Maritime ports: Policy focus in the uncertain future of Physical Internet

G.B. Mientjes (4306708)

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Prof.dr.ir. L.A. (Lóránt) Tavasszy (Chair)
Dr. J. (Jafar) Rezaei
Dr.ir. A. (Arjan) van Binsbergen
P.B.M. (Patrick) Fahim

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by

G.B. Mientjes (4306708)

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Student number:	4306708	
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Thesis committee:	Prof.dr.ir. L.A. (Lóránt) Tavasszy (Chair)	CiTG
	Dr. J. (Jafar) Rezaei	TPM
	Dr.ir. A. (Arjan) van Binsbergen	CiTG
	P.B.M. (Patrick) Fahim	TPM

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Summary

Physical Internet (hereafter: PI) is an innovation introduced to cope with the unsustainable effects of logistics on society, environment and economy. The underlying idea of PI is to move goods through the network similarly to how data is transferred through the Digital Internet (DI). This implies for the logitics system that the goods are not handled, stored or transported, but rather the package in which the goods are encapsulated is handled, stored and transported. Thereby, the PI network is constantly updating, to establish the most efficient and sustainable way to handle, store and transport all of the physical objects through the entire logistics system.

Unless, the promising effects of PI on the efficiency and sustainability of the logistics system, it is still highly uncertain what the implications of this innovation are on important logistics system components and system stakeholders in the global logistics system, like maritime ports. Maritime ports have a critical role in the logistics system, as their primary function is to transship goods between the vessels and the land modes, such as trucks and trains. For this reason, in this thesis the following Main Research Question (hereafter: MRQ) is established: *How could a maritime port be attractive in the future, given the uncertain development of Physical Internet?* To completely answer the MRQ, this question is divided into the following six Research Sub Questions (hereafter: RSQ):

1. *What are the external factors influencing the attractiveness of the maritime port in the uncertain future?*
2. *What are the PI port scenarios?*
3. *What are the Key Performance Indicators for the attractiveness of the maritime port in the uncertain future of PI?*
4. *Which PI policy directions can improve the attractiveness of the maritime port?*
5. *Which focus distribution of PI policy directions is the best-fit to improve the attractiveness of the maritime port in the different PI port scenarios?*
6. *What can be recommended to the maritime port to further develop (adaptive) policy in the uncertain future of Physical Internet?*

These research questions are, in particular answered for the Port Authority (hereafter: PA) of a landlord port, like the Port of Rotterdam (hereafter: PoR).

Research foundations
Physical Internet
PI was for the first time mentioned in 2006 and lately received more interest from policy makers and researchers. The latest definition of PI is:

'A global hyperconnected logistics system enabling massively open asset sharing and flow consolidation across numerous parties and modes through standardized encapsulation, modularization, protocols and interfaces' (Montreuil, 2016).

In this definition the standard encapsulation, modularitiy, protocols and interfaces are the main components of PI. However, in literature there is a lot of inconsistency about what these components actually are. In this thesis, for clarity reasons are the PI characteristics of Martinez de Ubago (2019) and Voster (2019): *The Operational dimension, the Digital dimension and the Governance dimension* used in the expert interviews. These characteristics are well differentiated.

Maritime port
All the activities and stakeholders in the maritime port are directly or indirectly related to the transshipment of goods between vessel and land modes. The role of the maritime port in the logistics system, and in particular the role of the PA is changing. The current role of the PA can already be better described as a facilitator within logistics system and what the role of a maritime port and the PA will become in PI is at this moment uncertain. Most likely a maritime port, like the PoR, will become a π-hub in the PI network, in which the maritime port connects different local/regional networks with each other.

Methodology
The overall thesis approach uses inspiration from adaptive policy making methodologies and in particular the first five steps of the Dynamic Adaptive Policy Pathways (hereafter: DAPP) approach. In figure 1 an overview of the entire thesis approach used to answer all the research questions is provided. For each RSQ the used methodology is briefly discussed:

In the first RSQ, external factors are identified by literature review, applications of theoretical frameworks and a stakeholder analysis. In the second RSQ, PI port scenarios are developed based on inspiration from the theoretical framework from Geels (2002) and the driving forces of Martinez de Ubago (2019). In the third RSQ, the port choice criteria classes for containers and vessels in the context of PI, defined by Fahim (2020), are used to define the Key Performance Indicators (hereafter: KPI) for the attractiveness of the maritime port. In the fourth RSQ, the methods literature review and expert interviews are used to identify policy measures the PA could apply to improve the attractiveness of the maritime port. Furthermore, literature review and expert interviews are used to determine particular roles the PA could play to improve the attractiveness of the maritime port in the uncertain future of PI. Based on these roles, the identified policy measures are aggregated into six PI policy directions used for further analysis. In the fifth RSQ, the Bayesian BWM is applied to determine the 'best-fit' focus distribution of PI policy directions in the different PI port scenarios. In the sixth RSQ, is based on patterns in and between the 'best-fit' focus distributions of PI policy directions, and the sell-by dates and path-dependencies of the different PI policy directions recommendations provided to the PA to make the maritime port attractive in the uncertain future of PI.

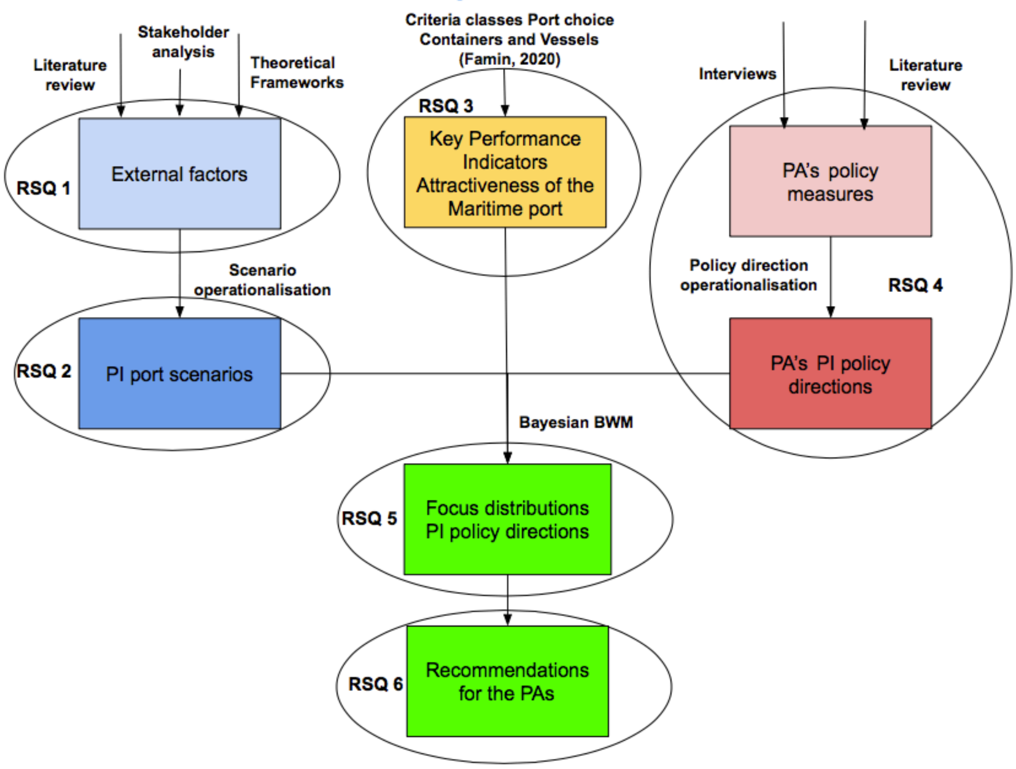

Figure 1: Overview thesis approach

Physical Internet scenarios
External factors
From literature review, the application of theoretical frameworks and a stakeholder analysis in total 39 external factors are clustered into the following external factor classes:

A Economic growth: Includes the growth of the (world) GDP.

B Demographic changes: Are the changes in size, growth and structure of the population.

C Flow patterns: Are logistics developments, which influences the trade flows through the maritime port, by affecting where goods are handled, stored and could be transported from and to.

D Global institutional integration: Refers to the ’rules of the game’ for global trade, set by formal institutions.

E Regulatory frameworks: Refers to regulation, set by formal institutions, which influences the breakthrough or development of (technological) innovations.

F Technological innovations: Are other technological innovations than PI that affect the attractiveness of the maritime port.

G Logistics market structure: Refers to tangible social structures between companies in logistics which have evolved specific role behaviour towards one another.

H Sustainability: Refers to a plan or a set of ideas of what to do about environmental, economic and social unsustainable effects of the port operations and port related activities.

As, the external factor classes D - G, are in line with the research objective *Supporting the maritime port in designing policy to be attractive in the future, given* ***the uncertain development of Physical Internet*** are these four external factor classes clustered into the following two driving forces:

- **Technological development:** Includes the external factor class F: *Technological innovations* and represents the development of innovations, like Big Data, IoT and Blockchain.
- **Institutional development:** Includes the external factor classes E: *Regulatory frameworks*, external factor class G: *Logistics market structure* and external factor class H: *Sustainability*, and represents the restrictions and/or support from institutions for implementing PI policy by the PA.

The extremes of the two driving forces (see axis figure 2) are used to develop the four PI port scenarios (see quadrants figure 2).

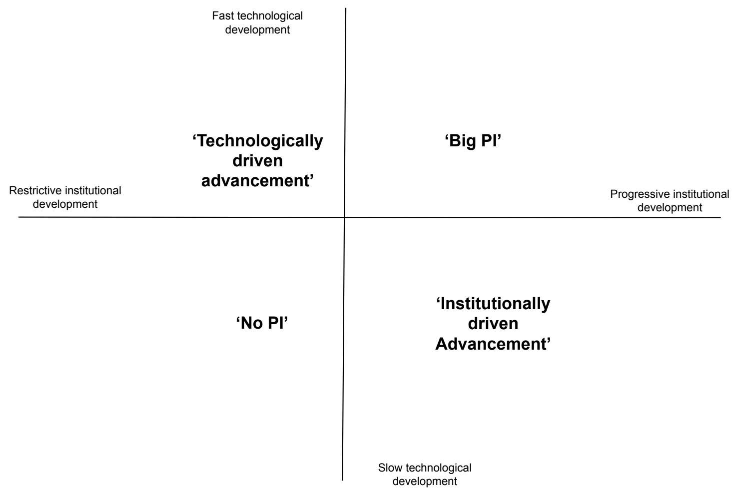

Figure 2: Scenario logic PI port scenarios

Key Performance Indicators for the attractiveness of the maritime port

As, it is considered that containers and vessels are the most important entities in the future of PI, the port choice criteria classes, determined by Fahim (2020) are used to develop the following four Key Performance Indicators (hereafter: KPI) for the attractiveness of the maritime port:

- **A Transport Chain Quality (TCQ):** Refers to the effectiveness of the port operations, including the speed, reliability and quality of operations, and the agility to respond to changes/disruptions in the port operations.
- **B Costs:** Refers to the costs for the port users.
- **C Digital Connectivity (DC):** Refers to the digital connectivity in the port and the seamless digital integration of the port in the supply chains.
- **D Physical Network Connectivity (PNQ):** Refers to the physical connectivity of the port, the reliability of the maritime operations and hinterland operations and the agility to respond to changes/disruptions in the maritime operations and the hinterland operations.

PI Policy directions

Identified PI policy directions

With the use of an in-depth literature review and 14 conducted interviews, six different PI policy directions are distinguished:

1. **Transport infrastructure (TI)**
2. **(PI) standardisation (PI) stand.)**
3. **Advanced Terminal Areas (ATA)**
4. **ICT Hardware (ICT-H)**
5. **Information systems and information exchange platforms (IS and IEP)**
6. **Sustainability Management (SM)**

'Best-fit' focus distributions PI policy directions

With the use of the Bayesian BWM, the 'best-fit' focus distributions of the different PI policy directions on the defined KPIs in the different PI port scenarios are assessed. In this application, perception of 21 experts are used. In table 1, the results are presented.

Table 1: 'best-fit' focus distribution PI policy directions on the KPIs of attractiveness of the maritime port in the different PI port scenarios

	'Big PI'				'Institutionally driven advancement'				'Technologically driven advancement'				'No PI'			
	TCQ	Costs	DC	PNC	TCQ	Costs	DC	PNC	TCQ	Costs	DC	PNC	TCQ	Costs	DC	PNC
TI	0.130	0.167	0.085	0.260	0.126	0.179	0.080	0.214	0.110	0.139	0.082	0.204	0.202	0.260	0.107	0.271
(PI) Stand.	0.195	0.222	0.228	0.166	0.214	0.175	0.226	0.190	0.247	0.190	0.257	0.211	0.173	0.182	0.194	0.154
ATA	0.141	0.134	0.108	0.196	0.169	0.165	0.099	0.175	0.132	0.139	0.112	0.141	0.172	0.163	0.117	0.176
ICT-H	0.179	0.165	0.207	0.132	0.179	0.158	0.232	0.141	0.16	0.178	0.197	0.135	0.151	0.131	0.230	0.131
IS and IEP	0.255	0.241	0.286	0.152	0.219	0.242	0.285	0.210	0.253	0.263	0.266	0.231	0.188	0.168	0.255	0.160
SM	0.100	0.073	0.087	0.095	0.094	0.082	0.078	0.072	0.098	0.092	0.087	0.079	0.115	0.096	0.097	0.107
Total	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Recommendations future (adaptive) policy making Port Authority

Based on patterns in and between the 'best-fit' focus distributions, the sell-by dates of the different PI policy directions and the path-dependencies between the different PI policy directions the following recommendations are provided to the PA to make the maritime port attractive in the uncertain future of PI:

- **Main focus points for the PA:** The PA should mainly focus on the PI policy direction *Information systems and Information exchange platforms*, especially to improve the KPI Digital Connectivity. In the PI port scenario 'No PI', it is advised the PA should focus less on this PI policy direction, as it is less effective. This also applies for the *(PI) Standardisation*. Which, however, generally should be less focus on across the different PI port scenarios. Still, it is advised to the PA to play an active role in developing (PI) standards in an early stage and dependent on the PI port scenario enforce/stimulate the usage of certain (PI) standards by the port community in a later stage. The PA should focus more on the PI policy direction *Transport Infrastructure* in the PI port scenario 'No PI', as other PI policy directions become less effective. Also, the PA should put more focus on this PI policy direction to improve the KPI Physical Network Connectivity.

- **Different policy focus outside the port territory:** To improve the KPI Physical Network Connectivity, the PA should to a lesser degree focus on the PI policy directions *Information systems and Information exchange platforms* and *(PI) Standardisation*. These PI policy directions are considered to be less impactful on maritime operations and hinterland operations, as these operations are outside the port territory and is less in the influence sphere of the PA.

- **General recommendations:** The PA could regardless of which scenario unfolds itself start pilots and best use cases to show what standardisation and sharing of assets, both physically and digitally (data) could bring to the port community. In general, for future (adaptive) policy making, it is always important to consider a broad perspective: what is the added value of the maritime port to the (PI) network and what could the PA influence with its policy, rather than the competitive approach: how can I attract the most companies to the port. This broader perspective will, regardless of which PI port scenario unfold itself make the maritime port attractive and make the implemented (PI) policy effective.

- **Other recommendations:** The PA should less focus on the PI policy direction *Advanced Terminal Areas*, as it is considered not entirely up to the PA to develop the terminal areas. This strongly depends on the terminal operators. The PA should advance the installation of *ICT Hardware*, as the effective usage of the *Information systems and Information exchange platforms* depends on it and the PA should focus the least on PI policy direction *Sustainability Management*.

A sensitivity analysis, conducted by including only the first six respondents for each PI port scenario, substantiate the consistency of these recommendations.

Conclusion
Regarding the MRQ: *How could a maritime port be attractive in the future, given the uncertain development* and the scope of the thesis on the PA of a landlord port like the Port of Rotterdam, it can be concluded that dependent on how this innovation will develop, different policy focus for the PA is recommended, however in general the PA should focus on developing and providing information systems and information platforms, and the PA should focus on developing and stimulating the usage of (PI) standards.

Scientific Contributions
This thesis fulfils scientific objective to improve the knowledge regarding the implications of PI in the future development of the maritime port, by the following scientific contributions:

1. **Recommendations to the Port Authorities to make the maritime port attractive in the uncertain future of PI**
2. **First set of theoretical backed PI policy directions**
3. **A new case of the (Bayesian) BWM, specifically to determine 'best-fit' focus distributions of policy in different (future) contexts**

Reflection on the thesis
The research offers room for discussion and room for future research:

This research only analyses four different PI port scenarios. This is relatively low to further develop (adaptive) policy making for the PA. For this reason, research based on more different scenarios is recommended. Also, in this thesis, only six aggregated PI policy directions are defined. These PI policy directions include much more specific policy measures. It is, therefore, recommended to conduct more research to these specific policy measures and to how these policy measures can be translated into an actual policy plan.

In this research, the KPIs for the attractiveness of the maritime port are based on the criteria classes used for the port choice of containers and vessels. In future research, it might also be valuable to consider bulk transport and the industry in the maritime port. Furthermore, it might also be valuable to determine the cost-effectiveness of the PI policy directions by performing additional research to the investment cost of the different PI policy directions. Or, analyse the impact of the PI policy measures in a more quantitative way, e.g. what are the effects of the directions on the container throughput in the different PI port scenarios.

In this research, it is both assumed that the experts could make judgments from the perspective of the PA and the reference port of the experts does not influence the results of the (Bayesian) BWM. As, only experts from North-west Europa filled in the questionnaire, it can, therefore be argued that the results are particularly of use for PAs in this area. It would be valuable to perform a comparable (Bayesian) BWM with experts from other geographical areas. Also, as the (Bayesian) BWM only provides insight in the 'best-fit' focus distributions of the PI policy directions on the KPIs in the different PI port scenarios, it is recommended to perform a *Gap analysis* for a particular ports to determine to which extend, in this port the different KPIs can be improved in the different PI port scenario. In combination with the results of this thesis the absolute contribution of PI policy directions in PI port scenarios can be determined. This provides valuable information for the PA to develop an actual policy plan. Alternatively, research can be recommended to determine the relative improvement of the KPIs in the PI port scenarios, by e.g. a (Bayesian) BWM. This can in combination with the results from this study and Fahim (2020) better estimate the overall 'best-fit' focus distributions of the PI policy directions in the different PI port scenarios.

This research is performed for the PA of a landlord port. For this reason, it can be recommended to perform a comparable research to the other types of maritime ports, to perform a comparable research from a different stakeholder's perspective and to perform a comparable research to other system components, like airports.

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List of Abbreviations

3PL	Third-party logistics service provider
AGV	Automated Guided Vehicle
AYC	Automated Yard Crane
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
B2B	Business to Business
B2G	Business to Government
BWM	Best Worst Method
CBER	Consortia Block Exemption Regulation
CER	Container Exchange Route
CIO	Chief Information Officer
COS	Consider-the-Opposite
CSCMP	Council of Supply Chain Management Professionals
DI	Digital Internet
EMS	Environmental Management System
ESI	Environmental Ship Index
EU	European Union
GDP	Gross Domestic Product
GPS	Global Positioning System
GHG	Green House Gasses
ICC	International Chamber of Commerce
IMO	International Maritime Organization
IoT	Internet of Things
IPIC	International Physical Internet Conference
IS	Information System
ISO	International Organization for Standardisation
JAGS	Just another Gibbs Sampler
KPI	Key Performance Indicator
MCMC	Markov-chain Monte Carlo
MCDM	Multi Criteria Decision Making
MEPC	Marine Environmental Protection Committee
MRQ	Mean Research Question
NOLI	New Open Logistics Interconnection
NQP	Network Quality of Port
OLI	Open Logistics Interconnection
OSI	Open Systems Interconnection
FV	Fundación Valenciaport
PA	Port Authorities
PCS	Port Community System
PMS	Port Management System
PI	Physical Internet
P/I grid	Power/Interest Grid
PoR	Port of Rotterdam
RFID	Radio Frequency Identification
RSQ	Research Sub Question
SAM	Selective Accessibility Model
SCM	Supply Chain Management

ST	Socio-Technical
SUTP	Sustainable Urban Transport Plan
TCP/IP	Transmission Control Protocol/Internet Protocol
TCQ	Transport Chain Quality
UDC	Urban Distribution Centre
UN	United Nations
WHO	World Health Organization
WTO	World Trade Organization

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1 Introduction

As, the world becomes more interconnected through globalisation, international trade is increasingly crucial for the global welfare. In 2018, the international trade was responsible for 30% of the worldwide Gross Domestic Product (hereafter: GDP) (UNCTAD, 2019). To facilitate this trade, logistics activities are performed in a global logistics system. The focus of the logistics system, until the end of the last century, was on fulfilling the customers' needs and minimizing the total costs. This, however, has some long-term negative implications for the environment, economy and society (Rajeev, Pati, Padhi, & Govindan, 2017). For this reason, the focus in the 21^{th} century changed to a more environmentally friendly focus. This can, for example be seen in the signing of the Paris Agreement (European Commission, 2015). In this agreement, over 150 countries inclined to reduce the amount of Green House Gasses (hereafter: GHG) with at least 40%, in 2030 in comparison to 1990.

As, logistics activities have a significant contribution to the total emission of GHG, some changes have to be made (European Environment Agency, 2017; OECD/ITF, 2015; Montreuil, 2011). Furthermore, logistics have societal and economical unsustainable effects. In 2011, Montreuil defined thirteen logistics symptoms around the world that cause either environmentally, economically or socially unsustainable effects (see table 1.1).

Table 1.1: Logistics issues from Montreuil (2011)

Unsustainability symptoms	Economical	Environmental	Societal
Shipments largely consist of air and packaging	x	x	
Travelling empty (<10% of transport is effective)	x	x	
Truckers are nearly always on the road	x		x
Products are stored in vast quantities, yet are unavailable when needed fast	x		x
Poor utilization of storage and production facilities	x	x	
Products do not reach the market in time	x	x	x
Products do not reach people who need them most	x		x
Fast and reliable intermodal transport in utopia	x	x	x
Moving goods in/through/ out of cities is a disaster	x	x	x
Networks are not secure or robust	x		x
Smart automation and technology are hard to justify	x		x
Innovation is stuck at a bottleneck	x	x	x

To deal with these symptoms and have a more sustainable and efficient global logistics system some innovations, like Synchromodality and Physical Internet (hereafter: PI) are suggested. Synchromodality's aim is to create the most efficient and most sustainable transportation plan for all orders in an entire network of different modes and routes, by using the available flexibility (Van Riessen, Negenborn, & Dekker, 2015). This will, for example, through asset sharing significantly reduce the number of empty travelling of vehicles and containers (see table 1.1).

Asset sharing is, also one of the key principles of PI. However, PI has a broader focus. This innovation not only focuses on the freight transportation system, but on the entire logistics system (Montreuil, 2016). Synchromodality can, therefore, be seen as a part of PI (ALICE, 2019).

The underlying idea of PI is to move goods through the logistics system similarly to how data is transferred through the Digital Internet (hereafter: DI). This implies for the global logistics system that the goods[1] themselves are not handled, stored or transported, but the package in which the goods are encapsulated is handled, stored and transported. The PI network is, furthermore constantly updating, to establish the most efficient and sustainable way to transfer all of the goods through the entire logistics system (Crainic & Montreuil, 2016). This potentially solves most of the logistics symptoms identified by Montreuil (2011). However, currently it is unknown what this innovation implicates for important logistics components and/or stakeholders, like the maritime port and the Port Authority (hereafter: PA).

The rest of the introduction is structured as follows: section 1.1 discusses the research context and research scope. In section 1.2, the research gap is presented. Hereafter, in section 1.3 the research objective is formulated. Section 1.4 provides the research question(s). In section 1.5, the scientific and social relevance of the thesis is treated and finally section 1.6 presents the thesis outline.

