular containers by providing an intercommunication channel. The open web platform makes actors in a logistics chains capable of exchanging information about modular containers for all container operations.

• Global protocols: standard protocols in PI has been interpreted as the global cooperation of actors to implement the PI system. Mutual agreements on information accessibility should be reached in collaboration with various actors in a logistics chain.

Due to the increasing demand for global transport, maritime transport has become important in the freight logistics industry because it is the most appropriate transportation mode for international shipping. [9, 10]. In recent trends in maritime logistics—port-centric logistics (PCL), ports are trying to include more value-added services (VASs). Therefore, ports will be likely to have the current issue on space utilization of transport units when they are handling containers.

Consistent to visibility of transport units, this project dedicates tracking and tracing module of logistics information system (LIS) is mainly concerned. Explicitly, the LIS of ports is called to terminal operating system (TOS). Every port terminal has been using TOS to track the flow of container throughout all operations within ports. [11] To emphasize its functionalities, T&T function or module in TOS can be hereafter termed as T&T system in spite of being parts of TOS in the view point of ports.

B. Research Methodology

For answering the main 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).

1) Adjusted RAMI 4.0

RAMI 4.0 was developed for interconnected and smart systems in the manufacturing industry in-line with the stream of Industry 4.0. [12] Hence, the framework can be aligned in the context of T&T system in ports. This project considers 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. [13]

Adjusted RAIM 4.0 (Fig. 1) guides the first and third phases of this project with four layers: asset, information, function, and business layer. [14]
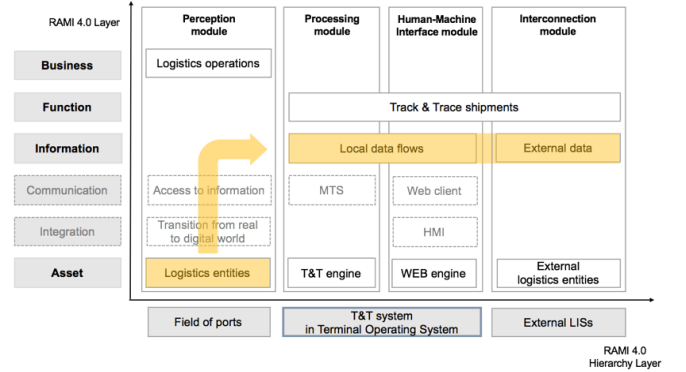

Fig. 1. Adjusted RAMI 4.0

a) Asset Layer: this layer is designed to clarify logistics entities regarding their characteristics and the relationships between them.

b) Information Layer: information flows generated from logistic entities are the main subjects of this layer. Thus, the flows from one entity to the others will be elaborated on.

c) Functional Layer: this layer represents activities and interactions in the T&T system of ports that represents background how the information flows can be formulated in technical viewpoint.

d) Business Layer: this layer describes business visions with logistic operational processes that show the utilization and transportation of logistic entities.

2) Use-case driven requirement engineering

The second phase in this project can be guided by the first two steps in requirement engineering process—requirement elicationa and analysis. The rest of phases are beyond the scope because this project concentrates on the visualization of a conceptual design of a T&T system for ports, not the documentation of requirements.
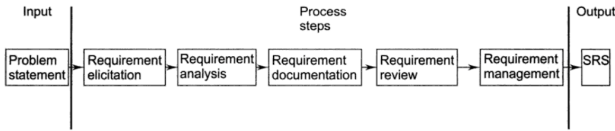
Fig. 2.   Requirement engineering process [15]

This paper is based on critical factors of requirement analysis in 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. [16]

With respect to the research scope, 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. 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 research 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.

III.   CURRENT PORTS

The illustration of the current ports in four layers has been omitted in this layer whereas a potential use-case and tentative design of PI ports have been emphasized. Primary findings have been elaborated as follows.

The central operational role of ports is to transship shipping containers from the sea to the land. [17-21] As to the issue of freight logistics in this project— inefficient space utilization on transport units, ports cannot do anything with the current position in maritime logistics. However, the inefficiency on transport units, mainly containers, 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.

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. Currently, 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.

Additionally, there are still rooms 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. [22, 23] Also, ports have made plans and decisions on their operations with external information from shipping companies and inland transport suppliers under authorization by LSP. However, it is noticeable ports communicate with the shipping companies and inland transport suppliers bilaterally. To conclude, ports need to extend information accessibility on transport units for decreasing inefficiency on space utilization of containers. Furthermore, ports can explore an advanced method of sharing information with actors involved in the maritime logistics chain. It will be necessary ports reach an agreement with related actors for their operational and informational movements enabling for the increasing space utilization rate in transport units.

In brief, points of improvement in modern ports can be summarized:

- 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

IV.   USE-CASE OF 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. 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.

A. Use-case 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. [24] 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.
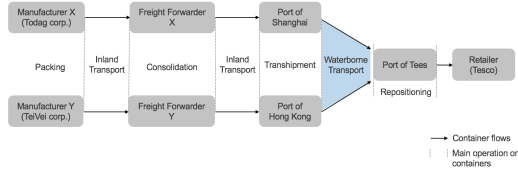
Fig. 3.   Overall logistics chain of the use case

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 Fig. 3. 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 and 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 Tescoo 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 Fig. 4. Lastly, Teesport can compose all grouped H-containers into a singular T-container according to the best use of space.
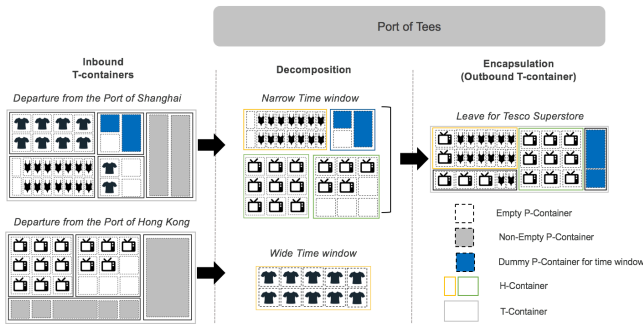

Fig. 4.   Potential use case of modular containers in repositioning operation

The use case diagram has been omitted because its detail has been covered in the next section.