1.1. Research context & scope

PI is an innovation in the field of logistics and Supply Chain Management (hereafter: SCM) (Zhong, Xu, Chen, & Huang, 2017). The term SCM was for the fist time mentioned in the beginning of the 1980s (Oliver & Webber, 1982; Yang, 2016). Throughout this decade and up until the end of the 1990s the term SCM was often confused with the term logistics. Nowadays, it is widely accepted that logistics is part of the SCM and concerns *'the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information in the supply chain'* (CSMP, 2013), while the term SCM, also encompasses the conversion, sourcing and procurement activities in the supply chain (CSMP, 2013; Lambert, Cooper, & Pagh, 1998).[2] In this thesis, PI is seen as an innovation within logistics, as this innovation especially affects this part of SCM. This can particularly be observed in the latest definition of PI Montreuil (2016):

'A global hyperconnected logistics system enabling massively open asset sharing and flow consolidation across numerous parties and modes through standardized encapsulation, modularization, protocols and interfaces.'

Within logistics, freight transportation has a crucial role. It provides the bridge between spatial separated places of supply and demand (Tavasszy & De Jong, 2013). The maritime freight transport is accountable for 80% of the merchandise trade volume. And, as maritime ports[3] primary function is to provide the connection between vessels and land modes, such as trucks and trains, maritime ports have a critical role in the global logistics system (UNCTAD, 2019; Ligteringen, 1999). For this reason, in this thesis is chosen to research the implications of PI on the future development of maritime ports.

Maritime ports not only provide the connection between vessels and land modes, but are much more complex. This becomes generally clear from the definition of Ibrahimi (2017):

'Territorial, operational and institutional cluster of interrelated social-economic resources, activities and legitimate actors engaged in appropriate agreements (in)directly related to the transfer of goods and people between land and sea vehicles, serving as a node for the foreign trade and tourism, for the industry, logistics and supply chains, and for the global transport system ever more intermodal in its hinterland and foreland.'

[1] For practical reasons the usage of the terms physical objects and goods are mixed

[2] Supply chain in this thesis refers to *"All activities associated with the flow and transformation of the goods from the raw materials stage (extraction), through to the end-user, as well as associated information flows."*(Handfield & Nichols Jr, 1999)

[3] For practical reasons the usage of the term maritime port and port is mixed

There are two important elements to distinguish from this definition. In the first place, there are several stakeholders involved. The stakeholders involved are, among others the terminal operator(s), shipping lines, ship brokers, freight forwarders, carriers and the Port Authority (hereafter: PA) (Nijdam & Van der Horst, 2017). The last-mentioned stakeholder, the PA, is responsible for the economic exploitation, long-term development of land, and takes care of the (basic) port infrastructure, including the access roads and berths (Brooks, 2004). Besides, this stakeholder positions itself as the coordinator that facilitates the ever-evolving port users' needs (Vis, Tavasszy, Roodbergen, Buijs, & Coelho, 2015; Van der Lugt, Dooms, & Parola, 2013). For these reasons, this stakeholder is chosen to be the problem owner of the thesis.

Secondly, from the definition can be retrieved that all the activities and all the stakeholders are (in)directly related to the transfer of goods and/or people between land and sea. The transfer of people is excluded, as the focus of PI is on transporting, handling and storing goods. Also, to further scope the thesis and built upon previous research of Fahim (2020), the focus of this thesis is on handling, transporting and storing containers and less on bulk goods or industrial activities of the port. This makes the two most important entities to consider the container and the vessel. These two entities are considered to be the only certainty in the future with PI. The stakeholders involved and in what form is unclear.

In general, four categories of maritime ports can be distinguished: the service port, the tool port, the landlord port and the private port (Brooks, 2004). These categories differ in the private or public responsibilities for the infrastructure, the superstructure, the port labour and other functions (see figure 1.2).

Table 1.2: Classification of maritime ports (Brooks, 2004)

Responsibilities	**Service**	**Tool**	**Landlord**	**Private**
Infrastructure	Public	Public	Public	Private
Superstructure	Public	Public	Private	Private
Port labour	Public	Private	Private	Private
Other functions	Majority public	Mixed	Mixed	Majority private

It is important to research the implications of PI on all the port categories, however it is impossible to accomplish this in a single research. For this reason, this thesis only focuses on the category landlord port. This category is chosen, as the implications of PI is still highly uncertain and it is, therefore, considered important to build upon available research (Martinez de Ubago, 2019; Voster, 2019).

In this particular model, the PA is responsible for the port safety, economic exploitation, the long-term development of the land, the maintenance of basic port infrastructure, including access roads and providing waterside access by e.g. dredging (Brooks, 2004). The PA, also has a regulator function, which includes e.g. licensing, permitting, vessel traffic safety, protection of public interest, environmental policies and customs. In this particular model, the private operators maintain and operate their own superstructure required for the transshipment of containers between vessels and the docks (Baltazar & Brooks, 2001). An advantage of this particular model is that the same entities own the handling equipment and perform the handling. This leads to better planning. However, there is also risk of overcapacity as more than one private operator could pressure for expansion by the PA (Brooks, 2004).

As the goal of this thesis is, also to have a social contribution and looking at a particular port provides insights in relevant details otherwise went unnoticed, in this thesis the Port of Rotterdam (hereafter: PoR) is chosen, as case study. This particular maritime port is chosen, mainly, because of two reasons:

- There is only limited knowledge available about the implications of PI on maritime ports. Therefore, it is important to built upon previous performed research. This previous performed research mainly focused on the PoR (Voster, 2019; Martinez de Ubago, 2019).
- The PA of PoR is interested in this new concept. It is working closely together with researchers in the project 'Towards virtual ports in a Physical Internet' (Rijksuniversiteit Groningen, 2016).

This scope, also implies that the problem owner of thesis is the PA of the PoR: the Havenbedrijf Rotterdam (PoR, n.d.a). In the following subsection, some research context about the PoR is provided.

Port of Rotterdam
The PoR is located in the Netherlands with a direct connection to the North-Sea via the river the Maas. The PoR has an important contribution to the Dutch economy. It is estimated that directly and indirectly, the PoR is responsible for 6,2% of the GDP and 384,500 jobs (PoR, n.d.). Other maritime ports in the areas are Le Havre, Dunkerque, Zeebrugge, Antwerpen, Amsterdam, Bremen and Hamburg (Rodrigue, 2010) (see figure 1.1). The PoR is the largest container port in this area, with a total volume of 14.51 million TEU in 2018. This makes the PoR the 11^{th} largest container port in the World. The second biggest port in the area is Hamburg, with 8.74 million TEU. This port has the 19^{th} position on the worldwide list (World Shipping Council, n.d.).

Figure 1.1: Maritime ports in area Hamburg-Le Havre (Martinez, 2019)

1.2. Research gap

The ultimate goal of the PA of a landlord port, like the PoR, is to satisfy the port customers, or to reframe this in the context of PI: to be as attractive for containers and vessels as possible. Unfortunately, achieving this goal is highly complex. The decisions the PA has to make are mostly about large scale and infrastructure like projects, which takes several years to implement, involves many different stakeholders and in most cases have an irreversible character (Rodrigue, 2010). Furthermore, in the meantime new stakeholders, other opinions, changes in the economy and new technological innovations, like PI influence the final effectiveness of the policy (Notteboom & Winkelmans, 2001).

At this moment, there is limited knowledge regarding the future adoption of PI and how this will influence the PA's policy making. To give insight in this uncertainty Martinez de Ubago (2019) constructed four scenarios for the development of maritime ports under the evolution of the PI. Only, how these scenarios influence the attractiveness of the maritime port and how the PA could adequately design policies is not further researched. Voster (2019) researched how the PA could design policy in the context of PI. Nevertheless, his research did not analyse the effects of policy on the attractiveness of the maritime port. Therefore, the research gap is formulated as follows:

Current knowledge does not provide insight in how a maritime port could be attractive given the uncertain development of Physical Internet.

1.3. Research objective

Given the research gap formulated in section 1.2, the overall research objective is formulated as:

Supporting the maritime port in designing policy to be attractive in the future, given the uncertain development of Physical Internet

The research objective is filled by evaluating policy directions the PA of a landlord port, like the PoR, could apply to make the maritime port attractive in different scenarios. The resulted recommendations are in particular addressed to the PA the PoR. Nevertheless, the scenarios and policy directions are defined in such a way that the recommendations are also applicable for other PAs of particular a landlord port. These, general recommendations are discussed in the conclusion (see section 7.1.2). Thereby, should be mentioned that the research objective is not to become more attractive than other maritime ports, only to improve the maritime ports attractiveness in the global logistics system.

1.4. Research question(s)

To achieve the research objective the following main research question (hereafter: MRQ) is formulated:

How could a maritime port be attractive in the future, given the uncertain development of Physical Internet?

To answer the main research question the following research sub questions (hereafter: RSQ) are developed:

1. *What are the external factors influencing the attractiveness of the maritime port in the uncertain future?*
2. *What are the PI port scenarios?*
3. *What are the Key Performance Indicators for the attractiveness of the maritime port?*
4. *Which PI policy directions can improve the attractiveness of the maritime port in the uncertain future of PI?*
5. *Which focus distribution of PI policy directions is the best-fit to improve the attractiveness of the maritime port in the different PI port scenarios?*
6. *What can be recommended to the maritime port to further develop (adaptive) policy in the uncertain future of Physical Internet?*

These are generally defined RSQs. However, as discussed in section 1.1, the problem owner of the thesis is the PA of a landlord port, like the PoR. For this reason, the RSQs are specifically answered for the PA of the PoR. Nevertheless, these answers are also applicable for other PAs of a landlord port. In section 7.1.2, the general recommendations are discussed. The contribution of each of the sub RSQs are briefly discussed below (see section 3.1 for a more elaborate explanation):

In the first RSQ, the external factors for the PA to make the maritime port attractive are identified by means of literature review, stakeholder analysis and theoretical frameworks. In the second RSQ, is based on the identified external factors four PI port scenarios operationalised. Hereafter, in the third RSQ, is based on the criteria classes for the port choice of containers and vessels, the Key Performance Indicators (hereafter: KPI) for the attractiveness of the maritime port developed (Fahim, 2020). In the fourth RSQ, is based on roles the PA could play to make the maritime port attractive in the uncertain future of PI and identified policy measures, identified by literature review and experts interviews, PI policy directions defined. Afterwards, in the fifth RSQ is by means of the Bayesian Best Worst Method (hereafter: BWM), the 'best-fit' focus distribution of the policy directions on the different KPIs in the different PI port scenarios determined. Thereafter, in the sixth RSQ is based on patterns in and between the 'best-fit' focus distribution of the PI policy directions, and the sell-by dates and path-dependencies of the PI policy directions, recommendations provided to the PA to make the maritime port attractive in the uncertain future of PI.

1.5. Scientific and social relevance

The overall scientific objective of the thesis is to improve the knowledge regarding the implications of PI on the future development of maritime ports. The main, corresponding scientific objective is to provide recommendations to the PA of a landlord port about future policy making in the uncertain future of PI. These recommendations are based on patterns in and between 'best-fit' focus distributions of PI policy directions on different KPIs in different PI port scenarios.

Another, related scientific objective is to provide the first set of PI policy directions the PA could apply to improve the attractiveness of the maritime port in the uncertain future of PI. Voster (2019) already provided some measures which in context of PI could be applied by the PA. However, these policy measures lack theoretical background.

The third scientific objective is to provide a new application of the Bayesian BWM. Only, Fahim (2020) used this methodology in the context of maritime ports and PI. More importantly, the scientific objective is to provide the first application of the BWM, which uses this methodology to provide recommendations based on patterns in and between 'best-fit' focus distributions of policies, being in this thesis PI policy directions, in different (future) contexts, being in this thesis different KPIs and different PI port scenarios. There are studies, which uses the BWM in assessing different policies (Abadi, Sahebi, Arab, Alavi, & Karachi, 2018; Mokhtarzadeh, Mahdiraji, Beheshti, & Zavadskas, 2018) or even assess the performance of different policies on different criteria (Safarzadeh, Khansefid, & Rasti-Barzoki, 2018). However, no comparable study is found, which uses the BWM to provide recommendations based on patterns in and between 'best-fit' focus distributions.

The fourth scientific objective is to provide new insights about the adoption of PI (in the maritime port) by means of the applications of two theoretical frameworks: the *Political- and economy model of transport innovations* of Feitelson and Salomon (2004) and the *Dynamic Multi-level perspective of technological transitions* of Geels (2004). This, however, might be limited, as only a partial adoption of these frameworks are used in this thesis.

The social relevance of the thesis, thereby, is the application on the PoR and the social aim is to provide recommendations for the PA of this port.

1.6. Thesis outline

The thesis is structured as follows (see figure 1.2 for an overview): In chapter 2 is, based on literature of the two main concepts of the thesis: PI and maritime ports, the foundations for the thesis outlined. Chapter 3, describes the overall thesis approach and the methodologies used to answer the RSQs and MRQ. Hereafter, in chapter 4 external factors for the PA to make the maritime port attractive are used to operationalize four PI port scenarios. Chapter 5, describes the KPIs for the attractiveness of the maritime port, the PI policy directions the PA could apply to make the maritime port attractive and shows the 'best-fit' focus distributions of these PI policy directions for the different KPIs in the different PI port scenarios. In chapter 6, are patterns in and between the focus distributions, path-dependencies and sell-by dates of the PI policy directions used to formulate recommendations for the PA to make the maritime port attractive. Finally, chapter 7 and chapter 8 are used for the thesis synthesis and answering the RSQs and the MRQ.

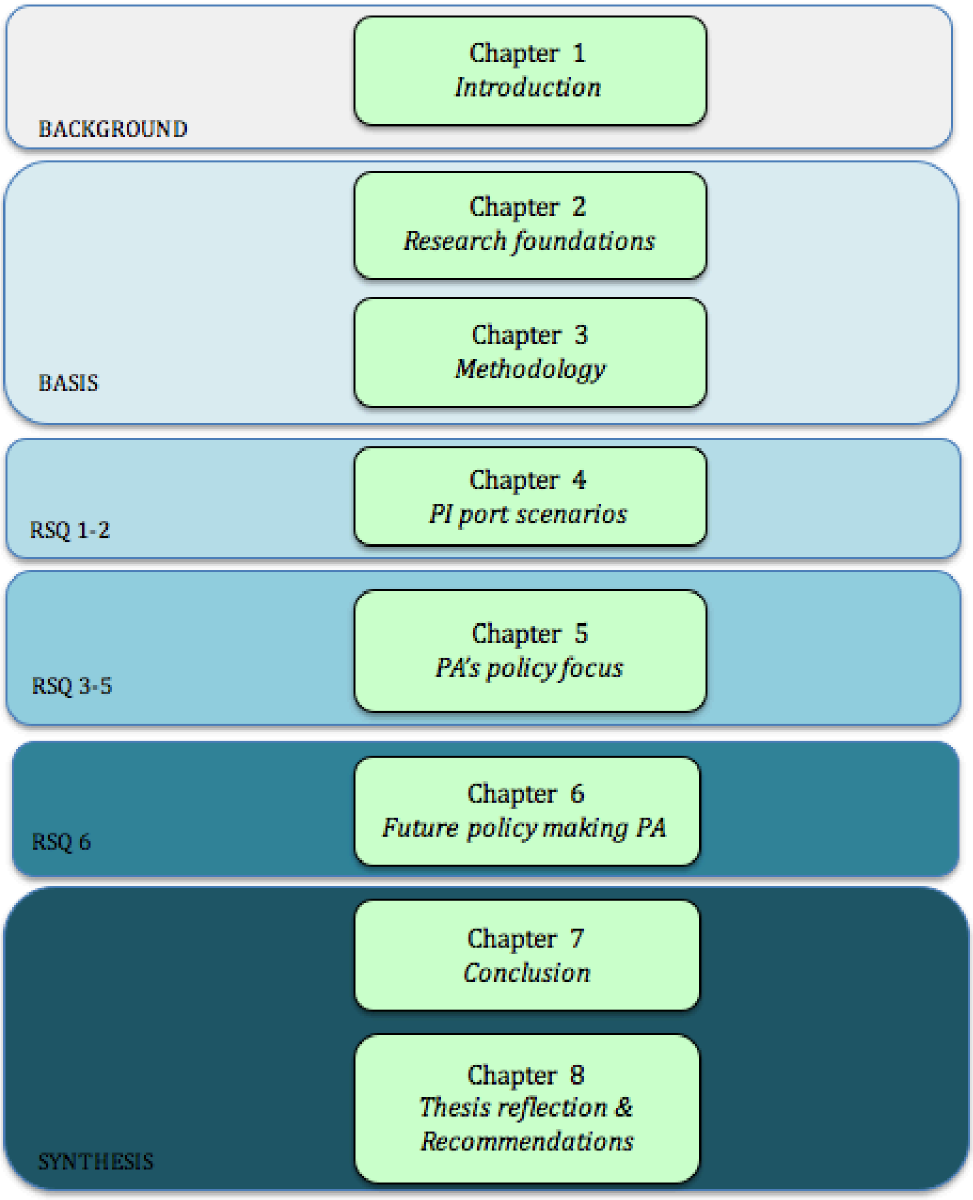

Figure 1.2: Thesis outline

2

Research foundations

In this chapter, the research foundations are presented by discussing the relevant literature of the two main concepts of the thesis: Physical Internet (hereafter: PI) and maritime ports.

The chapter is structured as follows:

- In section 2.1, the current state of research in the field of PI is summarised.
- In section 2.2, the relevant research about the maritime ports is discussed.

2.1. Physical Internet

The PI concept was firstly mentioned on the cover of The Economist in June 2006 (Markillie, 2006) and inspired Professor Benoit Montreuil, who started openly publishing about PI from 2009. These publications led to the first scientific publication in 2011: *Towards a Physical Internet: meeting the global logistics sustainability grand challenge*. In this paper, Montreuil (2011) introduced PI, as a response to the global logistics sustainability grand challenge. This challenge involves solving the unsustainable way of how currently physical objects are transported, handled, stored, realized and supplied (Pan, Ballot, Huang, & Montreuil, 2017) (see table 1.1 in chapter 1).

There is a growing pressure from policy makers to reduce these unsustainable effects of logistics. Unfortunately, there was no innovation in the field of transport and logistics that would sufficiently cope with the sustainable objectives until, in 2011 and 2012 two simulation studies showed that PI could cope with these goals. These simulation studies showed that only a partial adoption of PI could reduce the total travel distance and the CO_2 emission between 25% and 50% (Ballot, Montreuil, & Thivierge, 2013; Ballot, Gobet, & Montreuil, 2012).

The general idea of PI is based on a metaphor with the Digital Internet (hereafter DI): In the DI, the data processed through the network is not manipulated or managed, but the data package in which the data is encapsulated is managed and manipulated. This implies for PI, that the physical objects are encapsulated into, the so called, π-containers and it are these π-containers that are managed and manipulated through the PI network (Montreuil, 2011) (see figure 2.1). There are three π-containers types distinguishes (Krommenacker, Charpentier, Berger, & Sallez, 2016):

- **The P-container**: Is the π-container, in which the physical object is encapsulated. This π-container is as light as possible and is designed to easily insert and extract the physical object.
- **The H-container:** Is the π-container designed to be easily handled by the π-handlers. The characteristics of the H-container, therefore should be accommodated to the design characteristics of the π-handlers. In the H-containers, the P-containers are encapsulated.
- **The T-Container:** is the π-container designed to be easily transported by the π-movers. For this reason, the design of the T-containers has to be accommodated to the characteristics of the π-movers. In the T-containers, the H-containers and the P-containers are encapsulated.

Table 2.1: Key physical elements PI adapted from B. Montreuil, Meller, & Ballot, 2010

π-containers	π-nodes		π-movers
0,12 m	- π-sites	- π-transit	- π-vehicles
0,24 m	- π-facilities	- π-switch	- π-carriers
0,36 m	- π-system	- π-bridge	- π-conveyor
0,48 m		- π-sorter	- π-handler
0,6 m		- π-composer	
1,2 m		- π-store	
2,4 m		- π-gateway	
3,6 m		- π-hub	
4,8 m		- π-distributor	
6 m			
12 m			

In 2012, six years after the first time the term PI was used, is based on the DI metaphor the first definition of PI introduced by Montreuil, Meller, and Ballot (2012):

'An open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols'.

Using the DI metaphor in defining PI is a powerful tool. However, there are some key differences between physical object and data. Data can be transported at a much faster pace. The transportation of data is much cheaper and re-sending data is far easier and without significant delays (Crainic & Montreuil, 2016). This is important to consider by real-world applications of this innovation.

It is important to put the innovation of PI in perspective and understand that PI is not an innovation developed completely in isolation. PI is, for example related to other new innovations, like the Internet of Things (hereafter: IoT) and the before mentioned Synchromodality. These two innovations and their relationship with PI are, subsequently treated below.

IoT is in its core about combining physical objects and digital components (Wortmann & Flüchter, 2015). IoT allows human decision makers and automated controllers to constantly track and control the performance, energy usage and environmental conditions of equipment in real time, anywhere and anytime. In IoT, information sharing and collaboration between people, between people and devices and between devices is possible (I. Lee & Lee, 2015). This is crucial for PI, as it ensures easily, fast and fact-based, exchange of meaningful information and make adequate decisions by the physical elements and human decision makers possible (Montreuil, Meller, & Ballot, 2012). PI requires IoT and can, therefore be seen as an application of it (Treiblmaier, Mirkovski, & Lowry, 2016).

At this moment, the first applications of IoT are already used in, e.g. monitoring and controlling components in cars and in smart houses, where the residents can control the temperature and can receive certain notifications (I. Lee & Lee, 2015). These are relatively simple applications of IoT. More complex applications, like PI require numerous devise-connections and high data rates. These applications most likely require a 5G network and other more complex technological innovations (Ni, Lin, & Shen, 2018).

Another relatively new concept is Synchromodality. This concept is an innovation in the field of multimodal freight transportation and is defined as *'creating the most efficient and sustainable transportation plan for all orders in an entire network of different modes and routes, by using the available flexibility'* (Van Riessen et al., 2015). A key component of this innovation is the constant updating of the most efficient and sustainable transport plan, based on changes in operational circumstances and/or customers' requirements (Verweij, 2011). This is, also an important design characteristic of PI. The difference between PI and Synchromodality, however is the broader focus of PI on the entire logistics system. For this reason, Alliance For Logistics Innovations through Collaboration in Europe (hereafter: ALICE) has incorporated Synchromodality, as part of PI. Nevertheless, research to both these concepts is rather detached (Ambra, Caris, & Macharis, 2019).

PI on its own has, lately received more attention. The number of papers published in the field of PI has significantly increased (Ambra et al., 2019). Institutions are getting involved, like the EU with ALICE (ALICE, 2019). The number of projects in the field are increasing (CELDi, 2015; Modulushca, 2019; European Commission, n.d.a). An example of such a project is the project 'Towards virtual ports in a Physical Internet' in the Netherlands. In this project two postdocs, one promovendus and the Port Authority (hereafter: PA) of the Port of Rotterdam (hereafter: PoR) collaborate (Rijksuniversiteit Groningen, 2016).

Despite, this increase in interest, the state of literature is still in its infancy stage (Pan et al., 2017). This implies certain issues, like the lack of theoretical foundation and shared understanding of the main components of PI (see appendix A). This lack of theory building is one of the main concerns for the future adoption of PI, as it is dependent on a comprehensive implementation (Montreuil, Meller, & Ballot, 2012). Therefore, organisations like ALICE are currently stimulating the adoption of PI in Europe by collaborating with important logistics' stakeholders (ALICE, n.d.). They, for example, developed the Physical Internet roadmap in the SENSE project (see section 2.1.2).

That the research of PI is still in its early stage can also be seen in the redefinition of PI by Montreuil (2016) to:

'A global hyperconnected logistics system enabling massively open asset sharing and flow consolidation across numerous parties and modes through standardized encapsulation, modularization, protocols and interfaces'

The four main components retrieved from these definition are the: *modularity, encapsulation, protocols and interfaces*. There is a lot of inconsistency in literature about these components. In appendix A, these components are further discussed.

In the following section 2.1.1 the PI characteristics developed by Martinez de Ubago (2019) and Voster (2019) are discussed and in section 2.1.2 the PI roadmap composed by ALICE (2019) is treated.

2.1.1. Physical Internet characteristics

Considering the lack of consensus for some of the key components in the literature, Voster (2019) and Martinez de Ubago (2019) reframed the four main components of PI into three components to reduce the unclarity. In this distinction of PI components *Modularity* and *encapsulation* are merged into *Modularity* and *standard protocols* and *standard interfaces* are used as building blocks for all the PI components (adopted from Martinez de Ubago (2019)):

- **Modularity**: Encompasses the modular π-containers and the encapsulation of the goods in these π-containers. These π-containers are transported by π-vehicles and handled by all sorts of tools (see figure 2.1). All the equipment, vehicles and π-containers are equipped with *standard handling interfaces*. In order to encapsulate goods into the π-containers and transport, handle and store these π-containers through the network *standard protocols* are used.
- **Interconnectivity**: Is defined as *'the connectedness of the different π-movers, π-containers, π-hubs and other players in the logistics network.'* In this way, they share information and communicate to achieve a more efficient overall network. Both, *digital interfaces* and *standard protocols* are used to accomplish this.
- **Collaboration**: Is about the sharing of resources and assets between different stakeholders. *Digital interfaces* make it possible to match the available capacity with requested demand. These digital interfaces have to be standardised. Furthermore, from a business and legal perspective *standard protocols* are required to structure the exchange of data, the exchange of goods and the decision making in general.

The aim of this thesis is not to add any unclarity to the already inconsistent PI literature. However, as in this thesis experts are consulted the PI characteristics developed by Voster (2019) and Martinez de

Ubago (2019) are used. These PI characteristics are based on their PI components and are easy to understand and well-differentiated:

- **Operational dimension:** Refers to the physically executed operations by the different physical elements, from hubs, warehouses, vehicles to handling equipment.
- **Digital dimension:** Is about the digital connectivity between the different stakeholders in the logistics system.
- **Governance dimension:** For the exchange of data and good between business and other stakeholders are rules and protocols required. This dimension refers to this set of rules which enable a cooperative, safe and reliable PI.

2.1.2. Physical Internet roadmap

In the SENSE project coordinated by ETP-ALICE a roadmap for the future adoption of PI is developed (European Commission, 2017). The goal of the roadmap is to translate the academic vision into an industry roadmap and realize long and short-term benefits in terms of productivity and efficiency. In this roadmap five different areas are distinguished (ALICE, 2019):

- **PI nodes:** Roles of and operational models for physical nodes.
- **PI network services:** PI protocol stack and network management.
- **Governance:** Governance concept, bodies, regulation and trust building measures.
- **Access and adoption:** Benefits of PI and mental shift towards PI
- **System level functionality:** PI architecture, building blocks and information exchange.

Based on the assumption that PI is completely developed between 2035 - 2040 the roadmap is constructed (see figure 2.1).

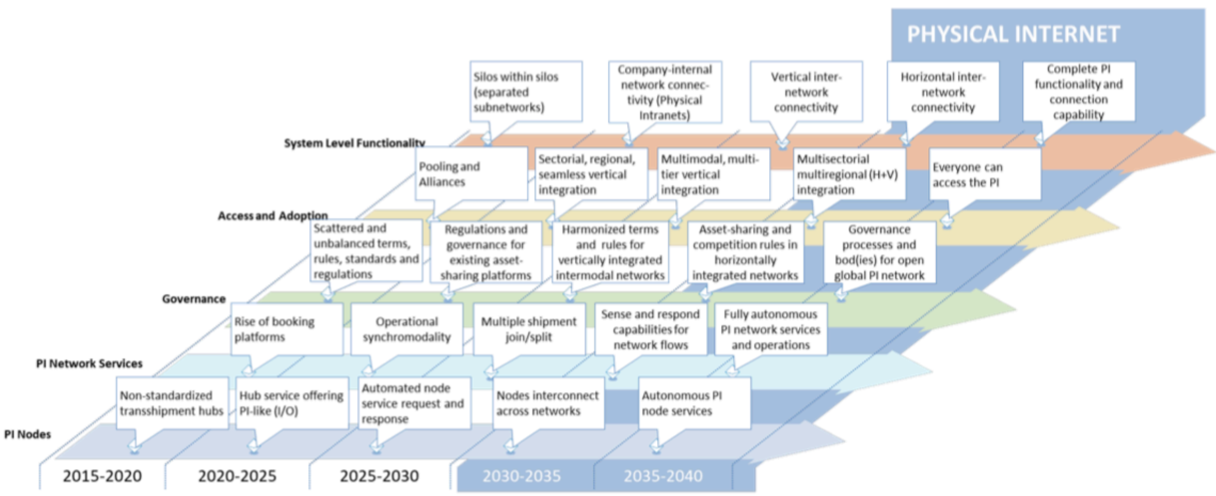

Figure 1: The Physical Internet roadmap

Figure 2.1: Physical Internet Roadmap (ALICE, 2019)

In this thesis the assumption of fully implemented PI in 2040 is not considered as a given, because of three reasons:

1. PI research is still in its infancy stage (Pan et al., 2017). There is still a lot of uncertainty about how PI will shape the future of logistics.

2. Until now there are no (global) standards for the π-containers, protocols and interfaces (see appendix A).

3. Experts do not expect a full adoption of PI in 2040. Martinez de Ubago (2019) showed with a Delphi study that different experts only expect a partial adoption of PI by 2040.

Still, the PI roadmap provides useful information about the potential development of PI and potential policy measures the PA could apply to improve the attractiveness of the maritime port (see appendix E).

2.2. Maritime ports

In this section, the relevant research about maritime ports for the thesis is discussed. This includes research about the role of the maritime port in the overall logistics system (see subsection 2.2.1), relevant research to the definitions of the maritime port (see subsection 2.2.2), research to different stakeholders in the maritime port (see subsection 2.2.3) and PI research relevant for the maritime port (see section 2.2.4).

2.2.1. The role of maritime ports

The maritime ports have a key role in the overall logistics system, as it is the link between the vessels and the land modes (Ligteringen, 1999). This is not the only function of the maritime port. The maritime ports have increasingly a hub function in the supply chain, as it is the place where imported goods are supplied from and the place were the goods shipped out are collected (Zondag, Bucci, Gützkow, & de Jong, 2010). Furthermore, secondary functions, like industry activities or other value-added serves are clustering at the maritime port area (Ligteringen, 1999).

The above described role of the maritime port can be classified, as the third generation port: *the supply chain management port* (UNCTAD, 1994; P. T. W. Lee & Cullinane, 2016) (see figure 2.2). The first generation of maritime ports *the cargo port*, developed before the 1960s and had three main functions: the transshipment function, the storage function and the trade function. The second generation of maritime ports, *the logistics port*, developed after the 1960s and added the industry function to the maritime port. The third generation of maritime ports, *the supply chain management port* developed after the 1980s and added the distribution function. The next generation of maritime ports, suggested by UNCTAD (1999) developed in the 2000s. This generation also referred to as *the globalized e-port* added the function of logistics control, in which vertical and horizontal integration of port strategies occur by, for example inland connections.

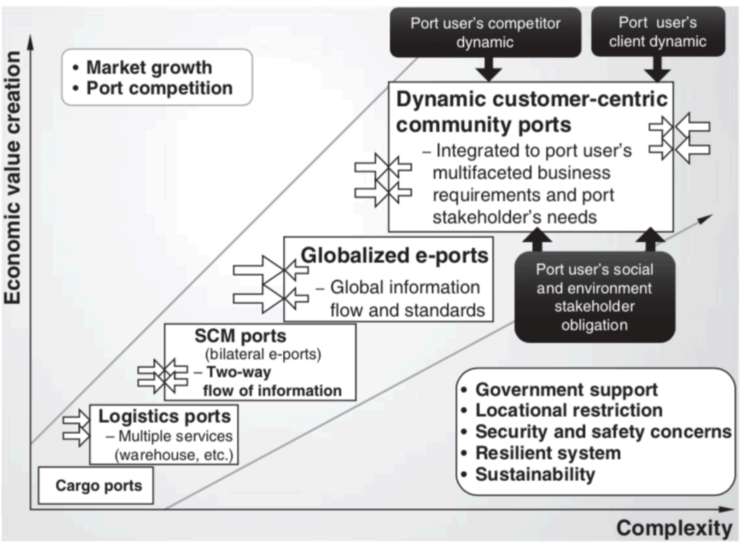

Figure 2.2: Evolution path of ports (P.T.W. Lee & Cullinane, 2016)

The fifth generation, suggested by Flynn, Lee, and Notteboom (2011), is driven by customer centric community interests, rather than the internal profit driven fourth generation. In this *Dynamic customer-centric community port*, information is distributed via a 'single window system' and logistic activities are seen as part of the maritime logistics chain (P. T. W. Lee & Cullinane, 2016). This is comparable with PI, however PI concern the entire logistics system, not only the maritime logistics chain.

This broadening of the perspective can also be seen in the port regionalization development. This development was first described by Notteboom and Rodrigue (2005), as the result of the change in customer focus to the total logistics costs and the relatively high costs of inland operations. Two types of regionalizaiton can be distinguished: *foreland regionalization* and *hinterland regionalization*. Foreland regionalization includes the development of ports into intermediate hubs, in which the goods are transferred from larger vessels to smaller vessels to be further transported to smaller more regional ports and vice versa (Rodrigue & Notteboom, 2010b). Hinterland regionalization includes the inland freight distribution and the inland terminals. There are two main reasons which favour the port hinterland regionalization (Notteboom & Rodrigue, 2005):

- **Globalisation:** Fragmented production and consumption systems require a corresponding distribution network, which port regionalization enables.
- **Local constraints:** Like limited land and congestion has forced freight activities to take place further inland.

The port regionalization and the increased containerisation caused the increasingly shared hinterlands between ports and the forming of port regions (Rodrigue, 2010). In the introduction, it is mentioned that the PoR shares hinterland with other ports in the Le Havre - Hamburg area. Port regions exists on a more regional scale. In the Le Havre - Hamburg area, there are three port regions distinguished: the Seine Estuary, the Extended Rhine-Scheldt Delta and the Helgoland Bay (see figure 2.3). The PoR is part of the Extended Rhine-Scheldt area (Rodrigue & Notteboom, 2010a). In the port vision 2030, the PA of the PoR mentions far reaching collaboration in sharing hinterland infrastructure with the other ports in the Rhine-Scheldt delta area to strengthen the position relative to the North German ports (PoR, 2011). Governments are encouraging such initiatives as these collaborations improves the overall logistics performance of the country (Dooms, Van der Lugt, & De Langen, 2013; Rodrigue & Notteboom, 2010b).

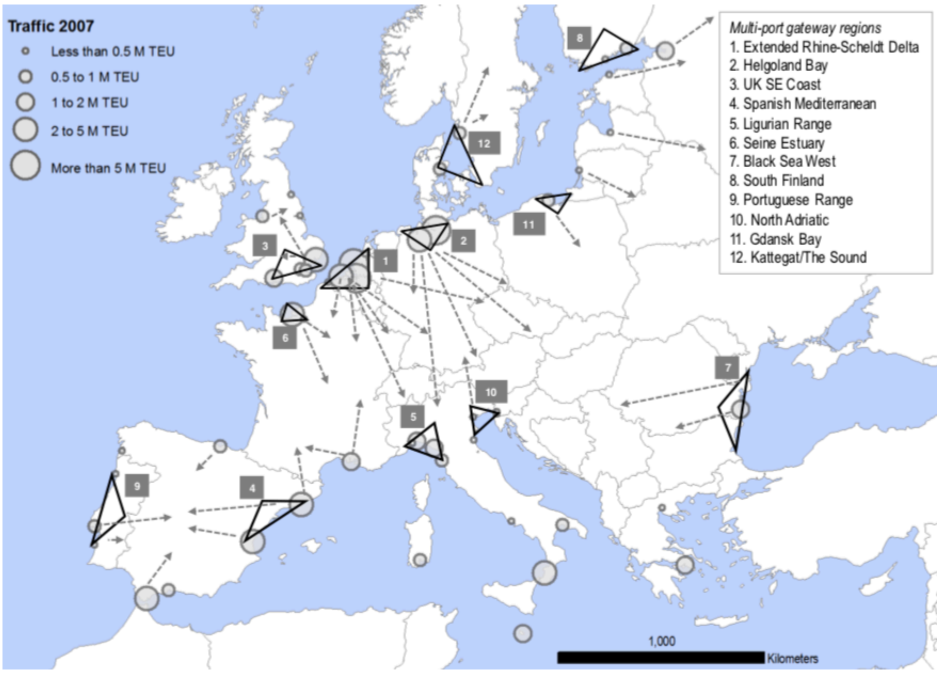

Figure 2.3: Port regions Europe (Rodrigue & Notteboom, 2010a)

2.2.2. Definitions of the maritime port

Since, a maritime port has many functions (see previous subsection 2.2.1), there are many different definitions of a maritime port available in literature. These definitions are not always consistent with each other. This inconstancy partly occurs, because the functions of the maritime ports are changing over time and due to the many perspectives, the maritime port can be faced from (Roso, Woxenius, & Lumsden, 2009). An often-used definition of Stopford (2008) defines the maritime port only as the geographical area were the maritime port is located:

'A geographical area where ships are brought alongside land to load and discharge cargo – usually a sheltered deep-water area such as a bay or river mount.'

A more extended definition is introduced by Ibrahimi (2017). This definition is based on a maritime port cluster interpretation, in which the maritime port is the centre of the cluster. This definition is already given in the introduction:

'Territorial, operational and institutional cluster of interrelated social-economic resources, activities and legitimate actors engaged in appropriate agreements (in)directly related to the transfer of goods and people between land and sea vehicles, serving as a node for the foreign trade and tourism, for the industry, logistics and supply chains, and for the global transport system ever more intermodal in its hinterland and foreland.'

This definition seems to be the most complete definition available in literature to describe a maritime port, like the PoR, in context of this thesis. This has the following reasoning: this definition describes the maritime port from a geographical perspective, but also describes the functions of a maritime port. This definition, thereby mentions all activities and stakeholders are directly or indirectly related to the transshipment of goods between vessels and land modes. This is in line with the container and vessel perspective used in this thesis. And, this definition acknowledges the relation of the port with its for- and hinterland, which is in line with the port regionalization development, the next generation of ports and the development of maritime ports within PI.

2.2.3. Stakeholders in the maritime port

A stakeholder in the perspective of a maritime port is any individual or group of persons holding a legitimate interest or being affected by the maritime port action or inaction (Notteboom & Winkelmans, 2002; Notteboom, Parola, Satta, & Penco, 2015). The stakeholders connected to the Port Community System (Hereafter: PCS): Portbase are, subsequently discussed below (Euro logistics, n.d.).

Terminal operator(s)

Terminal operators are public or private companies responsible for the exchange of goods between the vessels and the inland transportation modes. Their operations, also include temporary storage, repair of containers and inspection of the goods (Min, Ahn, Lee, & Park, 2017). The terminal operators can, for this reason, be indirectly linked to both the entities container and vessel in the context of PI. These terminal operator companies have an increasingly active role in the supply chain, as they increasingly confront the PA with operational considerations, like the berthing window, the dwell time charges, the truck slots (Verhoeven, 2010). The two leading container terminal operators are DP World and PSA (Dooms et al., 2013).

Shipping lines

Shipping lines companies manage the vessels and are responsible for the goods on the vessel (Martin & Thomas, 2001). In this thesis, when referred to a shipping line company, it really refers to a container shipping line company, as bulk transport is considered out of the scope of the thesis. The main revenue stream of shipping line companies is to sell vessel capacity to their customers. In the last decades, the shipping line business for containers rapidly changed due to the increase in global trade, new technological developments and the increase in outsourcing of transport activities (Heaver, 2002). Due to these changes shipping line companies are increasingly using large vessels and merging with each other or are forming alliances. The main reasons for forming an alliance are the economics of scale, the shared risk and to complement each other's resources. In figure 2.4 an overview of the development of shipping line alliances in the last two decades is shown (McKinsey & Company, n.d.).

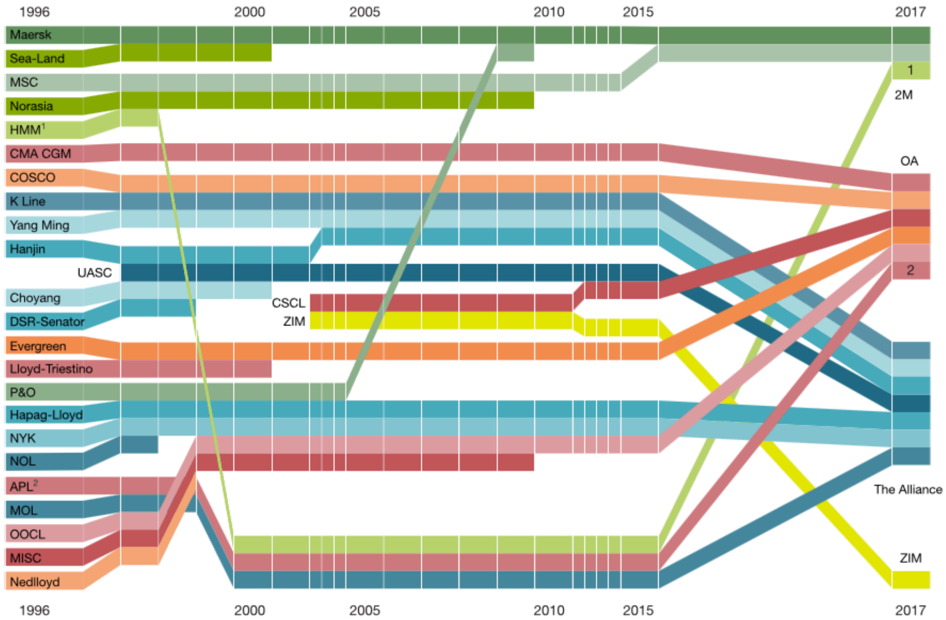

Figure 2.4: Development key alliances of shipping lines (McKinsey & Company, n.d.)

In context of PI, assuming the shipping line companies still exists, the shipping line companies can be directly linked to the vessels. However, the relation with the container is, as with the other stakeholders, a bit unclear. There is currently discussion about who has the ownership of the π-container during their journeys (Fahim, 2020).

Ship brokers
Ship brokers act, as an agent for the shipowner. Their main function is to match the sellers and buyers of vessels or transport services. Transport services include the catering and the handling of the goods on the vessels (Strandenes, 2000). In the context of PI, the ship brokers are both indirectly linked to the vessels and containers.

Freight forwarders
Freight forwarders, traditionally, play an intermediate role between the owner of the goods and the carriers. Their function mainly is to act on behalf of the shipper to find the most suitable (combination of) transport mode(s). Due to the changing customers' requirements the freight forwarders increasingly provide value-added logistics activities and some are effectively becoming third-party logistics service providers (hereafter: 3PL). In the context of PI, the freight forwarder can be indirectly linked to the entities vessels and containers. In some cases, even directly to the vessels, as freight forwarders nowadays also own their own means of transport (Saeed, 2013).

Carriers
Carriers are, in the context of a maritime port, the providers of inland transport (Henesey, Notteboom, & Davidsson, 2003). This include the transport by rail, road or inland waterways. Based on their network, their vehicle types and their capacity, one carrier can be more attractive than the other. Carriers, in the context of PI can be indirectly linked to the entity container.

Customs
The customs at the maritime port are responsible for the release of the goods entering and leaving the maritime port. This stakeholder can in the context be indirectly linked to the entity containers, as it performs inspections.

Port Authorities
As, the PA is the problem owner of the thesis, this stakeholder is discussed in more detail. The precise role of a PA differs from port to port. However, in general the responsibilities of the PA in a landlord port are economic exploitation, long-term development of the land in the port and the maintenance of basic port infrastructure (Brooks, 2004). For the PA, it is relevant to consider the opinion of the other stakeholders in the maritime port to improve the effectiveness of the policy and thereby fulfilling the stakeholders requirements.

In this interaction, the PA has to deal with many different types of stakeholders. The PA, itself, is owned by public institutions: The PA of the PoR has a shared ownership by the municipality of Rotterdam (70%) and the Dutch government (30%) (PoR, n.d.b). For this reason, the PA's goals are related to public interest, which include competitive and sustainable development. On the other hand, the PA has to be financial independent, which leads to conflicts with investment that take years to earn back (Van der Lugt et al., 2013). Another important public interest is the relation between the port and the city. In general, the PA is developing projects to improve the spatial and socio-economic relation with the port city. However, there are still conflicts of interest with urban authorities, when they claim land within the port territory (Daamen & Vries, 2013). The PA also has to interact with many different private companies, who in a landlord port are responsible for the superstructure and port labour.

The PA is increasingly aware of the competitive dependency on its hinterland, as port users are increasingly focused on the hinterland connectivity (Van der Lugt, Rodrigues, & Van den Berg, 2014). It is this part of the supply chain that is responsible for a large part of the logistic costs and is accountable for a lot of disruptions in the supply chain due to e.g. congestion (Zondag et al., 2010; Iannone, 2012). Furthermore, due to the increased integration of the port customers, being the carriers, the terminal operators and the shipping line companies, the role of the PA is becoming more complex (Van der Lugt, de Langen, & Hagdorn, 2017). Currently, the function of the PA can already be better described as facilitator within the logistics chains (Centin, 2012; Panayides & Song, 2013). Thereby, it is expected that the role of the PA will become more complex, as the port evolves to a *Dynamic customer-centric community port* or into a π-hub (see section 2.2.4). In the context of PI, the PA can be indirectly linked to both the entities container and vessel. The PA in general is interested in making the maritime port attractive for both these entities.

2.2.4. Physical Internet and maritime ports

Until, the research of Fahim (2020), Voster (2019) and Martinez de Ubago (2019), there was no literature available regarding the role of PI in the future development of maritime ports. Martinez de Ubago (2019) describes in his thesis maritime ports, like the PoR, as global hubs in the proposed interconnected multi-plane meshed network of PI (Montreuil, 2019). In this network the global hubs are the π-nodes that connect the different international regions with each other. Each of these international regions consists of local and regional networks. At the lower levels, the nodes, also called local hubs or access hubs, are places were the physical objects enter and/or leave the PI network (see figure 2.5). In this PI network, the PA could play the logistics coordinator role, providing informational services for coordination and interoperability of the shipments from and to the port (Sallez, Pan, Montreuil, Berger, & Ballot, 2016).

In PI literature, there are design studies conducted to specific types of π-hubs (Walha, Bekrar, Chaabane, & Loukil, 2016; Ballot et al., 2013), however no such study exists for the maritime port. Although, Krommenacker et al. (2016) describes the general process at a π-hub in the following three steps (see figure 2.6):

- **Unloading:** In this step, the incoming T-containers are unloading from the π-vehicles (see figure A.2 for the different π-container types).

- **Preparation (Composition/Decomposition):** In this step, the incoming T-containers are decomposed into H-containers. These H-containers are, afterwards, stored together based on their next destination. Thereafter, the H-containers with the same destination are composed into an outbound T-container.

- **Loading:** In this step, the composed outbound T-containers are loaded on the π-vehicles and send to the next destination.