B. 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 (Table 1) on modular containers in the open interface web. These contents of information are prerequisites to perform repositioning operations.

TABLE I.   CONTENTS OF INFORMATION IN MODULUSHCA PROJECT [22]

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)

•   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.

V.   DESIGN OF PI PORTS

The ultimate goal of this section is to suggest a conceptual design on PI ports utilizing the adjusted RAMI 4.0. For this, first, preliminary concepts for modeling have been discussed before reflecting them to the final design. On the basis of preliminary conceptual design, PI ports are illustrated in four layers in the adjusted RAMI 4.0.

A. Preliminary conceptual desgin

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

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exchange has been determined through simplified multi-criteria utility theory.

B. Conceptual desgin 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. The author has explained each layer with the focus on differences from that of the current port systems.

1) Asset layer

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.

2) Information layer

This layer formulates new information flows in PI ports by adapting the three PI elements (Fig. 5). 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) Function layer

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. [25, 26] 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

This business layer represents potential repositioning operation processes in PI ports by applying modular containers

[20]. 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.

VI. 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.

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
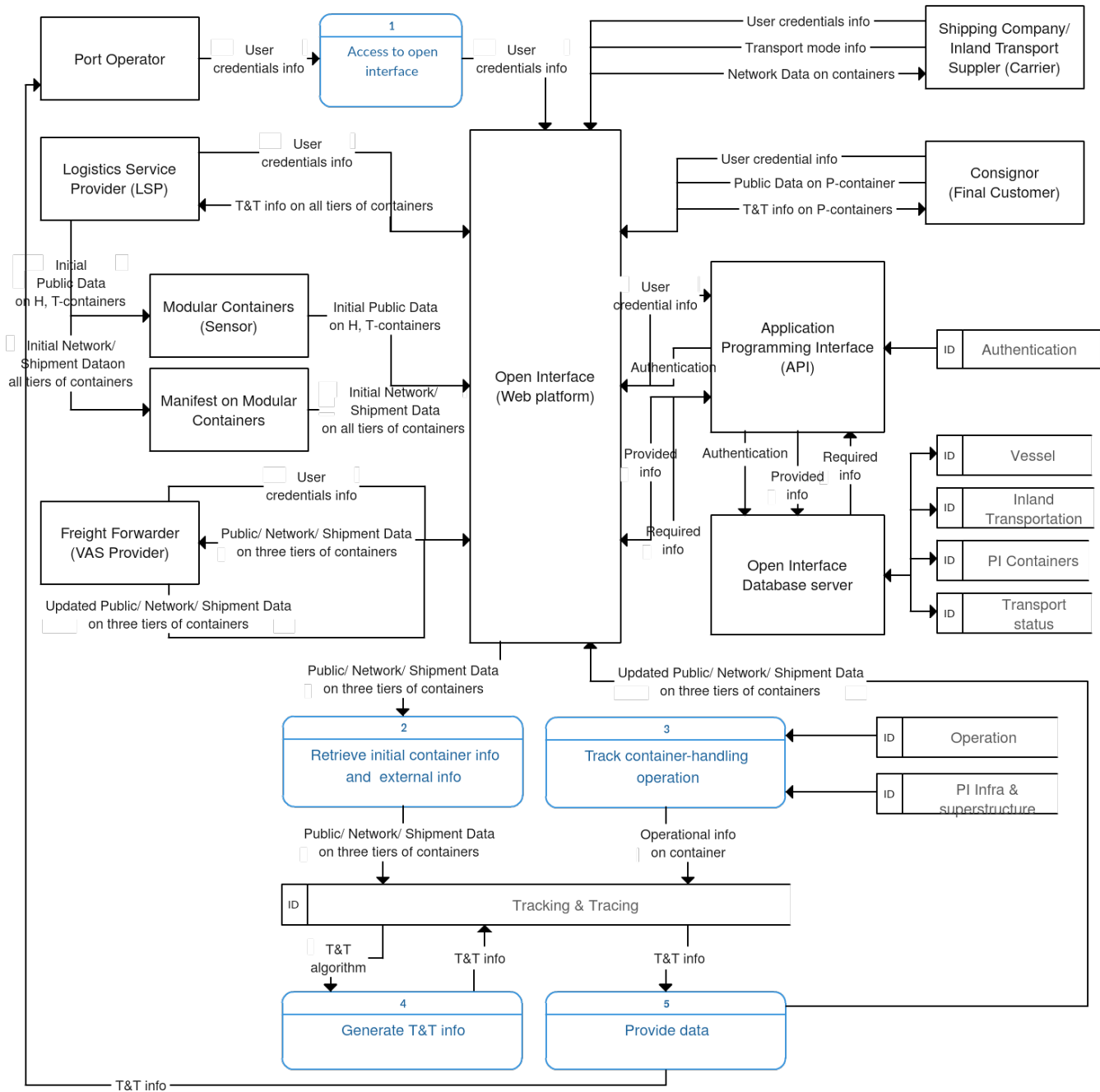
Fig. 5.   Information flows in PI ports

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