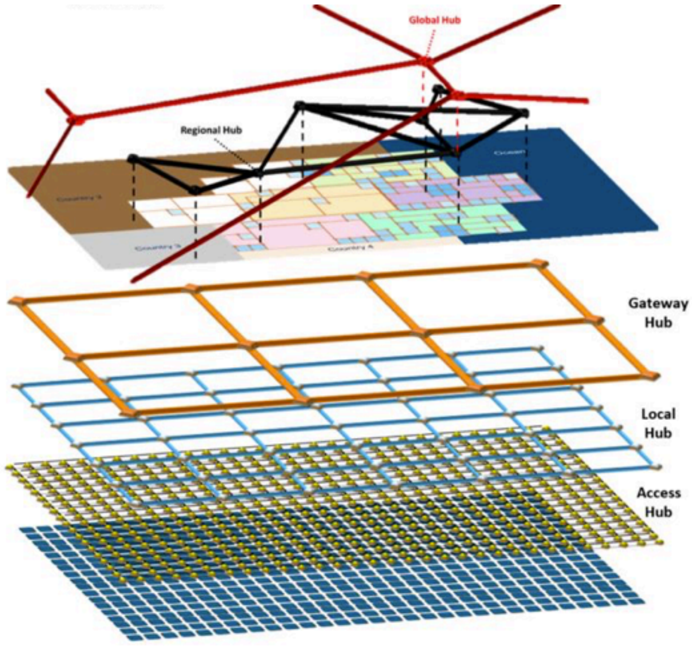

Figure 2.5: Multiple-plane meshed networks in PI proposed by Montreuil (2019) adapted from Martinez (2019)

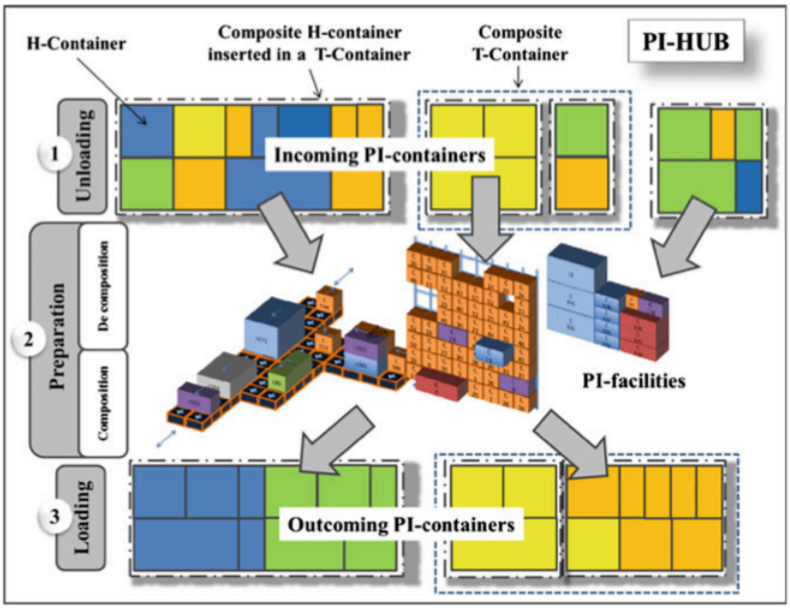

Figure 2.6: Example treatment in a π-hub (Krommenacker et al. 2016)

Montreuil, Buckley, Faugere, Khir, and Derhami (2018), further developed the main characteristics of a π-hub:

1. π-Hubs receive and ship T-containers from and to the next destination (another π-hub or a zone).
2. π-Hubs perform pre-consolidation to avoid sorting all containers and parcels.
3. A π-hub has less direct connections with sources and destinations of a parcel, the higher the

hub is in the multiple-plane meshed network (see figure 2.5). Their main connections are other intermediate hubs on the same level.

4. π-Hubs are multi-modal and multi-party service providers.

5. π-Hubs have agile and flexible shipping times.

6. π-Hubs are able to perform smart and dynamic decisions on routing and consolidation, also for their internal flows.

7. π-Hubs dynamically exchange data and information on the states of the goods, the π-containers, the vehicles, the routes and other hubs and accommodate their decisions accordingly.

These studies are all relevant for the design of the maritime port as a π-hub, however further research is required. To make a start the multi-layer perspective from Martinez de Ubago (2019) can be used (see figure 2.7). At the lowest level of this perspective, the π-cranes and π-AGVs are located. These π-handlers are capable of autonomously communicating with each other. Nevertheless, these entities are dependent on decisions made by the higher layers. This kind of structure is suggested because it prevents, among other things issues with reliability, scalability and responsiveness (Martinez de Ubago, 2019).

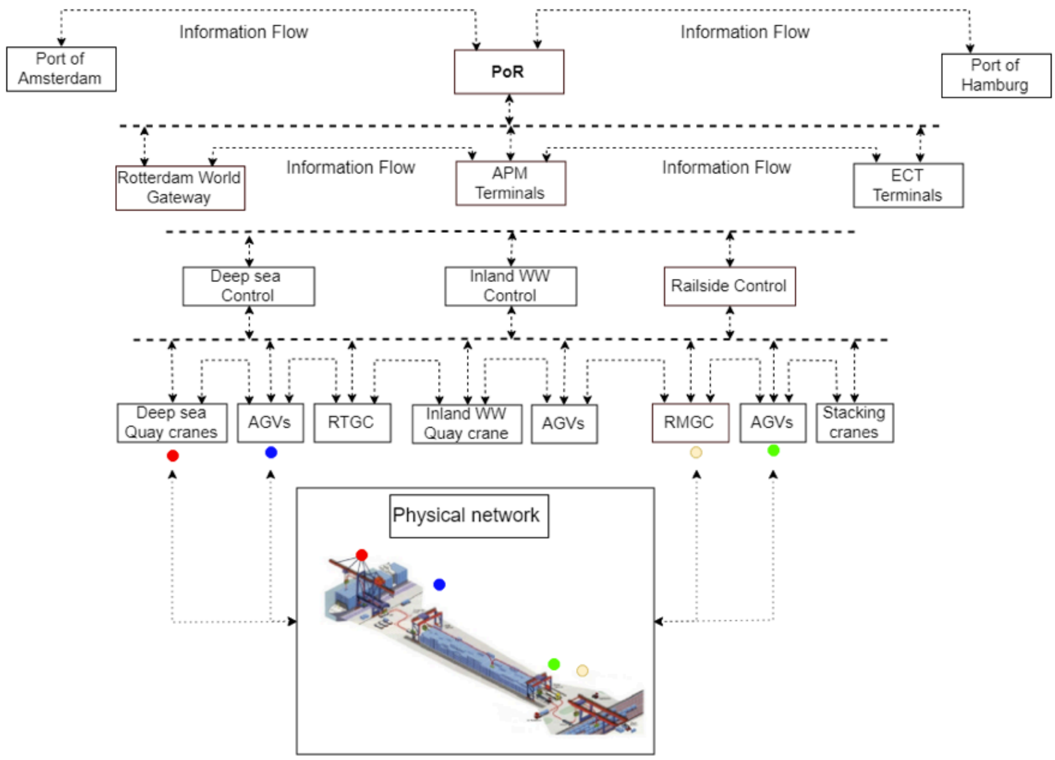

Figure 2.7: Multi-layer perspective PoR in context of PI (Martinez, 2019)

In maritime literature, there are comparable developments to PI considered, including the development of maritime pots into the *Dynamic customer-centric community port* and port regionalization, discussed in section 2.2.1.

Nevertheless, nothing concrete about the implications of PI on the future development of maritime ports is researched until Voster (2019) and Martinez de Ubago (2019) developed the PI port framework. This framework is based on the roadmap created by ALICE (2019) briefly discussed in section 2.1.2 and the PI characterises, mentioned in subsection 2.1.1 (Voster, 2019). The PI port framework builds up from local achieved PI, at port level (up to level 2), to regional achieved PI (at level 3) to a global PI (at level 4) (see table 2.2).

Table 2.2: 'PI port framework. Evolution levels of three dimensions which influence the development of port connectivity towards a 'PI port'' (Voster, 2019; Martinez, 2019)

	Current State	Level 1	Level 2	Level 3	Level 4
Port connectivty	Unconnected terminals within ports Unbalanced alliances in maritime shiping lines	Unconnected terminals within ports. Full integration of vertical supply chains by alliances	Intra-terminals connected horizontally: 'Physical Intranet' within port	Inter-terminals connected horizontally: Open Ports	Global hub hyperconnectivity
Governance dimension	Current Incoterms. Unbalanced regulations for asset sharing platforms	Next Incoterms (Rotterdam rules). Regulations for asset sharing platforms.	Harmonized rules and standards for intra-port connectivity	Harmonized competition rules and standards in horizontally integrated ports	Governance processes and bodies for an open global PI network
Operational dimension	(Semi) automation of yard handling operations at terminals	Mode Hinterland synchromodality	Automated crossdocking and reshuffling operations	Automated node service and response across networks	Fully autonomous PI network operations
Digital dimension	Tracking systems. Port Community Systems (PCS) at niche level	Full PCS with dedicated connection to hinterlands	Digital platform allowing for communication and Decision Making at port	Standardized digital platforms distributed in ports at regional level	Inter-network standardized digital platforms distributed at global level

After the conducted research, by Voster (2019) and Martinez de Ubago (2019), Fahim (2020) researched the criteria for the port choice of containers and vessels in the context of PI. Based on literature and expert interviews, Fahim (2020) established thirteen port selection criteria (see figure 2.8). These port selection criteria are grouped into four different classes (Fahim, 2020):

A Transport Chain Quality (hereafter TCQ): In this class, the criteria *level of service, physical port infrastructure, reliability, safety & security* and *sustainability* are grouped. *The level of service* refers to the transit time, the availability of vessels, the port throughput time and the route congestion. *The physical port infrastructure* refers to the available handling capacity and the overall efficiency of port operations. *Reliability* refers to the risk of disruption. *Safety & security* concerns issues with theft, injuries and casualties. *Sustainability* refers to the total emissions, the nuisances and the social responsibility.

B Cost: In this class, the criteria *transport cost* and *transshipment cost/seaport duties* are grouped. *The transport cost* depends on the costs of a particular vessel with a particular route. *The transshipment cost/seaport duties* relate to the handling and the operational costs of the terminal and costs related to retain the port services.

C Technology: In this class, the criteria *automation of operations, Information System (hereafter: IS)* and *SMART* are grouped. *The automation of operations* refers to the level at which operation are taken place in an automated way. *IS* refers to the level at which the stakeholders are connected with each other via the PCS. *SMART* refers to the usage of machine learning, optimisation and simulation.

D Network Quality of Port (hereafter: NQP): In this class, the criteria *geographical location, logistics/maintenance facilities* and *network interconnectivity* are grouped. *Geographical location* refers to the location of the maritime port. *Logistics/maintenance facilities* refer to the facilities for value-added services, warehousing and repair. *Network interconnectivity* refers to the connectivity of the maritime port with its hinterland and foreland.

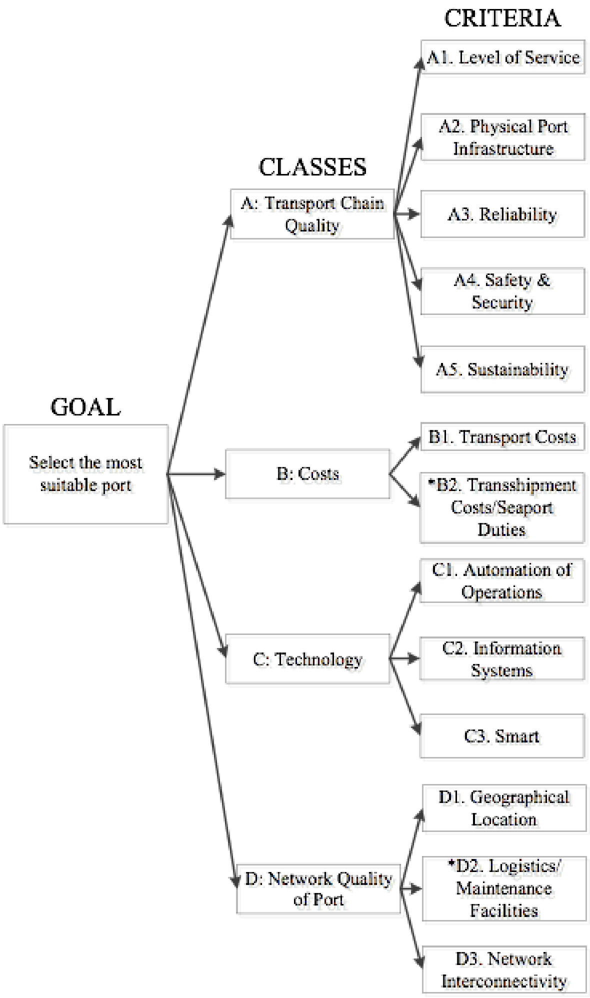

Figure 2.8: Port selection criteria hierarchy (Fahim, 2020)

Fahim (2020), also researched the importance of the criteria with the Bayesian BWM method. In this method is based on experts evaluation of the criteria the importance weights of the criteria classes established (see table 2.3). Both, researchers with a background in PI and/or policy making in the maritime port, and practitioners with expertise in policy making in the maritime port are used in determining the importance weights.

Table 2.3: Criteria class weights from the container and vessel perspective (Fahim, 2020)

	Transport chain Quality	Cost	Technology	Network quality of port
Container perspective	0.305	0.325	0.145	0.225
Vessel perspective	0.264	0.369	0.160	0.207

3 Methodology

In this chapter, the methodology of the thesis is described.

The chapter is structured as follows:

- In section 3.1, the overall thesis approach is described.
- In section 3.2, the method literature review is discussed. This method is used in almost all conducted academic research and is applied throughout the entire thesis (Wilding, Wagner, Seuring, & Gold, 2012; Rowley & Slack, 2004).
- In section 3.3, the theoretical frameworks applied are treated. These theoretical frameworks are used to determine external factors for the Port Authority (hereafter: PA) to make the maritime port attractive.
- In section 3.4, the stakeholder analysis is discussed. This method is used to determine external factors for the PA to make the maritime port attractive.
- In section 3.5, the method experts interviews is discussed. This method is mainly used to determine and define PI policy directions.
- In section 3.6, the scenario operationalisation is described.
- In section 3.7, the Bayesian Best Worts Method (hereafter: BWM) is treated. This method is used to determine the 'best-fit' focus distributions of the PI policy directions
- In section 3.8, the method Sensitivity analysis is treated.

3.1. Overall thesis approach

The objective of the thesis, with its corresponding research scope is to support the PA of landlord ports, like the Port of Rotterdam (hereafter: PoR) in making the maritime port attractive in the uncertain future of Physical Internet (hereafter: PI). To develop a corresponding thesis approach, it is important to understand that policy making for the PA is very complex. It involves making large-scale decision about e.g. infrastructure in a very uncertain future. To cope with such uncertainty, often, scenarios are the best available language to use (Van der Heijden, 2011).

Börjeson, Höjer, Dreborg, Ekvall, and Finnveden (2006) distinguishes three groups of scenario types:

- **Predictive scenario type:** In this scenario type, the objective is to predict what is going to happen. The concepts of probability and likelihood are often used to describe the future.
- **Explorative scenario type:** In this scenario type, the objective is to explore what could possible happen.

- **Normative scenario type:** In this scenario type, the objective is to assess how a certain target can be reached.

As, in this thesis the focus is on describing what are possible futures of PI, the explorative scenario types are used. Furthermore, external factors outside the control of the PA are used to develop PI port scenarios and assess the PI policy directions in the future of PI. Börjeson et al. (2006) describes this as external scenarios.

Researchers have come up with several approaches to support decision making with (external) scenarios. In most of these approaches, it is assumed that the future is predictable or that a certain phenomenon is likely to persist (Duinker & Greig, 2007; Dessai & Hulme, 2007). In these studies, only ‘robust’ strategies are developed that work in particular futures. Unfortunately, there is a chance that the future will unfolds itself in an unexpected way or not according to the scenarios. In this case, it is very likely that the strategies meant to work in the scenarios are of no use anymore (Haasnoot, Kwakkel, Walker, & ter Maat, 2013). An example of such an unexpected change is the outbreak of COVID-19.

Besides, as time passes by, more information will come available. This information will give more certainty about how the future will further unfold itself and which (PI) policy directions are more useful. Therefore, Walker, Rahman, and Cave (2001) suggests that policy making should be adaptive. Not optimal for a particular set of futures, but robust across a range of scenarios that could happen. Figure 3.1, shows the difference between adaptive policy making and the static robust policy making (Indriana, 2019). In adaptive policy making are developments monitored to implement the most appropriate policies along the way, instead of applying a fixed policy plan, determined beforehand.

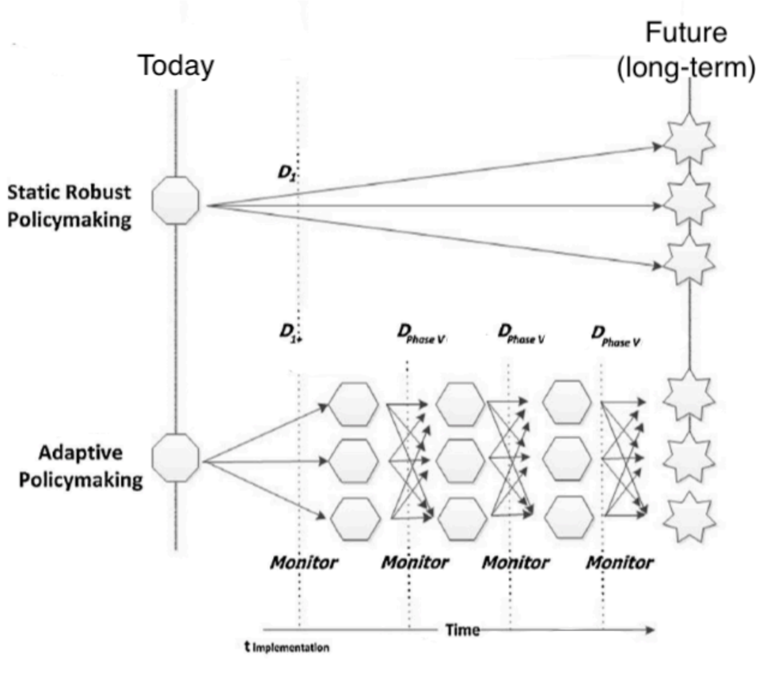

Figure 3.1: Different policy making paradigms adapted from Indriana (2019)

As, the future of PI is highly uncertain, with a lot of plausible futures, it seems appropriate to use adaptive policy making approach as inspiration to develop the overall thesis approach (Martinez de Ubago, 2019). Recently, more of these adaptive approaches are developed. Most of which require computational models, like Exploratory Modelling and Analysis (Bankes, Walker, & Kwakkel, 2013; Weaver et al., 2013), Robust Decision Making (Groves & Lempert, 2007; Kasprzyk, Nataraj, Reed, & Lempert, 2013), Real Options (De Neufville & Scholtes, 2011), Decision scaling (Brown, Ghile, Laverty, & Li, 2012; Poff et al., 2016) and Adaptive Policy making (Hamarat, Kwakkel, & Pruyt, 2013; Kwakkel, Walker, & Marchau, 2010).

For computational models quantitative information is required. This information is lacking. Only, recently the implications of PI on the maritime ports are researched and so far only in a qualitative way (Voster, 2019; Martinez de Ubago, 2019).

An adaptive approach that is applicable with qualitative and quantitative information is the Dynamic Adaptive Policy Pathways (hereafter: DAPP) (see figure 3.2). This approach could be applied with a very limited number of scenarios (Haasnoot, Middelkoop, Offermans, Van Beek, & Van Deursen, 2012; Haasnoot, Middelkoop, Van Beek, & Van Deursen, 2011).

Figure 3.2: Steps (Dynamic) Adaptive Policy Pathways approach (Haasnoot et al., 2013)

A disadvantage of this method is, that the adaptive policy pathways created, are translated into an actual policy plan. This is out of the scope of the thesis. The scope of the thesis is on providing insight in potential future situations and which PI policy directions are effective if the future unfolds itself in a certain way. The creation of the actual policy plan is in the end up to the PA.

This issue with the DAPP approach is in some way solved in the Dynamic Roadmap approach used by Bauwens (2015). However, this approach determines the sell-by dates, the moment after which a certain policy measure is no longer useful, based on the transport layer model of TRAIL (Evers, Bovy, de Kroes, Sommerhalder, & Thissen, 1994). This is not necessarily the case in this thesis. An approach that solves both the issues of the DAPP and the Dynamic Roadmap is a predecessor of the DAPP approach: the Adaptive Pathway approach. In this approach possible policy pathways are shown in an adaptation pathway map and analysed based on criteria in scorecards (see figure 3.3 for an example). The steps of Adaptation Pathways are comparable with the first five steps of the DAPP approach (see figure 3.2). However, the sequence of actions is different. In the Adaptation Pathways approach, first the policy measures are determined and afterwards the scenarios are developed. This is the other way around in the DAPP approach. For this reason, the thesis approach uses insights from the first five steps of the DAPP approach.

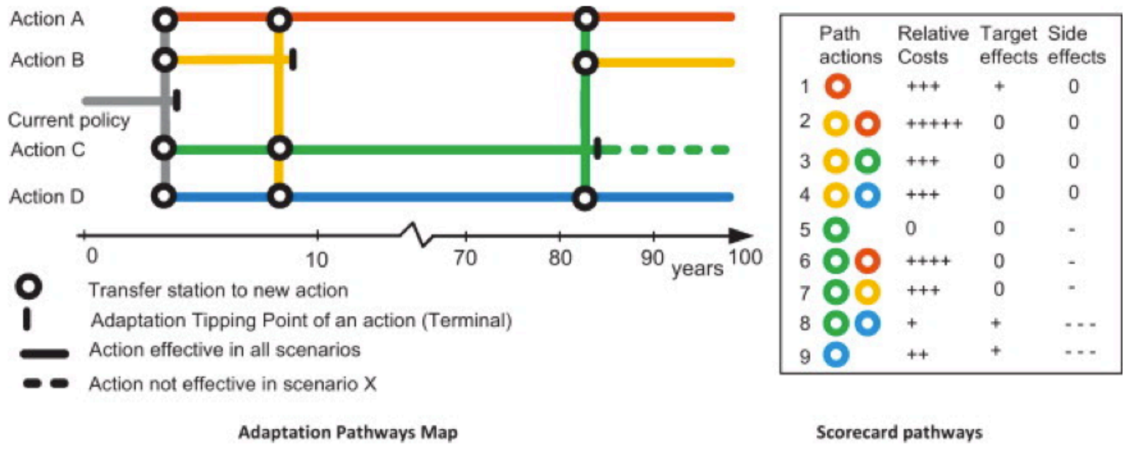

Figure 3.3: Example adaptive pathway map (left) scorecard pathways (right) (Haasnoot et al., 2013)

An overview of the thesis approach is described below:

For answering the first RSQ: *What are the external factors influencing the attractiveness of the maritime port in the uncertain future?* External factors are identified with the use of literature review (see section 3.2), applications of theoretical frameworks (see section 3.3) and a stakeholder analysis (see section 3.4).

For answering the second RSQ: *What are the PI port scenarios?* Insights from the *Dynamic multi-level perspective on technological transitions* from Geels (2002) and the driving forces of Martinez de Ubago (2019) are used to operationalize four PI port scenarios, based on the identified external factors (see section 3.6).

For answering the third RSQ *What are the Key Performance Indicators for the attractiveness of the maritime port in the uncertain future of PI?* the port choice criteria classes for containers and vessels in the context of PI, defined by Fahim (2020) are used to define the KPI for the attractiveness of the maritime port.

For answering the fourth RSQ *Which PI policy directions can improve the attractiveness of the maritime port?* The methods literature review (see section 3.2) and expert interviews (see section 3.3) are applied to identify policy measures the PA could apply to improve the attractiveness of the maritime port. Furthermore, literature review and expert interviews are used to determine particular roles the PA could play to improve the attractiveness of the maritime port in the uncertain future of PI. Based on these roles, the identified policy measures are aggregated into six PI policy directions used for further analysis.

For answering the fifth RSQ: *Which focus distribution of PI policy directions is the best-fit to improve the attractiveness of the maritime port in the different PI port scenarios?* The Bayesian BWM is applied to establish the 'best-fit' focus distributions of PI policy directions on the different the KPIs in the different PI port scenarios (see section 3.7). This methodology uses experts perceptions in a questionnaire and requires data processing in Matlab. Besides, a sensitivity analysis (see section 3.8) is conducted to research how the uncertainty in the output can be explained from the input sources.

For answering the sixth RSQ: *What can be recommended to the maritime port to further develop (adaptive) policy in the uncertain future of Physical Internet?* Is based on patterns in and between 'best-fit' focus distributions of PI policy directions, and the sell-by dates and path-dependencies of the different PI policy directions recommendations provided to the PA to make the maritime port attractive in the uncertain future of PI. An overview of the thesis approach in relation with the RSQs is presented in figure 3.4.

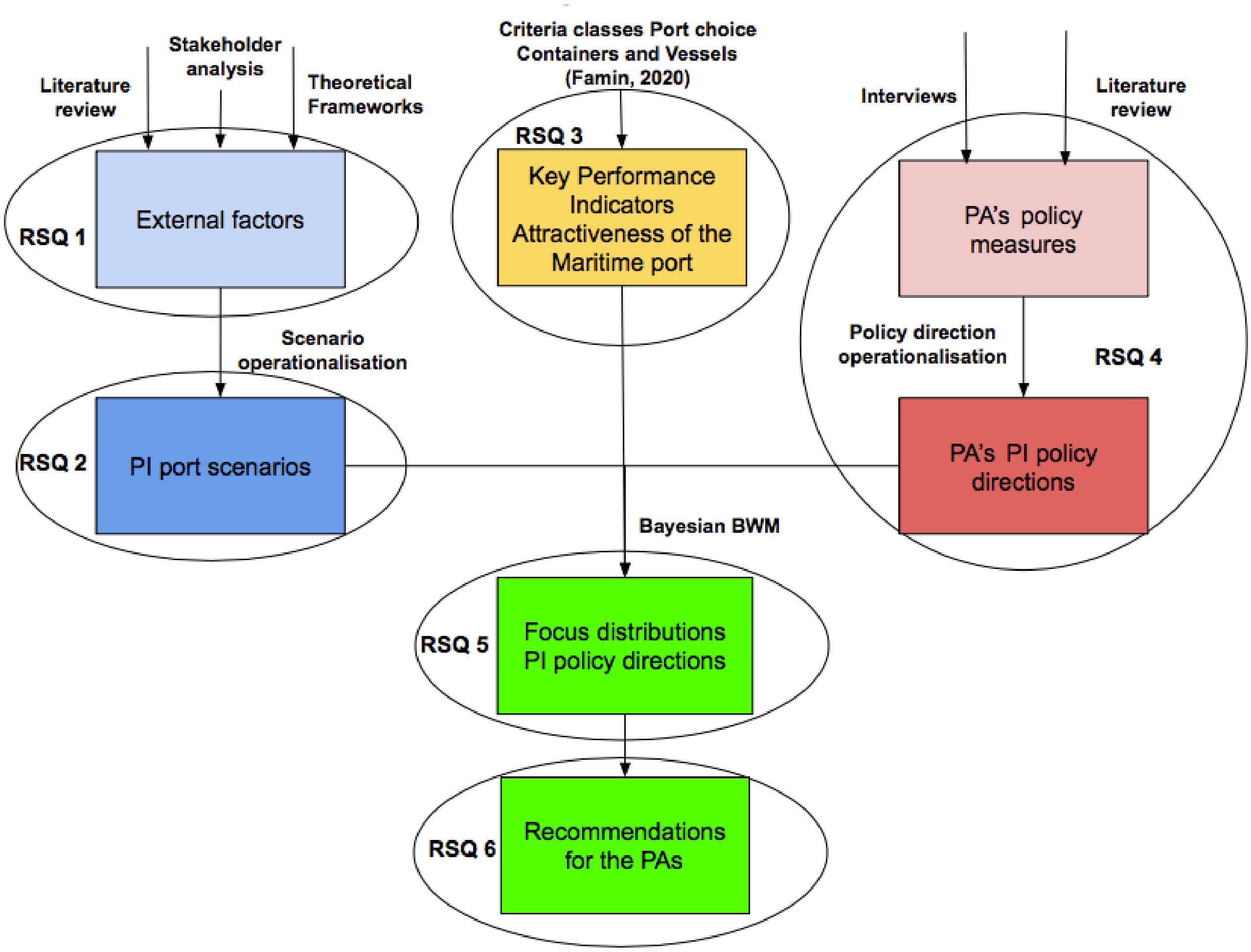

Figure 3.4: Overview thesis approach

3.2. Literature review

As mentioned, in the introduction of this chapter literature review is an important part of conducting academic research. This method helps by identifying the overall research topic, the contribution of the research, the understanding of the theoretical concepts, the use of methods for the research and analysing the results (Rowley & Slack, 2004).

Related to literature review is the method desk research. This method focuses on answering research questions by collecting facts and data and less on gathering theoretical knowledge, which is the goal of literature review. In the thesis, the focus is on improving the theoretical knowledge regarding the implications of PI in the maritime port (see section 1.5). Therefore, mainly the method literature review is used. Although, to answer the research questions for the PA of the PoR in particular the method desk research is also applied.

To conduct the literature review, search engines, like, Google scholar, Scopus, Elsevier, Web of science and Google are used (Rowley & Slack, 2004). In these search engines keywords and Boolean operators (AND and OR) are applied to find relevant papers. When a paper is found, the relevancy is determined by reading the abstract and the conclusion. Afterwards, if the paper is judged to be relevant, the rest of the paper is read, and the reference is documented. Furthermore, this paper is used to find new relevant papers by forward snowballing and backward snowballing. Forward snowballing is finding citations in the paper and backward snowballing is looking in the reference list for other relevant papers (Wohlin, 2014; Jalali & Wohlin, 2012).

Table 3.1 gives an overview of the number of publications per source type.

Table 3.1: Sources categorised

Type of source	Number of publications
Journal paper	152
Proceeding	1
Book chapter	5
Report	10
Web page	32
Thesis	5
Governmental report	1
Conference paper	26
Book	25
Webinar	6
Lecture notes/slides	2
Laws	2

An overview of all the literature used for the research foundations is provided in appendix B. Furthermore, in the same appendix an overview of the literature used to substantiate the methodologies used in this thesis is provided. In appendix D, an overview of the literature used to determine an define the external factors is provided. In appendix E, an overview of the literature and desk top research used to determine the policy measures and the PI policy directions the PA could apply to improve the attractiveness is provided. In section 8.1 the total number of used scientific papers for the research foundations, external factors and PI policy directions is presented.

3.3. Application of Theoretical frameworks

There are theoretical frameworks designed to explain why certain innovations are adopted and other innovations are not (Feitelson & Salomon, 2004). Applying these theoretical frameworks on the adoption of PI in the maritime port gives useful insight in what are important external factors for the PA to make the maritime port attractive.

There are a lot of these frameworks available in literature (Geurs & Van Wee, 2004; Woolthuis, Lankhuizen, & Gilsing, 2005; Williamson, 1998; Feitelson & Salomon, 2004; Geels, 2004). However, in this thesis only two theoretical frameworks are applied: the *Political- economy model of transport innovation* by Feitelson and Salomon (2004) and the *Dynamic multi-level perspective on technological transitions* by Geels (2004). These frameworks are chosen because of two reasons: firstly, these frameworks are designed for or applied on innovations in the transport sector. Secondly, both frameworks are complementary to each other and fill in the weaknesses of the other framework.

Also, Martinez de Ubago (2019) recommended both these frameworks to further develop a robust framework to create PI port scenarios. Both frameworks are partially applied in the thesis, as a full application of both frameworks can be a study on its own. The focus of these applications is to identify and define the external factors for the PA to make the maritime port attractive and to improve the framework from which the PI port scenarios are developed. In the following subsections 3.3.1 and 3.3.2 the two frameworks are, subsequently, discussed.

3.3.1. Political- economy model of transport innovation

Feitelson and Salomon (2004) argue that innovations in the transport sector should be seen as an outcome of societal processes within most cases significant governmental involvement. In their framework they use technical, social and political feasibility to describe this process (see figure 3.5).

Technical feasibility, in essence describes whether an innovation is cost-effective and implementable. From a social perspective an innovation is feasible, when the majority of people are likely to support it. This feasibility is dependent on the public perceptions of problems and the effectiveness of the innovation in solving these problems. Furthermore, the social feasibility is influenced by the sanctioned discourse, which is a function of the dominant ideologies and what the media and elites perceive as acceptable. For the political feasibility is, the social feasibility important. However, as transport innovation are not decisive in the changes for re-election, also other incentives are playing a role for the political feasibility. This could, include the need of support to finance campaigns or preventing any negative publicity from active lobbies by working with them.

This framework provides insight in external factors for the PA to make the maritime port more attractive. However, this framework has two main disadvantages:

- This framework is relatively static and does not consider the evolution of PI over time.
- The framework describes an innovation, as a failure or a success: the innovation is adopted or not. However, a partial adaption of PI in the maritime port or changes in the current way the logistics system works could also have an impact.

To cope with these disadvantages the *Dynamic multi-level perspective on technological transitions* of Geels (2004) is also applied.

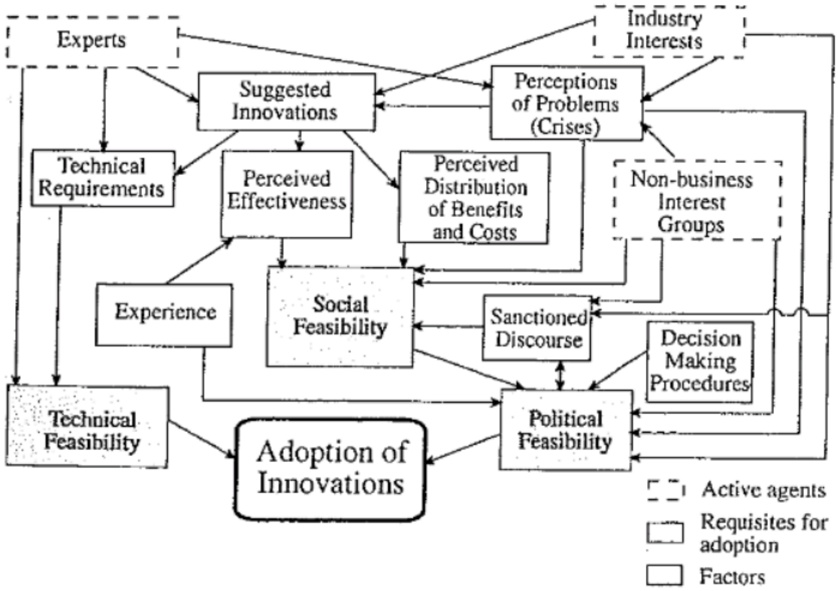

Figure 3.5: Political economy model of transport innovations (Feitelson & Salomon, 2004)

3.3.2. Dynamic multi-level perspective on technological transitions

The *Dynamic multi-level perspective on technological transitions* describes systems of innovation from a sectoral perspective. Furthermore, Geels (2004) also incorporated the technical system and the large technical system approaches in his framework (Carlsson & Stankiewicz, 1991; Hughes, 1993). Empirical studies have shown that the *Dynamic multi-level perspective on technological transitions* justifies the complexity of the real-world. However, this is also a disadvantage, as it requires more data and more complex analysis (Geels, 2002). Therefore, in this thesis this framework is only used to better understand external factors for the PA to make the maritime port attractive and to develop the PI port scenarios.

The framework consists of three different levels (see figure 3.6): the landscape level, at which the external environment is located. The meso-level at which the Socio Technical (hereafter ST) regimes are located, like in case of this thesis the logistics (see section 4.1.1). These regimes are semi-coherent set of rules that are carried by social groups. These sets of rules provide coordination for the stakeholders' activities and are responsible for stability and incremental change. At the lowest level, technological niches, like PI, are located. From this level new radical innovations emerge. This process of breakthrough is in most cases very long and it is highly uncertain whether the new innovation will actually breakthrough. A new innovation could be fully adapted or could only influence certain elements in the ST-regime. This solves the two limitation of the *Political- economy model of transport innovations*. Besides, the framework also takes into account multiple games that take plays at the same time, like other innovations trying to breakthrough.

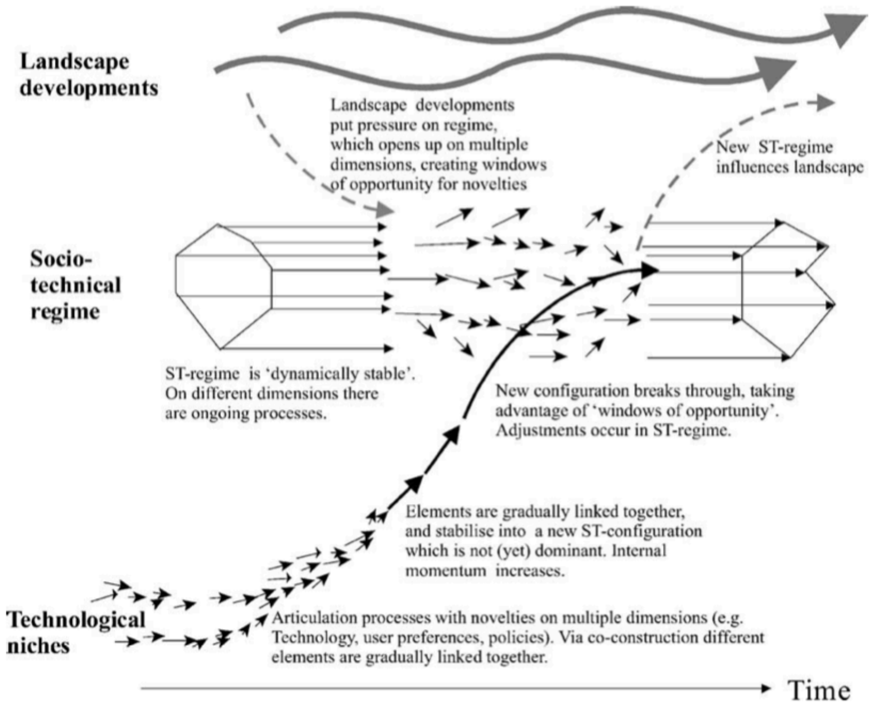

Figure 3.6: Dynamic multi-layer perspective of technological transition (Geels, 2004)

3.4. Stakeholder analysis

Stakeholders are any individual or group of persons holding a legitimate interest or being affected by the maritime port action or in action (Notteboom & Winkelmans, 2002; Notteboom, 2012). In section 2.2.3, it is already discussed that the successfulness of the PA's policy is dependent on other stakeholders in the maritime port. Therefore, to identify external factors for the PA to make the maritime port attractive, it is crucial to analyse the power, interest and influence of the stakeholders (Brugha & Varvasovszky, 2000). The stakeholder analysis, conducted in this thesis, also includes stakeholders outside the maritime port, which can be defined as a stakeholder following the definition of Notteboom and Winkelmans (2002).

3.5. Expert Interviews

Expert interviews are conducted to get insight in policy measures the PA could apply to improve the attractiveness of the maritime port and to operationalize the PI port directions (Weiss, 1995). Also, other insights from the interviews are used in the rest of the thesis (Gubrium & Holstein, 2001). To avoid any biasness and to allow the experts to express their opinions freely, the interviews had an open structure. However, sometimes the PI port framework (see figure 2.2) is used to guide the discussion.

Both, researchers and practitioners are approached for the interviews. In case of determining policy measures, there is a fundamental difference between researchers and practitioners, which is important to consider. Practitioners look more at operational issues than researchers (Gopinath & Hoffman, 1995).

To identify the right candidates for the interviews the expert knowledge is assessed by:

- Looking at the publications of the expert: are these publications related to the subject PI and/or policy making in maritime ports.
- Looking at the work experience of the expert: is their work experience related to policy making in the maritime port.

A researcher or a practitioner is perceived as an expert when he or she is part of a small community of people currently working, studying or are dedicated to the subject. Furthermore, whether the expert is open-minded to explore the boundaries of his/her research area is also taken into account (Enserink et al., 2010).

In total 14 interviews are conducted (see appendix F). This is more than the eight - twelve expert interviews, mentioned by Enserink et al. (2010) to have enough breadth for e.g. cross checking of opinions. Besides, literature is used to check the opinions of the experts. All the 14 interviews are performed online, via either Skype, Zoom or Teams, due to COVID-19 restrictions. This, on the one hand, had advantages, such as no travel time for both parties. However, it made performing the actual interview harder, as it was more difficult to read nonverbal ques, about for example when someone was finishing his or hers story or thinking about what he or she wanted to say next.

In appendix F an overview of the interviewees and a summary of each interview is given. The findings from the interviews are, mainly, used in section 5.2.

3.6. Scenario operationalisation

To evaluate the 'best-fit' focus distribution of the different PI policy directions in the future, different alternative future outcomes of the external environment are created (Postma & Liebl, 2005). These alternative futures, in this thesis referred to as PI port scenarios are operationalised, by the following procedure:

1. **External factor clustering:** The external factors identified with literature review, the theoretical frameworks and the stakeholder analysis are clustered into external factor classes based on inspiration from the *Dynamic multi-level perspective on technological transitions* from Geels (2002) and insights from previous research of Martinez de Ubago (2019).
2. **Driving forces development:** To further develop the PI port scenarios three main points are important to consider:
   - The PI port scenarios should satisfy the following criteria as good as possible: *Internal consistency, creativity, importance, completeness, plausibility, relevance and transparency* (Amer, Daim, & Jetter, 2013).
   - The PI port scenarios should be easy to understand for experts in the questionnaire.
   - The number of PI port scenarios should be limited. Otherwise, the results of the questionnaire used in the Bayesian BWM will be biased due to fatigue of the respondents.

   For these reasons are, based on the external factor classes, two driving forces developed and used to create four different PI port scenarios. This limits the number of questions for the respondents.
3. **Creating two possible future outcomes:** To create the four different PI port scenarios, is for both the driving forces, the most positive and most negative future outcome for the time period 2020 - 2040 described. These futures are developed based on the external factor classes and external factors incorporated in the driving force. The time period 2020 - 2040 is chosen as, 2040 is the goal from the project ALICE to have PI fully implemented (ALICE, 2019). However, in this thesis, in developing the scenarios, it is considered that this is very unlikely (see section 2.1.2)
4. **PI port operationalization:** After determining the possible future outcomes of both driving forces is with the use of scenario logic of Enserink et al. (2010) four different PI port scenarios developed.

The PI port scenarios are, unless the focus of the thesis on the PA of the PoR, described for a PA of landlord ports in general (see section 4.2). This makes the results of the thesis more generally applicable.

3.7. Best Worst Method

With literature review and experts interviews different PI policy directions are identified. These PI policy directions are, like the PI port scenarios formulated, in such a way that these are applicable for a PA of a landlord port in general. To answer the fifth RSQ and determine the 'best-fit' focus distribution of these PI policy directions for the different KPIs, the (Bayesian) BWM is applied. Other methods considered are other Multi Criteria Decision Making (hereafter: MCDM) method, especially the Analytic Hierarchy Process (hereafter: AHP) method. These alternatives are briefly discussed below.

3.7.1. Multi Criteria Decision Making (MCDM)

MCDM is a branch of Operational Research that deals with decision problems with a number of criteria (Pohekar & Ramachandran, 2004). A generally used MCDM method is the AHP. This method uses pairwise comparison by experts to construct priority scales (Saaty, 1977) and is often used in identifying the relevancy of factors in port choice (Lirn, Thanopoulou, Beynon, & Beresford, 2004; Ugboma, Ugboma, & Ogwude, 2006; Tongzon, 2009; Nazemzadeh & Vanelslander, 2015).

Nevertheless, due to the unstructured way the comparisons are performed, there is inconsistency in the full pairwise comparison matrix of AHP (Rezaei, 2015). A source of this inconsistency is the fact that it is easy for the respondents to determine the direction of a preference of a factor i over a factor j, but it is hard to determine the strength of this relation. This source of inconsistency is reduced in the BWM, because the respondents beforehand determine the best and the worst factor. In this way, the respondents have a better understanding of the range of evaluation, before actually performing the pairwise comparisons (Rezaei, 2015, 2020).

This sequence of actions, furthermore, reduces the potential anchoring bias of the respondents. The anchoring bias is the phenomenon that respondents stay close to a considered specific numerical value for an unknown quantity, before estimating this unknown quantity. Kahneman (n.d.) in his book *Thinking, Fast and Slow* provides an adequate example of this anchoring bias:

In an experiment in which respondents had to estimate the age at which Ghandi died. The respondents, if asked whether Ghandi was older than 114 years old, when he passed away ended up with a much higher estimate of his age when he died, in comparison to the estimate when this number was only 35 years.

Two main cognitive mechanisms help explain the anchoring bias: the *anchoring and adjustment process* and the *Selective Accessibility Model* (hereafter: SAM) (Adame, 2016; Kahneman, n.d.). The first cognitive mechanism explains the anchoring bias by an adjustment process of the respondent. The respondent starts with the anchor value and afterwards makes adjustment until the numerical value arrives at an acceptable level (Kahneman, Slovic, Slovic, & Tversky, 1982). The second mechanism, SAM, explains the anchoring bias by the influence of the anchor on the accessibility of semantic knowledge of the respondent when making the finally estimate (Mussweiler & Strack, 1999; Strack & Mussweiler, 1997). In this explanation, the anchor merely, provides a suggestion to the respondent, which is used during the estimation (Kahneman, n.d.). A strategy that is proven to reduce the anchoring bias is the Consider-the-Opposite strategy (hereafter: COS) (Mussweiler, Strack, & Pfeiffer, 2000). This COS strategy is used in the BWM, as the respondents first determine two opposite reference points (the best anchor and the worst anchor). These two anchors might reduce the anchor bias of the respondents during the pairwise comparisons, as both anchors cancel out the anchoring effect to one side of the numerical scale. This, therefore, is an explanation why the anchoring bias could be lower in BWM in comparison to AHP (Rezaei, 2020).

Another advantage of BWM is the lower number of comparisons. Instead of the $n(n-1)/2$ comparisons required in a full pairwise comparison matrix, only $2n-3$ comparisons are required (n stands for the number of factors analysed) (Rezaei, 2015). This reduces the workload for the respondents and potentially reduces the inconsistency, as a smaller number of comparisons reduces the confusion by the respondents (Rezaei, 2020). Other pairwise comparison methods, like Simple Multi-attribute Rating Technique and Swing only uses one vector of pairwise comparisons (Edwards & Barron, 1994). This reduces the workload for the experts even more. Nevertheless, the consistency of the results in these methods cannot be checked. Therefore, BWM seems to be the most data and time efficient method that for pairwise comparisons also provides insight in the consistency of the results (Rezaei, 2020). Another advantage of BWM is the usage of integers, which makes the analyses easier (Rezaei, 2015).

For all the above provided reasons, the BWM is chosen to determine the 'best-fit' focus distribution of the PI policy directions. This method is already used in port choice for refrigerated transport chain by Apparcel (2019), used in analysing the importance of port performance criteria for port choice of different logistics stakeholders (Rezaei, Van Wulfften Palthe, Tavasszy, Wiegmans, & Van der Laan, 2019), is often used in suppliers selection studies (Cheraghalipour & Farsad, 2018; Rezaei, Nispeling, Sarkis, & Tavasszy, 2016; Rezaei, Wang, & Tavasszy, 2015), is used in assessing the performance of the supply chains (Ahmadi, Kusi-Sarpong, & Rezaei, 2017) and is used in assessing contributing factors in supply chain competitiveness (Sadeghi, Rasouli, & Jandaghi, 2016). Mi, Tang, Liao, Shen, and Lev (2019) provides a more elaborate overview of the applications of the BWM.

3.7.2. Bayesian Best Worst Method

The (original) BWM is a method that finds optimal weights based on preferences. Nevertheless, when the preferences of more than one expert is used in a group decision-making problem, this method is sensitive for outliers and provide limited information about the overall preference. For this reason, Mohammadi and Rezaei (2019) developed the Bayesian BWM method. In this method, the same input is used as in the original BWM. The first four steps of both the methods are the same (see procedure below). However, in the fifth step, when the optimal weights are calculated the Bayesian BWM uses probability distributions and a hierarchical model instead of averages and a linear programming problem. This makes the results less sensitive to outliers. The Bayesian BWM is, therefore, preferred over the original BWM.

Below the procedure of the Bayesian BWM is elaborated in five steps, adopted from Rezaei (2015), Mohammadi and Rezaei (2019) and Fahim (2020):

1. *Determine a set of decision criteria* c_1, c_2,..., c_n
   This step is performed by answering the fourth RSQ. In this RSQ, the methods literature review and experts interviews are used to identify the policy measures for the PA to improve the attractiveness of the maritime port. These policy measures are clustered into PI policy directions (e.g. the decision criteria) to reduce the complexity for the respondents (see section 5.2).

   The following steps 2, 3 and 4 are performed with the use of a questionnaire and are repeated for all the different KPIs in all the different PI port scenarios.

2. *Determine the best (e.g. most impactful) and the worst (e.g. least impactful) PI policy direction*
   In this step, the respondents identify the most impactful and least impactful PI policy direction. No comparison made yet.

3. *Determine the preference of the best PI policy direction over all the other PI policy directions using a number between 1 and 9*
   In this step, the respondents compare the most impactful PI policy direction with the other PI policy directions on a scale between 1 and 9. This leads to the following Best-to-Others vector:

   $$A_B = (a_{B1}, a_{B2}, ..., a_{Bn})$$

   In which, a_{Bj} indicates the preference of the most impactful PI policy direction B over the PI policy direction j. $a_{Bj} = 1$, if the PI policy direction j is as impactful as the most impactful PI policy direction B and $a_{Bj} = 9$, if the PI policy direction j is much less impactful than the most impactful PI policy direction B. This means a_{BB} has to be equal to one.

4. *Determine the preference of all the PI policy directions over the worst PI policy direction using a number between 1 and 9*
   In this step, the respondents compare the other PI policy direction with the least impactful PI policy direction with a number between 1 and 9. These leads to the following Other-to-worse vector:

$$A_W = (a_{1W}, a_{2W}, ..., a_{nW})^T$$

   In which, a_{jW} indicates the impact of PI policy direction j over the least impactful PI policy direction W. $a_{jW} = 1$, if PI policy direction j is as impactful as the least impactful PI policy direction W and $a_{jW} = 9$, if the PI policy direction is much more impactful than the least impactful PI policy direction W. This also means a_{WW} has to be equal to one.

5. *Obtaining the aggregated weights w^* = (w_1^*, w_2^*), ..., w_n^* and the weight for each expert w^k, k = 1, ..., K.*
   These weights are obtained based on the following probabilistic model:

$$A_B^k|w^k\ multinomial(1/w^k), \forall k = 1, ..., K$$

$$A_W^k|w^k\ multinomial(w^k), \forall k = 1, ..., K$$

$$w^k|w^*\ Dir(xw^*), \forall k = 1, ..., K$$

$$gamma(0.1, 0.1)$$

$$w^*\ Dir(1)$$

   In which, *multinomial* stands for the multinomial distribution, *Dir* stands for the Dirichlet distribution and *gamma(0.1, 0.1)* stands for the gamma distribution with the shape parameters of 0.1. Nevertheless, this model does not have a closed form. For this reason, Markov-chain Monte Carlo (hereafter: MCMC) methods, like *"just another Gibbs sampler"* (hereafter: JAGS) is used. The useful outcome of the model is the posterior distribution of weights for every single expert and the w^*. Nevertheless, this does not provide insight in the confidence of the superiority between the PI policy directions. The Bayesian BWM also calibrates the degree of superiority by means of credal ranking. For credal ranking is credal ordering used:

   Definition 1 Credal Ordering: For a pair of PI policy directions pd_i and pd_j the credal ordering O is defined as:

$$O = (pd_i, pd_j, R, d)$$

   In which, R is the relation between PI policy direction pd_i and pd_j, either > or <. and d ∈ [0,1] represents the confidence of the relation.

   Definition 2 Credal ranking: For a set of PI policy directions PD = (pd_1, pd_2, ..., pd_n), the credal ranking is a set of credal orderings which includes all pairs of (pd_i, pd_j) for all pd_i, pd_j ∈ PD

   The confidence provides more insight in the certainty of the relation. To find the confidence of each credal ordering a new Bayesian BWM test is performed. The test is predicated on the posterior distribution of w^*. The confidence that pd_i being superior to pd_j is computed by:

$$P(pd_i > pd_j) = \int I_{(w_i^* > w_j^*)} P(w^*)$$

   In which, I is equal to one when the condition in the subscript holds and 0 otherwise and $P(w^*)$ is the posterior distribution of w^*. This integration can be approximated by the samples via the MCMC. Having Q samples from the posterior distribution, the confidence can be computed as:

$$P(pd_i > pd_j) = \frac{1}{Q} \sum_{q=1}^{Q} I(w_i^{q*} > w_j^{q*})$$

$$P(pd_j > pd_i) = \frac{1}{Q} \sum_{q=1}^{Q} I(w_i^{q*} > w_j^{q*})$$

In which, w^{q*} is the q^{th} sample of w^* from the MCMC samples. Based on this information is for each pair of PI policy direction, the confidence superiority determined. The credal ranking could be changed into a traditional ranking. In which, $P(pd_i > pd_j) + P(pd_j > pd_i) = 1$. Hence, pd_i is more important than pd_j, if and only if $P(pd_i > pd_j) > 0.50$. As a result, can the traditional ranking be obtained by applying a threshold of 0.50 in the credal ranking. The credal ranking for the different KPIs in the different PI port scenarios is presented in appendix I and the resulted 'best-fit' focus distribution is presented in section 5.3. The Bayesian step 5 is performed with a MATLAB model developed by Mohammadi and Rezaei (2019).

The second until the fourth step of the Bayesian BWM is conducted with the use of a questionnaire. For the applicability of the results, it is important to consider who to approach for the questionnaire. There are, for instance fundamental differences between researchers and practitioners. Both, these groups have very different assumptions on how knowledge is created. Researchers make assumptions about the real-world, which play a crucial role in dealing with, among other things, future uncertainties (Shrivastava & Mitroff, 1984). To bridge this gap in the thesis, both researchers from the field of PI and maritime ports are asked to fill in the questionnaire, and practitioners with work experience related to policy making in maritime ports are asked to fill in the questionnaire. The expertise of the experts is in the same way judged as the interviews (see section 3.5).

To prevent biasness and inconsistency in the results, all the questionnaires are conducted via interviews. Also, to reduce the workload for the respondents, each respondent only performs the questionnaire for all the KPIs for two PI port scenario (see appendix G).

Still, due to the combination of the expert perceptions used in the (Bayesian) BWM and the highly hypothetical future situations described to the experts in the questionnaire, the resulted weights are not considered to be precise enough to exactly determine the focus distributions of PI policy directions on the different KPIs in the different PI port scenarios. Nevertheless, patterns in and the 'best-fit' focus distributions for the different KPIs and the different PI port scenario can be used to formulate recommendations for future (adaptive) policy making by the PA to make the maritime port attractive in the uncertain future of PI.

In total 30 respondents are approached to fill in the questionnaire and in total 21 respondents performed the questionnaire. These respondents are equally divided over the different PI port scenarios based on their geographical background, their knowledge level and their reference port. In this way, it can be checked, whether these differences influences the results (see section 3.8.) In appendix G an overview of the respondents background is given. The twelve resulted respondents for the PI port scenarios 'Big PI' and 'No PI' and eleven respondents for the PI port scenarios 'Institutionally driven advancement' and 'Technologically driven advancement' is seen as sufficient (Enserink et al., 2010).

To get insight in the 'absolute' contribution of the different PI policy directions in the different PI port scenarios, the potential improvement of a KPI in a PI port scenario for a particular port has to be determined. This requires more research (see appendix J).

(Overall) focus distribution of PI port scenarios
When the following two assumptions are taken, the importance weights of the criteria classes estimated by Fahim (2020) (see section 2.2.4) can be used to estimate the overall 'best-fit' focus distribution of the PI policy directions in the different PI port scenarios:

- The (potential) improvement of a KPI is relatively the same to the (potential) improvement of the other KPIs across the different PI port scenarios.
- The weights of Fahim (2020) for the criteria classes are representative for the KPIs and consistent across the different PI port scenarios.

With these assumptions the (relative) overall impact of the PI policy directions in the PI port scenarios is determined by the summed multiplication of the importance weight (w) for the criteria classes with the (relative) impact of PI policy direction (x) on KPI (z) in a PI port scenario (y).

$$P_{xy} = \sum_{z} w_z * P_{xyz}$$

3.8. Sensitivity Analysis

Sensitivity analysis is defined as *'the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input'* (Saltelli, Tarantola, Campolongo, & Ratto, 2004). In this thesis, sensitivity analysis is conducted by checking the results of the Bayesian BWM on consistency by only considering the first six respondents.

Sensitivity analysis could also be performed, by changing the most impactful policy direction of the respondents with the next most impactful policy direction and changing the least impactful policy direction of the respondents with the next least impactful policy direction (Rezaei et al., 2016). Nevertheless, the credal ranking in the Bayesian BWM already provides comparable insights and in this thesis only the patterns in and between the 'best-fit' focus distribution are used to draw conclusions. For this reason, this is not required in this thesis.

Furthermore, sensitivity analysis, with a sub-goal to validate the results could be conducted by only taking into account the judgments of respondents with a particular background. In this, the distinction between researchers and practitioners could be researched, the distinction between respondents with a lot of knowledge of PI and less knowledge of PI could be researched, the distinction between respondents with different geographical areas could be researched and the distinction between respondents with a lot of knowledge about policy making in the port and less knowledge about policy making in the port could be researched. However, as the respondents groups become particularly small and for this reason sensitive for outliers no real conclusions can be drawn. For this reason, this sensitivity analysis is considered to be out of the scope of the thesis.

4

Physical Internet port scenarios

In this chapter, PI port scenarios are operationalized based on external factors for the Port Authority (hereafter: PA) to make the maritime port attractive.

The chapter is structured as follows:

- In section 4.1, the external factors for the PA to make the maritime port are identified.
- In section 4.2, the external factors and external factors are used to develop the PI port scenarios.

4.1. External factors

In this section, is based on the applications of the theoretical frameworks: *Politial- economy model of transport innovations* and *Dynamic multi-level perspective on the technological transition* (see section 4.1.1) and a stakeholder analysis (see section 4.1.2) external factors for the PA to make the maritime port attractive determined (see section 4.1.3).

4.1.1. Theoretical Frameworks

Political- economy model of transport innovations

In this subsection, the application of the *Politial- economy model of transport innovations* on the adoption of PI in the maritime port to determine external factors for the PA is treated. In this theoretical framework, the adoption of an innovation is based on the technical feasibility, the social feasibility and the political feasibility.

Technical feasibility

The technical feasibility of the adoption of PI in maritime port is influenced by the technical requirements and the experts (see figure 3.5). Currently, the number of experts researching the PI is increasing, which improves the technological feasibility.

The technical requirements for the adoption of PI in the maritime port, include among other things the key characteristics of the π-containers (see figure 4.1). Currently, research to the design of the π-containers is conducted (Landschützer, Ehrentraut, & Jodin, 2015). Also, research is conducted to the other physical elements of PI: the π-nodes and π-movers, as all these physical elements should be aligned to each other (Walha et al., 2016; Ballot et al., 2013). The π-containers and other physical elements should be smart and connected (see figure 4.1). Therefore, IoT technologies and corresponding wireless sensors, like Radio Frequency Identification (hereafter: RFID) and for Global Positioning System (hereafter: GPS) sensors have to be installed on the π-containers and the other physical elements of PI (Sallez, Berger, Bonte, & Trentesaux, 2015; Zhong et al., 2017; T. Kim, Ramos, & Mohammed, 2017). To cope with the large amount of data provided by all the sensors and enable fast and fact-based decison making, Big data analysis is required (Zhong et al., 2017).

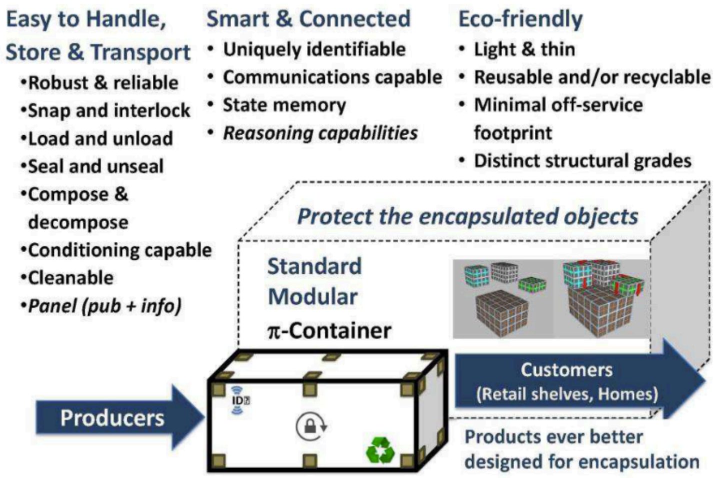

Figure 4.1: Key characteristics of π container (Montreuil, Ballot & Tremblay, 2015)

Furthermore, as PI requires numerous connections between the physical elements at high data rate, it is expected that a 5G network is required to ensure reliable and fast exchange of information (Ni et al., 2018). This network is, currently being implemented around the world (Forbes, 2019). Nevertheless, there are some issues with privacy and the safety and security of data with 5G and IoT (Ahmad et al., 2017; Khan & Salah, 2018). These issues are, also applicable for PI, as this innovation is an application of e.g. IoT and depends on data security. For this reason, research has to be conducted to standard digital interfaces and standard protocols, which ensure safe, transparent and reliable transfer of information. A potential enabler for solving these security problems is Blockchain technology (Khan & Salah, 2018). Treiblmaier (2019) already researched the combination of Blockchain technology and PI to achieve sustainability. In general, (global) accepted standardised protocols and interfaces are required for the adoption of PI. This has to be further researched (see appendix A).

The technical feasibility, also includes whether the innovation could be economically viable. The innovation has to pass the initial benefit-costs analysis. This is not an issue for PI, as research has already shown that this innovation could have tremendous positive effects on the logistics efficiency (Ballot, Montreuil, & Thivierge, 2012; Meller, Montreuil, Thivierge, & Montreuil, 2012; Darvish, Larrain, & Coelho, 2016).

Research to PI is still in its infancy stage (Pan et al., 2017; Treiblmaier et al., 2016). This is certainly the case for the adoption of PI in the real-world (Martinez de Ubago, 2019; Voster, 2019). Still, the adoption of PI in the maritime port in the future seems technical feasible, as long as the issues with safe and secure data transmission and (global) standardisation of the physical elements, protocols and interfaces are solved.

Social feasibility
The social feasibility of the adoption of PI in the maritime port is more difficult to assess, as PI is a relatively new innovation with a lack of awareness by the public. There are currently no comparable innovations available. Still, some remarks can be made:

PI has tremendous advantages, as it solves the logistics issues shown in table 1.1. Furthermore, there is a growing believe that negative externalities of the logistics systems have to be reduced. This can be seen in the growing research and media attention for e.g. congestion, climate change and nuisance (Bektaş, Ehmke, Psaraftis, & Puchinger, 2019; Hill & Gale, 2009). This is all positive for the social feasibility.

Nevertheless, there are also some potential negative influences on the social feasibility. The issues with privacy and the safety and security of data have to be solved, before the adoption of PI in the maritime port becomes socially feasible. Besides, due to the automation, most likely applied in PI, there will be people in the maritime port losing their jobs (Montreuil, 2011; ALICE, 2019). These are in most cases people from the lower classes (Aaronson & Phelan, 2019). This will lead to an increase in social inequality.

To conclude, the adoption of PI in the maritime port is potentially social feasible, as the perceived effectiveness is very high. Nevertheless, before the adoption of PI in the maritime port becomes socially feasible the issues with privacy and, the safety and security of data have to be solved.

Political feasibility
The political feasibility is like the social feasibility difficult to assess, as PI is a relatively new innovation. Nevertheless, some remarks can be made:

The political feasibility depends on the social feasibility. For this reason, the adoption of PI in maritime ports is not political feasible, as long as there are issues with privacy and the safety and security of data. Also, there are large (vertical) alliances who potentially will lobby against the adoption of PI in the maritime port, as this innovation could affect their interest in a negative way (see section 4.1.2).

On the other hand, there is a growing believe that the negative externalities of logistics have to be solved. This growing believe is also visible by policy makers, as they increasingly pressure stakeholders to address these externalities (Tob-Ogu, Kumar, Cullen, & Ballantyne, 2018). For this reason, the adoption of PI in the maritime port, potentially is political feasible. However, not before the issues with privacy and the safety and security of data are solved.

Dynamic multi-level perspective on technological transition
In this subsection, the application of the *Dynamic multi-level perspective on the technological transition* on the adoption of PI in the maritime port to determine external factors for the PA is treated.

Currently, PI can be seen as an innovation at niche level. It is being protected from the markets by investments of the EU and research institutions (European Commission, 2017). Besides, conferences are organised to get stakeholders together and to build up social structures required for maintaining the innovation (IPIC, 2019). As, PI is an innovation in the field of logistics. It is nested within in the logistics-regime, at the meso-level (Zhong et al., 2017) (see figure 4.2). Furthermore, as the scope of this research is about PI in the maritime port, only developments in logistics, which affect the attractiveness of the maritime port are considered.

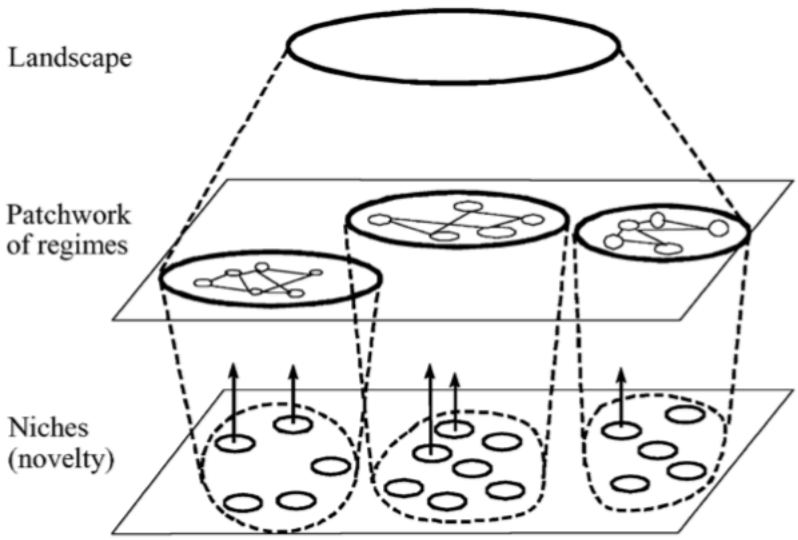

Figure 4.2: Multi level nested hierarchy (Geels, 2004)

To stimulate the breakthrough of PI to the logistics-regime, the SENSE project has created a roadmap (European Commission, 2017) (see subsection 2.1.2). Also, business models are created that, for example, stimulate the efficient usage of warehousing spaces and transport volume (Stockbooking, n.d.; Mxmove, n.d.). Besides, when more stakeholders are willing to join PI is a stimulation for the adoption of PI in the maritime port. The functionality of PI depends on the number of stakeholders (network externalities).

Other stimulus for the breakthrough of PI are landscape changes that put pressure on the logistics-regime. The landscape level includes mostly slow-moving trajectories over which the stakeholders in the logistics-regime have (almost) no control. This includes, for example economic growth, demographic developments, digitalization of society and mass individualisation. Furthermore, the adoption of PI in the maritime port could also be stimulated by the negative externalities of the regime. Stakeholders in the regime tend to downplay these effects, however due to outside pressure from governments and consumers, solutions for these negative externalities could come on the agendas of the regime stakeholders (Geels, 2004). For logistics this are the following negative effects:

- *Safety:* Safety includes the causalities and injuries caused by logistics activities, like handling and transportation. Especially, for transportation this negative externality is perceived as a problem (SWOV, 1982).

- *(Excessive) land use:* The (excessive) land use required to perform the logistics activities leads to local problems in urban areas. For this reason, e.g. land constraints are imposed by the government (Lindholm & Behrends, 2012). This is, especially a problem with maritime ports in urban areas, as there is limited land available near the waterfront (P. Hall, 2008).

- *Air pollution:* Air pollution is a negative externality caused by the emission of GHG with severe impact on human health. The World Health organisation (hereafter: WHO) estimates that on a yearly basis 4.2 million people die because of the consequences of air pollution (WHO, n.d.). The freight transportation in Europe is accountable for approximately 11-13% of the emissions of GHG (European Environment Agency, 2017; OECD/ITF, 2015). This is significant even without considering the other sources of emissions due to logistics. For this reason, this negative externality has received growing attention. Several policy regulations are implemented to counter this negative externality, like the European air pollution standards or the implementation of low emission zones (Mostert, Caris, & Limbourg, 2017).

- *Water pollution:* This is, especially a negative externality caused by port (related) activities. The maritime port may produce sewage, bilge wastes, solid waste and leakage of harmful materials both from land and form vessel (Gupta, Gupta, & Patil, 2005). This could have negative consequences on aquatic life and on those who consume the water (Goel, 2006). For this reason, institution like the International Maritime Organization (hereafter: IMO) and the Marine Environmental Protection Committee (hereafter: MEPC) have introduced regulation for the port and shipping industry (Di Vaio & Varriale, 2018). An example of such regulation is the MARPOL 73/78/97 convention. This convention deals with the prevention of water pollution by vessels from operational or accidental causes (IMO, n.d.).

- *Climate change:* The emissions of GHG due to logistics activities also have a significant contribution to the climate change. The EU aims to limit the temperature increase to only 2 degrees in 2100 by collectively reducing the GHG emission by 60 to 80% in 2050, in comparison to 1990 (European commission, 2020).

- *Congestion:* In Europe congestion around urban areas is accountable for 1% of the European GDP (European Commission, n.d.b). A large contributor to this problem is the freight transportation. For this reason, there is a growing pressure on logistics and maritime ports due to e.g. policy measures that aims to reduce the number of trucks in certain areas (Lindholm & Behrends, 2012).

- *Nuisance:* Logistics activities are a large contributor to nuisance. In the EU around 100 million people are affected by harmful levels of nuisance caused by road traffic. Furthermore, rail traffic, air traffic and industry activities are major sources of nuisance. To reduce this externality the

EU, for example has implemented the EU's seventh environment action (European Environment Agency, 2019).

Due to these pressures, maritime ports with a strong environmental record and high community support are favoured, even by trade partners and investors (Lam & Notteboom, 2014). All this pressure on the logistics and the maritime ports could potentially open opportunities for the adoption of PI (in the maritime port). Nevertheless, there are also potential bottlenecks for the adoption of PI in the maritime port. These bottlenecks are located at the logistics-regime level (see figure 3.6 meso-level). Developments at this level are incentives for taking incremental steps and not for implementing a radical new innovation, like PI. This level includes the (vertical) alliances and the long-term terminal contracts. In both the (vertical) alliances and the long-term terminal contracts stakeholders are embedded in interdependent networks with mutual dependencies (see 4.1.2). These interdependencies have the function of providing stability to coordinate activities. However, it is difficult to change these networks once they are formed. Both the (vertical) alliances and terminal operators have high sunk investments. These high sunk investments will, partly, be destroyed by implementing PI. Therefore, it is likely that these stakeholders will stick to their current way of operating, as long as possible. Also, the adoption of PI in the maritime port is dependent on the willingness of stakeholders in logistics to share assets, both physical and digital. This might be limited due to potential lose of competitive advantages.

Regulation and formal rules are a potential bottleneck for implementing PI. Countries and different regions in the world have different regulation. This leads to issues with customs. The goods transferred through PI are encapsulated in three π-containers. To perform customs all the three π-containers have to be decomposed. This leads to extra handling time and disruptions in the supply chain. Also, the different regulation and formal rules between different countries leads to problems with the development of (global) standardisation of the physical elements, protocols and interfaces. A current example of regulation integration between countries is the Rotterdam Rules. This UN Convention on Contracts for the International Carriage of Goods Wholly or Partly by Sea replaces the Hague Rules, Hague-visibly Rules and the Hamburg rules. The goal of the Rotterdam Rules is to uniform the laws in the field of maritime carriage and providing: *'the modern industry needs in terms of door-to-door carriage'* (Rotterdam Rules, 2009). Nevertheless, the Bill-of-Lading[1] meant to become a Negotiable Electronic Transport Document is still transferred physically between stakeholders, due to legal restrictions (Thijsen, 2020). Other important regulation is the Incoterms, set by the International Chamber of Commerce (hereafter: ICC). This regulation holds universal meaning for buyers and sellers around the world essential for trade (ICC, n.d.). Furthermore, trade agreements between countries and tariffs are relevant institutional factors that affect the adoption of PI and the attractiveness of the maritime port (Eicher & Henn, 2011).

Also, other developments in the logistics-regime affects the attractiveness of the maritime port and are relevant for the adoption of PI. In the last decades, the increase in vessels size accelerated to achieve lower unit costs per container. To facilitate these vessels, the maritime ports have adapted the maritime access, the port infrastructure, the equipment and the hinterland transport connections (Merk, 2018). Whether, this development will continue in the future is uncertain. Furthermore, new trade routes are emerging. China is, for example, investing in new infrastructure between Asia and Europe, which will affect the maritime trade routes (PoR, 2018). And, a new maritime trade route is emerging due to the melting of the North-Pole. What the economic effects are is however highly uncertain (Liu & Kronbak, 2010).

In the last decades companies reallocated parts of their business to other countries, also called offshoring, to achieve (labour related) costs reduction. This, however has some disadvantages, like the loss of strategic flexibility, loss of core activities and increase in transport costs (Lonsdale & Cox, 2000; Dachs, Kinkel, Jäger, & Palčič, 2019). For these reasons, the reallocation of business activities back to their home countries (backshoring) or to countries nearby (nearshoring) has received increased attention and might even be encouraged by the recent outbreak of COVID-19 (Dachs et al., 2019; Slepniov, Brazinskas, & Wæhrens, 2013). This outbreak has shown the vulnerability of the global supply chain

[1] Bill-of-Lading is a paper-based negotiable document that confirms that the cargo may be transferred from one party to another by endorsement (Bergami, 2010)

when countries are in lock down and the importance of having your own production for vital products in your own country (NOS, 2020). This might also be an incentive for companies to increase the safety stock to absorb interruptions in the supply chain.

Besides, Geels (2004) explains that the adoption of an innovation is dependent on the developments of other innovations trying to breakthrough. This includes the following technological innovations: Internet of Things (hereafter: IoT), Big data, 5G, Blockchain, Drones, Hyperloop, 3D printing, Machine learning, Automated Guided Vehicle (hereafter: AGV)/equipment/vessel, Artificial Intelligence (hereafter: AI) and 'Industry 4.0'.

4.1.2. Stakeholder Analysis

In this section, the power interest and influence of all the relevant stakeholders holding a legitimate interest or being affected by the maritime port action or inaction are discussed (Notteboom & Winkelmans, 2002). This provides useful insight in external factors for the PA to make the maritime port attractive. In appendix C, the corresponding Power/Intererst grid and Stakeholders influence diagram are presented.

Terminal operator(s)
In the past, terminal operators, mostly had a local function. However, due to pressure on costs these local terminal operators are often privatised and/or increasingly forming large partnerships (Min et al., 2017). The PA and terminal operators are linked to each other by terminal concessions. In these contracts, the terminal operator agrees with the PA to use and operate certain port facilities over a period of time (Yip, Liu, Fu, & Feng, 2014). This provides the PA some power over the terminal operator during the negotiation period. Afterwards, the PA almost has no power during the contract period (Van der Lugt et al., 2014). These periods are, in the PoR usually between 20 and 30 years and in case of the Maasvlakte II even 60 years (Getting the deal through, 2019).

Next to the contractual relations, the PA and the terminal operator are interdependent and interrelated in an economic, regulatory and geographical way. Both stakeholders are in an economic sense dependent on each other, as both their revenues depends on the attractiveness of the maritime port. This attractiveness is, thereby influenced by the actions of both the stakeholders. This relation promotes the pressure from the terminal operator on the PA to meet their interest (Verhoeven, 2010). Their main interests are low transport costs, high quality of infrastructure and no interference with the logistics chain (De Langen, 2006). The PA has some regulatory power over the terminal operators regarding issues with the environment and safety. The PA and the terminal operators are geographical related, as both stakeholders act in the same area. This interdependency is enhanced by the high sunk costs the terminal operator made (Van der Lugt et al., 2014).

There is a deviation between the interest of the PA and the terminal operators. This is mainly for two reasons:

- The terminal operators have an increased global focus, while the PA's interests is mainly the competitiveness of their port area (Dooms et al., 2013). The increased global perspective of the terminal operators occurred for two reasons: firstly, the terminal operators are pressured to work together, due to costs and deliberately introducing competition in the maritime port (Van der Lugt et al., 2014). The second reason, is to achieve a competitive advantage. The terminal operators are increasingly offering integrated logistics services and working together with e.g. shipping line companies (Van der Horst & De Langen, 2008; De Langen & Chouly, 2009). This vertical integration is further enhanced by the increased pressure from the shippers to look at the performance of the entire supply chain (Van der Lugt et al., 2014).

- The PA is increasingly aware of the competitive dependency on its hinterland performance. For this reason, the PA is investing in inland terminals (PoR, 2011). However, with this development the PA is actively entering the space of the terminal operators (Van der Lugt et al., 2014)

This deviation between both stakeholders has some implications for the future adoption of PI in the maritime port. In the first place, terminal operators have power due to the long concession contracts. Thereby, it is the terminal operator that decide about the investment in new terminal equipment. Of course, the terminal operators are interested in improving their operations. However, due to their high sunk costs this stakeholder is not likely to change their equipment very quickly. This is a bottleneck for implementing PI in the maritime port, as this innovations requires adaptation of the equipment for the handling of the π-containers. Furthermore, the terminal operators are interested in optimising their own operations, taking into account their co-operations with e.g. shipping line companies and other terminal operators. This could hinder horizontal integration at the maritime port, as the terminal operators do not want to loss their competitive advantages.

Shipping line companies
Shipping line companies are less directly related to the PA. However, the shipping line companies are still off key importance for the PA. The attractiveness of the maritime port is, traditionally, dependent on the port choice of these stakeholders (Rezaei et al., 2019). The factors important for the port choice of shipping line companies are, among other factors: the port location, the terminal handling charges, the customs regulating, the service reliability and the berth availability (Chang, Lee, & Tongzon, 2008).

As discussed, in section 2.2.3 are shipping line companies forming alliances. Thereby, shipping line companies are vertically integrating with terminal operators and carriers. This provides the shipping line companies the possibility to extract monopoly profits and getting more bargaining power (Zhu et al., 2019). This leads to potential issues for the adoption of PI in the maritime port or the implementation of other policy measures by the PA. Furthermore, shipping line companies have made high sunk investments and are, therefore not likely to change their operations very quickly.

Ship brokers
The main function of ship brokers is to match the sellers and buyers of vessels or transport services. The first function, the matching of sellers and buyers of vessels will probably not change in the future with PI. However, the second function, the matching of the sellers and buyers of transport services might change. This function could be more efficiently arranged via PI. For this reason, ship brokers are not really interested in PI. However, this stakeholder has almost no power to influence the adoption of PI in the maritime port, as their competitive advantages of their extensive network, knowledge of agents' operations will disappear (Strandenes, 2000).

Freight forwarders
Freight forwards function is to find the most suitable combination of transport mode(s) for the shipper (Saeed, 2013). Tongzon (2009) identified seven factors influencing the freight forwards port choice: the frequency of ship visits, the port efficiency, the adequate infrastructure, the location, the port charges, the quick response to port users' needs and the port's reputation for cargo damage.

In the context of PI, freight forwarders could lose their intermediate function between the owners of the goods and the carriers, as PI will take over this function by open asset sharing and flow consolidation (Montreuil, 2016). What the function of freight forwarders will become in this hyperconnected logistics system of PI is uncertain. It might be the case that freight forwarders effectively become third-party logistics service provider in a particular geographical area or sector of PI.

The influence of freight forwarders in the maritime port is limited. The only measure that freight forwarders could take is choosing to send the shippers goods via other maritime ports (De Langen, 2006). However, in this freight forwarders are dependent on the shipping line companies services and the customer's requirements.

Carriers
In this thesis, the carriers are referred to the hinterland transportation companies (Henesey et al., 2003). These carriers are in general interested in low transport cost, high quality of infrastructure and no interference in the maritime port (Van der Horst & De Langen, 2008). As discussed before, the hinterland connectivity via these carriers is crucial for the competitiveness of the maritime port (Tongzon, 2009). Carriers have similar interests in the maritime port, as the shipping line company. However, carriers have less power. There is more choice between companies and transport modes in the hinterland.

Customs
The Customs in the PoR are dependent on the regulation imposed by the EU and the Dutch government (Dutch Tax Authority, n.d.). Therefore, this stakeholder almost has no influence. However, this stakeholder is interested in the developments regarding PI, as it will most likely change their operations. PI will put pressure on the efficiency, as interruptions in the supply chain have a high impact on the performance of the PI network. Therefore, the customs have to, most likely, further automate their procedures. PI, also implies that the customs will have to work with general accepted standardised digital platforms for the entire PI network, not only with their PCS: Portbase.

Another possibility is that PI might reduce the necessity of customs at the maritime port. The goods traveling through the PI network could potentially be checked on the regulation requirements of the regions, where it has to travel through when entering the PI. This might even be necessary as the goods are encapsulated in three π-containers, which increases the difficulty of performing the customs at the maritime port. At this moment, the customs already have problems, due to the unexpected increase of parcels from China in the last couple of years. And, for these goods, the customs know one day in advance when the goods will arrive in the port. In the future with PI, this could be only one hour (see interview 1 in appendix F.2).

Local residents
The local residents have an interest in limited traffic congestion, emissions of GHG and nuisance (De Langen, 2006). PI in the maritime port will generally increase the efficiency and sustainability, which would be in line with their interest. Nevertheless, the power of the local residents is limited to political pressure, which in case of the maritime ports is very low (De Langen, 2006).

Municipality of Rotterdam
The municipality of Rotterdam is interested in the contribution of the maritime port to the regional economy (De Langen, 2006). The municipality is the largest shareholder of the PA and therefore has significant power to influence the PA. PI, most likely will make the port and thereby related areas more attractive for business. For this reason, the municipality of Rotterdam will most likely support he adoption of PI in the PoR.

Dutch Government
The Dutch government is, like the municipality of Rotterdam a shareholder in the PA and, for this reason has significant power over the PA. Besides, the Dutch government could implement port laws or other regulation influencing the maritime port. And, it is this stakeholder that invest in the basic infrastructure in the hinterland of the port (Rodrigue & Notteboom, 2006).

The Dutch government is most likely interested in the adoption of PI in the maritime port, as it potentially makes the country more attractive for business and reduces the transport costs for residents and firms (De Langen, 2006). Besides, the Dutch government is interested in achieving the Paris agreement goals (European Commission, 2015). This might even encourage them to take their own measures to promote the adoption of PI in the Netherlands.

The Dutch government might be less interested in the consequences on labour. The PI leads to automation of a lot of processes, currently performed by humans (Montreuil, 2011). The exact effects on labour are uncertain. It might be a reason for the Dutch government to implement laws for labour protection. Besides, there might be issues with cybersecurity. PI relies on sharing information between different stakeholders (Montreuil, 2011). This could lead to issues with privacy or sharing of confidential information of companies protected by laws (Wettenbank, 2000, 2018).

Other maritime ports
Other maritime ports with the same hinterland are generally speaking competitors. However, in the port region, they also collaborate to increase the competitiveness of the region, like the Extended Rhine-Scheldt (PoR, 2011). In PI, this collaboration will be extended to a more continental or global level to improve the performance of the entire logistics system. Nevertheless, there will still to some degree be competition between maritime ports with the same hinterland. Therefore, it might be advantageous for

the PA of PoR to invest in an early stage in this new innovation to get a head-start.

European Union
The EU is investing money in the development of PI via ETP-ALICE to finally reach zero emission in 2050 (ALICE, n.d.). This investment provides the required protection to develop this new innovation. Furthermore, it provides the EU to have influence in how this innovation will shape the logistics system in Europe. This could, in a later stage, include European laws about, for instance the standardisation of the π-containers, protocols and interfaces or standardisation required for the digitalisation. Other institutions that could play a role in setting and/or developing standards are the WTO, the ISO, the IMO, the GS1 and the UN (WTO, n.d.; UN, n.d.; ISO, n.d.; IMO, n.d.; GS1, n.d.). These stakeholders should, before implementing such regulation, give the logistics' stakeholders the time to adapt their operations to these new standards. Most of these stakeholders have made high sunk costs.

Like the Dutch government, the EU might counteract the adoption of PI in the maritime port, as mostly low-class jobs will be lost and/or because of the violations of cybersecurity and antitrust regulation (Posner, 2009; Ordover & Willig, 1985).

4.1.3. External factor classes

With the application of the theoretical frameworks and the stakeholder analysis in total 39 external factors are identified (see table 4.1 for an overview). These 39 external factors are, for clarity reason clustered into eight external factor classes. This clustering is, both based on insights from the *Dynamic multi-level perspective on technological transitions* from Geels (2002) and the eight driving forces from Martinez de Ubago (2019):

In this clustering, three main points from the *Dynamic multi-level perspective on technological transitions* are applied: In the first place, in this clustering the landscape level and logistics-regime level are distinguished. The landscape level includes the external factor classes: *Demographic changes* and *Economic growth*. The logistics-regime level includes the external factor classes: *Flow patterns*, *Global institutional integration* and *Logistics market structure*. Secondly, it is acknowledged that the logistics activities in and around the maritime port have negative externalities, which increases the pressure for change. This is included in the external factor class *Sustainability*. Thirdly, it is acknowledged that it is important to consider the development of other innovations trying to breakthrough. These technological innovations are included in the external factor class *Technological innovations*.

To make the external factor classes more relatable, also four driving forces of Martinez de Ubago (2019) are directly adopted. This include the classes: *Demographic changes*, *Technological innovations*, *Regulatory frameworks* and *Global institutional integration*. Furthermore, the class *Logistics market structure* is based on the driving force business models. However, as the focus of this thesis is on logistics and it is also important to take factors like 'Willingness to share assets' and 'Network externalities' into account this class has a broader perspective. This reasoning leads to the following eight external factors classes, subsequently defined below. In table 4.1 the corresponding external factors are shown and in appendix D the description of the external factors is provided.

- **A Economic growth:** Includes the growth of the (world) GDP (Henderson, Storeygard, & Weil, 2012).

- **B Demographic changes:** Are the changes in size, growth and structure of the population (IMF, n.d.).

- **C Flow patterns:** Are logistics' developments, which affects the trade flows through the port by affecting where goods are handled, stored and could be transported from and to.[2]

[2]It can be argued that the class Flow patterns also includes external factors from the classes Global institutional integration and Logistic market structure as these classes include logistics' developments affecting trade flows. However, for clarity reason are only the logistic developments that are not considered in these classes E and class G clustered in the class Flow patterns.

D Global institutional integration: Refers to the 'rules of the game', set by formal institutions[3] for global trade.

E Regulatory frameworks: Refers to regulation set by formal institutions, which influences the breakthrough or development of (technological) innovations.

F Technological innovations: Are other technological innovations, which affect the attractiveness of the maritime port.

G Logistics market structure: Refers to tangible social structures between companies in logistics which have evolved specific role behaviour towards one another.[4]

H Sustainability: Refers to a plan or a set of ideas of what to do about environmental, economic and social unsustainable effects of the port operations and the port related activities.

Table 4.1: External factors clustered

A. Economic growth	**B. Demographic changes**	**C. Flow patterns**	**D. Global institutional integration**
1. (World) GDP	1. Population growth 2. Migration flows 3. Urbanisation	1. Nearshoring & Backshoring 2. Safety stock 3. Increase in vessel size 4. New trade routes 5. Digitalisation of society 6. Mass individualism 7. Hinterland infrastructure	1. Trade agreements 2. Import tarriffs & quotas 3. Different tax environments
E. Regulatory frameworks	**F. Technological innovations**	**G. Logistics market structure**	**H. Sustainability**
1. Cybersecurity 2. Antitrust policies 3. Labour protection 4. (PI) standardisation	1. Internet of Things 2. Big data 3. Artificial Intelligence 4. Blockchain 5. Drones 6. Hyperloop 7. 3D printing 8. Machine learning 9. 5G network 10. Industry 4.0 11. Automated Guided Vehicles/equipment/vessels	1. (Vertical) Alliances 2. (Long-term) Terminal contracts 3. (New) Business models 4. Network externalities 5. Willingness to share assets	1. Environmental regulation 2. Land-use planning 3. Traffic measures 4. Work condition regulation 5. National subsidies

4.2. PI port scenarios

To operationalize a total of four scenarios, the above described eight external factor classes are aggregated into two driving forces, by firstly excluding the first four external factor classes A until D. These external factor classes are not in line with the research objective: *Supporting the PA in designing policy to be attractive given **the uncertain development of Physical Internet**.* These classes are rather about the uncertainty on the demand side.

[3]Institution refer to 'the humanly devised constraints that structure political, economic and social interactions' (Williamson, 1998) and formal institutions only refer to governmental institutions, like the EU and the Dutch government.

[4]Wellman and Berkowitz (1988) describes markets as 'tangible social structures encompassing sets of producers that have evolved specific role behaviors towards one another and accustomed set of buyers'. As this class only considers the social structures and the stakeholders in logistics the name and definition of the class is adapted.

The remaining four external factor classes are clustered into the following two driving forces:

- **Technological development:** Includes the external factor class F: *Technological innovations* and represents the development of these innovations.
- **Institutional development:** Includes the external factor classes E: *Regulatory frameworks*, external factor class G: *Logistics market structure* and external factor class H: *Sustainability*, and represents the restrictions and/or support from institutions for implementing PI policy by the PA.

For both these driving forces the most positive and most negative future development between 2020 and 2040 is developed (See table 4.2 for an overview):

- **Fast technological development:** In this future the technological innovations will rapidly develop.
- **Slow technological development:** In this future the technological innovations will only slowly develop.
- **Restrictive institutional development:** In this future, the regulation set by formal institutions will be a major bottleneck for the adoption of new (technological) innovations and there will be no fully developed PI standardisation established even by 2050. Also, in this future logistics stakeholders are not willing to share assets, not willing to use new business models and not willing to join PI. '(vertical) alliances' and '(long-term) terminal contracts' are a major bottleneck for changes in the port operations and port related activities. In this future, it is expected that there will be major restrictions for implementing policy, due to sustainability pressure and there are no additional sustainable incentives to implement PI like policy measures.
- **Progressive institutional development:** In this future, the regulation set by formal institutions will only be a marginal bottleneck for the adoption of new (technological) innovations and full PI standardisation will be established by 2040. In this future, stakeholders in logistics are willing to share assets, to use new business models and to join PI. The (Vertical) Alliances and (Long-term) Terminal contracts will not be a major bottleneck for changing the port operations and port related activities. In this future, it is expected that there will only be limited restrictions for implementing policy, due to sustainability pressure and there are additional sustainable incentives to implement PI like policy measures.

Table 4.2: Positive and negative future outcome driving forces

Future outcome	Technological development	Institutional development
Positive	Fast	Progressive
Negative	Slow	Restrictive

These extreme positive and extreme negative future outcomes are presented into the scenario logic of Enserink et al. (2010) (see figure 4.3). The quadrants in figure 4.3 represents the different PI port scenarios, as a combination of an extreme positive and an extreme negative future outcome of both the driving forces. The resulting four different PI port scenarios are, subsequently, provided below.

PI port scenario 1: 'Big Physical Internet'
In this PI port scenario, there are a lot of technological opportunities. The legal restrictions are limited and there are additional sustainable incentives to implement PI like policy measures. The logistics stakeholders are willing to share data and physical resources, apply new innovations, apply new business models and cooperate with each other. In 2040, there will be full developed PI specific interfaces, protocols and modular containers.

PI port scenario 2: ’Institutionally driven Advancement’
In this PI port scenario, the legal restrictions are limited and there are additional sustainable incentives to implement PI like policy measures. The logistics stakeholders are willing to share data and physical resources, apply new innovations, apply new business models and cooperate with each other. There will be full developed PI standardisation for the protocols, the interfaces and modular containers in 2040. However, due to technological limitations in computing power of distributed systems and entities, limited development of IoT, Big Data, AI and Blockchain applications, the autonomous real time decision making capacity and connectivity between stakeholders, between stakeholders and physical objects and between physical objects is limited.

PI port scenario 3: ’Technologically driven advancement’
In this PI port scenario, the technological development is fast and provides opportunities to implement worldwide PI. Nevertheless, due to legal restrictions, limited sustainable incentives, limited developed PI standards and the logistics stakeholders not willing to share data, apply new innovations, apply new business models or cooperate with each other, only limited number of PI applications are applied around the world. These applications are, furthermore, taking place in a rather unstructured way and often have limited scope of one company or one (vertical) alliance.

PI port scenario 4: ’No PI’
In this PI port scenario, due to technological limitations in computing power of distributed systems and entities, limited development of IoT, Big Data, AI and Blockchain applications, the autonomous real time decision making capacity and connectivity between stakeholders, between stakeholders and physical objects and between physical objects is limited. Furthermore, legal restrictions, limited sustainable incentives, limited developed (PI) standards and the logistics stakeholders not willing to share data, apply new innovations, apply new business models or cooperate with each other, limits the number of PI applications. In this PI port scenario, PI stays in its infancy stage and only occasionally pilots are started.

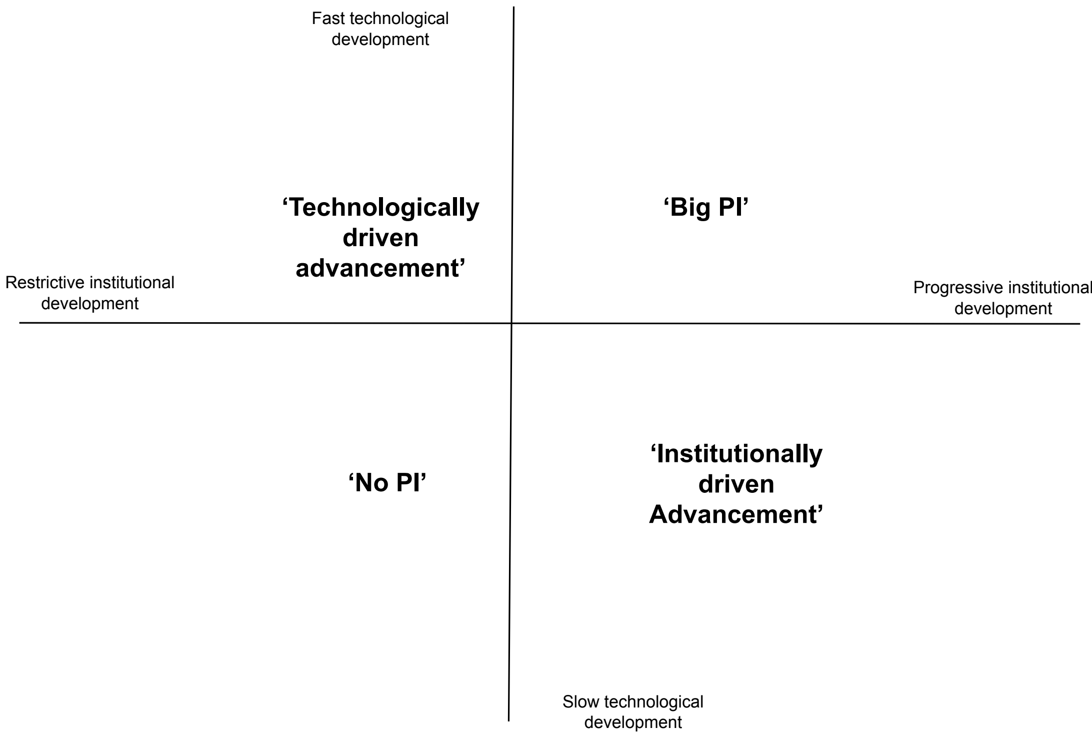

Figure 4.3: Scenario logic PI port scenarios

5

Port Authority’s policy focus

In this chapter, PI policy directions the Port Authority (hereafter: PA) could implement to improve the attractiveness of the maritime port are determined and assessed.

The chapter is structured as follows:

- In section 5.1, the Key Performance Indicators (hereafter: KPI) for the attractiveness of the maritime port used to evaluate the PI policy directions are outlined.
- In section 5.2, the PI policy directions identified by means of interviews and literature review are described.
- In section 5.3, the ’best-fit’ focus distributions of the PI policy directions on the attractiveness of maritime ports in the different PI port scenarios are presented.

5.1. Key Performance Indicators for the attractiveness of the maritime port

As, the containers and vessels are considered to be the two most important entities for the maritime port in the future of Physical Internet (hereafter: PI), it can be argued that the criteria for making these entities chose for the maritime port (port choice), in essence the same as the criteria for making the maritime port attractive. For this reason, the criteria classes for the port choice of these two entities, defined by Fahim (2020) (see section 2.2.4), are used to develop the KPIs for the attractiveness of the maritime port. Other port choice criteria are considered to be less relevant, as either a specific stakeholders perspective is chosen or the criteria are not applicable for PI (Tongzon, 2009; Chang et al., 2008; Rezaei et al., 2019).

To prevent confusion by the respondents between the KPIs and the PI port scenarios, which include the technological development, the criteria classes C *’Technology’* and D *’Network Quality of Port’* are redefined. Furthermore, to reduce the workload in the questionnaire the descriptions of the KPIs are shortened to the following:

A **Transport Chain Quality (TCQ):** Refers to the effectiveness of the port operations, including the speed, reliability and quality of operations, and the agility to respond to changes/disruptions in the port operations.

B **Costs:** Refers to the costs for the port users.

C **Digital Connectivity (DC):** Refers to the digital connectivity in the port and the seamless digital integration of the port in the supply chains.

D **Physical Network Connectivity (PNQ):** Refers to the physical connectivity of the port, the reliability of the maritime operations and the hinterland operations, and the agility to respond to changes/disruptions in the maritime operations and the hinterland operations.

5.2. PI policy directions

The PA could play several roles to improve the attractiveness of the maritime port in the uncertain future of PI. The most important roles, determined by literature review and 14 expert interviews are used to develop six PI policy directions the PA could apply (see appendix E and appendix F). For each of these six PI policy directions, the considered role is treated below:

1. **Transport Infrastructure:** From both literature in the research area hinterland and foreland (see appendix E.2) and appendix E.3), and the interviews (see appendix F.16) can be concluded that the PA should play a role in improving the accessibility of the port, both by land and by sea.

2. **(PI) standardisation:** In literature, there are only a few references to the advancement of standardisation by the PA (see appendix E.8). However, from the interviews can be concluded that advancing the (PI) standardisation could potentially be an important role for the PA (see appendix F.16).

3. **Advanced Terminal Areas:** An important element of PI is to enable open asset sharing and flow consolidation. For this to happen reshuffling activities in the maritime port are required (see PI port framework operational level 2: *Automated crossdocking and reshuffling operations*). In this, the PA could play a crucial role, as it is responsible for the land development of the port (see appendix E.1 and appendix E.7). This potential role of the PA was also mentioned during the interviews (see appendix F.16).

4. **ICT Hardware:** From literature (see appendix E.4) and interviews (see appendix F.16) can be concluded that the PA could play a role in advancing the installation of sensors and wireless communication technologies. This enables fast and fact based exchange of information required to improve the efficiency and sustainability of the port operations and the port related activities.

5. **Information systems and information exchange platforms:** To enable the reshuffling activities in the maritime port information platforms should be in place. In both literature (see appendix E.4) and interviews (see appendix F.16), it was often discussed that the PA could have a particular role in this. Besides, the PA has an important role in providing information systems, such as the Port Community System (hereafter: PCS) and the Port Management System (hereafter: PMS).

6. **Sustainability Management:** As, the PA is responsible for the environmental policy and protecting the public interests (see appendix E.1), the PA should consider taking policy measures to reduce the negative externalities of port operations. This is, both discussed in literature (see appendix E.5 and appendix E.6) and in the interviews (see appendix F.16). This PI policy direction might be to a lesser degree related to PI, however as PI has to goal to improve the efficiency and sustainability of the global logistics system, this PI policy direction is still considered relevant.

Based on these considered roles, policy measures, the PA could apply are used to develop the definitions of these PI policy directions. The definitions of the six PI policy direction are presented below.

5.2.1. Transport Infrastructure

This PI policy direction includes investments in the port infrastructure, such as to increase the rail shunting capacity and improve the waterside access, by deepening the river to relax draft restrictions. In the long-term, this could also include investments in offshore ports or Hyperloop terminals. This PI policy direction, also includes investments, by among other means joint ventures and collaborations with stakeholders from the port community and governments, in developing hinterland infrastructure, inland terminals, dedicated transport services, air freight connections and potentially in the long-term Hyperloop connections.

The definition of this PI policy direction is based on expert interviews (see appendix F) and based on policy measures related to the traditional role of a PA in a landlord port and the research area Hinterland (see appendix E.1 and appendix E.2).

5.2.2. (PI) standardisation

This PI policy direction includes the development of standards required for e.g. the digitalization of the Bill-of-Lading and customs declarations, the development of nautical standards and the development of standardisation of PI specific interfaces, protocols and modular containers. In this, the PA could set their own standards, lobby at organisations like the EU, WTO, IMO, ISO, GS1, and/or collaborate with stakeholders from the port community and other PAs in setting (PI) standards. Furthermore, the PA could show with best use cases and pilots, which standards might work and which standards be less useful. In the long-term, the PA could stimulate or enforce the usage of certain standards by incentives or rules in the concession, by access regulation or by pricing strategies.

The definition of this PI policy direction is based on expert interviews (see appendix F), policy measures related to the traditional role of a PA in a landlord port and the available research on (PI) standardisation by the PA (see appendix E.1 and appendix E.8).

5.2.3. Advanced Terminal Areas

This PI policy direction in the short term, includes showing with best use cases and pilots what sharing of assets and goods could bring to the port community. In the long-term, the PA could develop and operate its own shared warehouses, in which reshuffling operations of modular π-containers take place. Alternatively, it could outsource this function (to a 3PL), but keep it within the port area. Besides, the PA could use their concession power, access regulation or pricing strategies to enforce/stimulate reshuffling operations taking place in the port area.

The definition of this PI policy direction is based on expert interviews (see appendix F) and policy measures related to the traditional role of a PA in a landlord port and the research area Port-centric logistics (see appendix E.1 and appendix E.7).

5.2.4. ICT Hardware

This PI policy direction includes, the installation of sensors, e.g. RFID tags and wireless communication technologies, such as 5G. This enables swift exchange of large data volumes, required for the (e.g. IoT) applications, such as predictive maintenance, or applications required for the digital visibility of shipment and port operations. In this, the PA could play the role of facilitator, stimulating the implementation of physical (digital) infrastructure by the port community. This could be done by e.g. using their concession power.

The definition of this PI policy direction is based on expert interviews (see appendix F) and policy measures related to the traditional role of a PA in a landlord port and the research area Smart port (see appendix E.1 and see appendix E.4).

5.2.5. Information systems and information exchange platforms

This PI policy direction, includes the PA showing with best use cases and pilots what data and data sharing could bring to the port community. It includes, the PA integrating its different Information Systems (hereafter: IS) and stimulate the alignment of ISs used by the port community, ensuring interoperability. The PA could improve the Smart functionalities of the PMS and contribute to the PCS by applying AI, IoT and Big data applications. As, a neutral stakeholder, the PA could, furthermore play the role of logistics coordinator and develop a digital platform offering informational services required for reshuffling activities, the interoperability, the coordination of shipments and the corresponding money streams, complementing the Business-to-Government PCS (Sallez et al., 2016). And, the PA could, in the long-term, connect their ISs and platforms with the hinterland and maritime side to digitally integrate the port within the complete supply chains.

The definition of this PI policy direction is based on expert interviews (see appendix F) and based on policy measures related to the traditional role of a PA in a landlord port and the research area Smart port (see appendix E.1 and appendix E.4).

5.2.6. Sustainability Management

In this PI policy direction, the PA develops monitoring systems, controlling safety, air quality, water quality and nuisance. The PA takes specific measures to comply with, among others environmental regulation, work condition regulation and traffic measures. The PA implements policy to reduce the negative externalities of their operations and encourage/stimulate the stakeholders to implement sustainable policy by incentives and rules in the concessions, by access regulation and by pricing strategies.

The definition of this PI policy direction is based on expert interviews (see appendix F) and based on policy measures related to the traditional role of a PA in a landlord port , the research areas Sustainable port and Port-city interface (see appendix E.1), see appendix E.5 and see appendix E.6.

5.3. Evaluation of PI policy directions

In this section, the Bayesian Best Worst Method (hereafter: BWM) is used to evaluate the 'best-fit' focus distributions of the PI policy directions on the different KPIs in the PI port scenarios.

5.3.1. Data collection

To collect the data a questionnaire is presented to respondents with a background in PI and/or a background in policy making for maritime ports (see appendix G). In total 21 experts conducted the questionnaire via an interview. All these experts conducted the Bayesian BWM for at least two PI port scenarios. This led to in total twelve respondents for the PI port scenarios 'Big PI' and 'No PI' and in total eleven respondents for the PI port scenarios 'Institutionally driven PI' and 'Technologically driven PI'. In appendix H the provided information to the respondents is shown.

5.3.2. 'best-fit' focus distribution PI policy directions

In this subsection, for all the PI port scenarios, the 'best-fit' focus distributions of the PI policy directions on the different KPIs for the attractiveness of the maritime port is described. In this description, the credal ranking is used to estimate the confidence a PI policy direction is more impactful in comparisons to another PI policy direction[1] (see appendix I). Thereafter, the overall 'best-fit' focus distribution of the different PI policy directions for the different PI port scenarios is estimated and finally the results from the sensitivity analysis are discussed.

PI port scenario 1: 'Big Physical Internet'

In table 5.1, the 'best-fit' focus distributions of the different PI policy directions for the different KPIs in PI port scenario 'Big PI' are presented.

Table 5.1: 'best-fit' focus distributions policy directions on the different KPIs in PI port scenario 1: 'Big PI'

	Transport Chain Quality	Costs	Digital Connectivity	Physical Network Quality
Transport Infrastructure	0.130	0.167	0.085	0.260
(PI) Standardisation	0.195	0.222	0.228	0.166
Advanced Terminal Areas	0.141	0.134	0.108	0.196
ICT Hardware	0.179	0.165	0.207	0.132
Information systems and Information exchange platforms	0.255	0.241	0.286	0.152
Sustainability Management	0.100	0.073	0.087	0.095
Total	1	1	1	1

[1]When the credal ranking of a PI policy direction being more impactful, in comparison to another is 0.9 or higher, it has a very confidence it is more impactful, when it is between 0.6 and 0.7, it only has a moderate confidence it is more impactful and when it is between 0.5 and 0.6, it cannot be stated that this PI policy direction is more impactful. Only the relations with the above described confidence levels are described

The PI policy direction *Information systems and information exchange platforms* is the most impactful PI policy directions for the KPI Transport Chain Quality. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The PI policy direction *(PI) standardisation* only has marginal confidence (between 0.6 and 0.7), it is more impactful, in comparison to the PI policy direction *ICT hardware*. Also, the PI policy direction *Advanced Terminal Areas* only has a marginal confidence, it is more impactful in comparison to the PI policy direction *Transport Infrastructure*.

For the KPI Costs, the most impactful PI policy direction is the *Information systems and Information exchange platforms*. The confidence level of PI policy direction *Transport Infrastructure* being more impactful, in comparison to *ICT Hardware* is significantly low (below 0.6), it cannot be stated that PI policy direction *Transport Infrastructure* is more impactful.

For the KPI Digital Connectivity, the PI policy direction *Information systems and Information exchange platforms* is the most impactful PI policy direction. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The confidence of the PI policy direction *Sustainability Management* over the policy direction *Transport Infrastructure* is significantly low, it cannot be stated that *Transport Infrastructure* is less impactful.

For the KPI Physical Network Connectivity, the PI policy direction *Transport Infrastructure* is the most impactful. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The PI policy direction *(PI) Standardisation*, only has a moderate confidence (between 0.6 and 0.7), it is more impactful in comparison to the PI policy direction *Information systems and Information exchange platforms*.

In figure 5.1, the 'best-fit' focus distributions of the PI policy directions for the different KPIs in PI port scenario 'Big PI' are presented in a histogram.

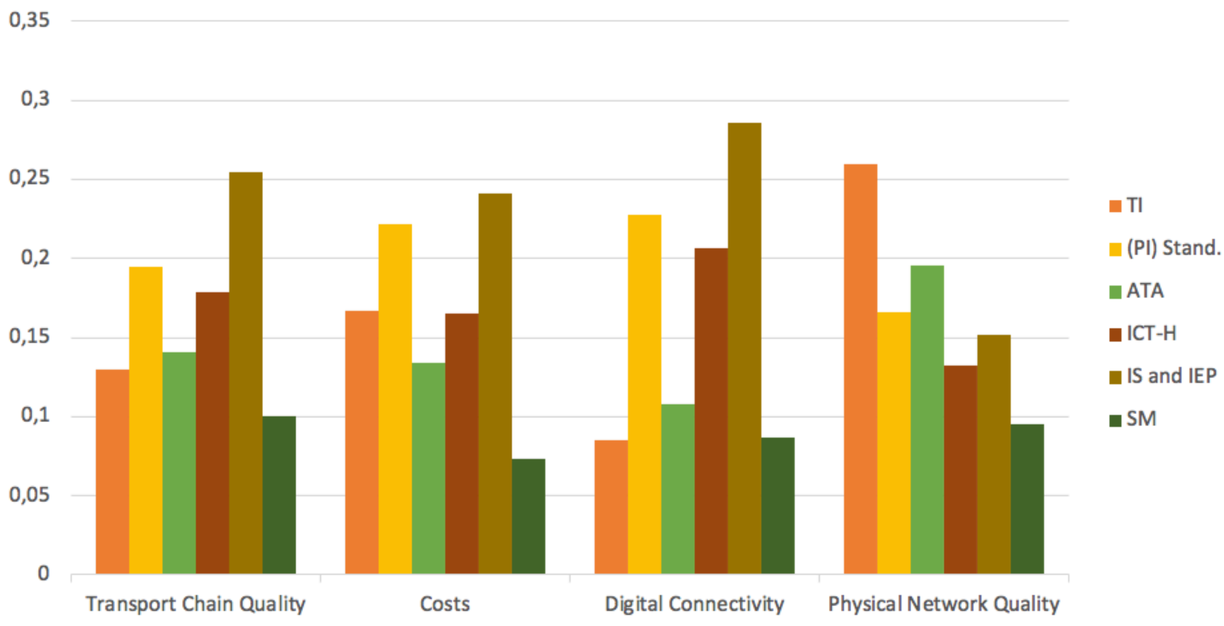

Figure 5.1: Histogram PI port scenario 'Big PI'

PI port scenario 2: 'Institutionally driven Advancement'
In table 5.2, the 'best-fit' focus distributions of the different PI policy directions for the different KPIs in the PI port scenario 'Institutionally driven advancement' are presented.

Table 5.2: 'best-fit' focus distributions policy directions on the different KPIs in PI port scenario 2: 'Institutionally driven advancement'

	Transport Chain Quality	Costs	Digital Connectivity	Physical Network Quality
Transport Infrastructure	0.126	0.179	0.080	0.214
(PI) Standardisation	0.214	0.175	0.226	0.190
Advanced Terminal Areas	0.169	0.165	0.099	0.175
ICT Hardware	0.179	0.158	0.232	0.141
Information systems and Information exchange platforms	0.219	0.242	0.285	0.210
Sustainability Management	0.094	0.082	0.078	0.072
Total	1	1	1	1

The PI policy direction *Information systems and information exchange platforms* is the most impactful PI policy direction on the KPI Transport Chain Quality. Nevertheless, the confidence level of *Information systems and information exchange platforms* being more impactful, in comparison to *(PI) Standardisation* is significantly low, it cannot be stated *Information systems and information exchange platforms* is more impactful. The PI policy direction *ICT Hardware* only has a moderate confidence level (between 0.6 and 0.7), it is more impactful in comparison to the PI policy direction *Advanced Terminal Areas*.

For the KPI Costs, the most impactful PI policy direction is the PI policy direction *Information systems and information exchange platforms*. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The confidence level of the PI policy direction *Transport Infrastructure* over *(PI) Standardisation* is significantly low it cannot be stated *Transport Infrastructure* is more impactful. Besides, both these PI policy directions only have a moderate confidence level of being more impactful, in comparison to the PI policy direction *Advanced Terminal Areas*. The confidence level of *Advanced Terminal Areas* over the PI policy direction *ICT Hardware* is significantly low it cannot be stated that *Advanced Terminal Areas* is more impactful.

For the KPI Digital Connectivity, the PI policy direction *Information systems and information exchange platforms* is the most impactful. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The confidence level of the PI policy direction *ICT Hardware* over the PI policy direction *(PI) Standardisation* is significantly low, it cannot be stated that *ICT Hardware* is more impactful. This also applies for the confidence level of policy direction *Transport Infrastructure* over the PI policy direction *Sustainability Management*.

For the KPI Physical Network Connectivity, the PI policy direction *Transport Infrastructure* is the most impactful PI policy direction. Nevertheless, the confidence level of *Transport Infrastructure* being more impactful in comparison to the *Information systems and information exchange platforms* is significantly low, it cannot be stated *Transport Infrastructure* is more impactful. The PI policy direction *(PI) Standardisation* only has a moderate confidence, it is more impactful in comparison to the fourth most impactful PI policy direction *Advanced Terminal Areas*.

In figure 5.2, the 'best-fit' focus distributions of the policy directions on the different KPIs in PI port scenario 'Institutionally driven advancement' are presented in a histogram.

PI port scenario 3: 'Technologically driven advancement'
In table 5.3 the 'best-fit' focus distributions of the different PI policy directions for the different KPIs in PI port scenario 'Technologically driven advancement' are presented.

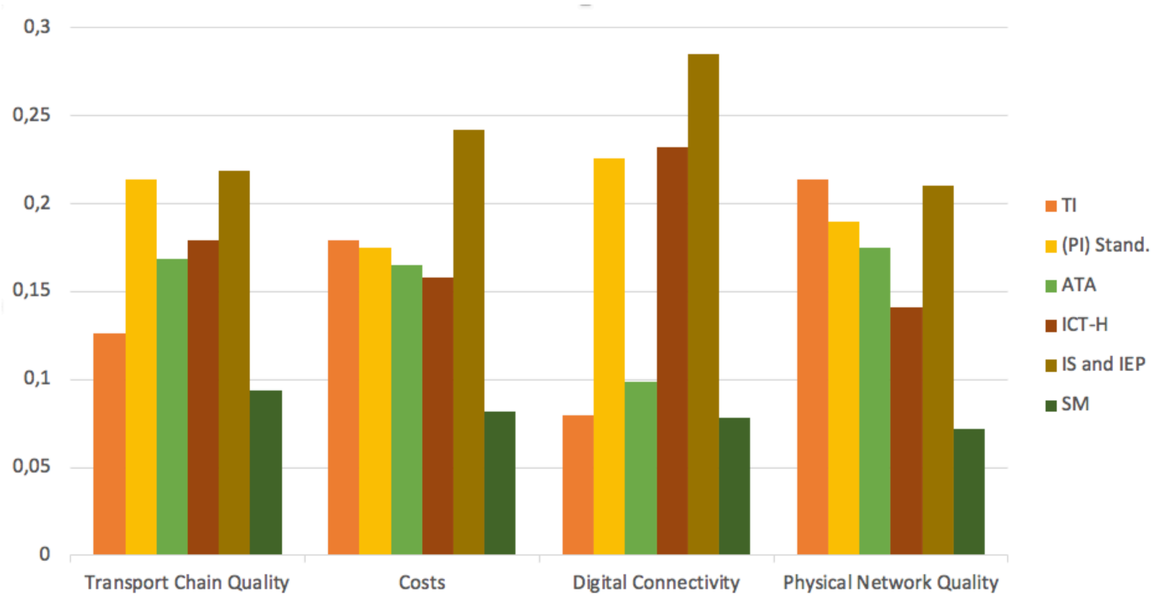

Figure 5.2: Histogram PI port scenario 'Institutionally driven advancement'

Table 5.3: 'best-fit' focus distributions policy directions on the different KPIs in PI port scenario 3: 'Technologically driven advancement'

	Transport Chain Quality	Costs	Digital Connectivity	Physical Network Quality
Transport Infrastructure	0.110	0.139	0.082	0.204
(PI) Standardisation	0.247	0.190	0.257	0.211
Advanced Terminal Areas	0.132	0.139	0.112	0.141
ICT Hardware	0.160	0.178	0.197	0.135
Information systems and Information exchange platforms	0.253	0.263	0.266	0.231
Sustainability Management	0.098	0.092	0.087	0.079
Total	**1**	**1**	**1**	**1**

The PI policy direction *Information systems and information exchange platforms* is the most impactful PI policy direction on the KPI Transport Chain Quality. Nevertheless, the confidence level of *Information systems and information exchange platforms* being more impactful, in comparison to the PI policy direction *(PI) Standardisation* is significantly low, it cannot be stated that *Information systems and information exchange platforms* is more impactful.

For the KPI Costs, the PI policy direction *Information systems and information exchange platforms* is the most impactful. This PI policy direction has a very high confidence, it is more impactful, in comparison to the other PI policy directions. The PI policy direction *(PI) Standardisation* only has a moderate confidence, it is more impactful in comparison to the PI policy direction *ICT Hardware*. The confidence level of the PI policy direction *Transport Infrastructure* over the PI policy direction *Advanced Terminal Areas* is significantly low, it cannot be stated that *Transport Infrastructure* is more impactful.

For the KPI Digital Connectivity, the PI policy direction *Information systems and information exchange platforms* is the most impactful. Nevertheless, the confidence level of *Information systems and information exchange platforms* being more impactful, in comparison to the PI policy direction *(PI) Standardisation* is significantly low, it cannot be stated that *Information systems and information exchange platforms* is more impactful.

For the KPI Physical Network Connectivity, the most impactful PI policy direction is the PI policy direction *Information systems and information exchange platforms*. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The confidence level of the PI policy direction *(PI) Standardisation* over the PI policy direction *Transport Infrastructure* is significantly low, it cannot be stated that *(PI) Standardisation* is more impactful.

In figure 5.3, the 'best-fit' focus distributions of the PI policy directions on the different KPIs in PI port scenario 'Technologically driven advancement' are presented in a histogram.

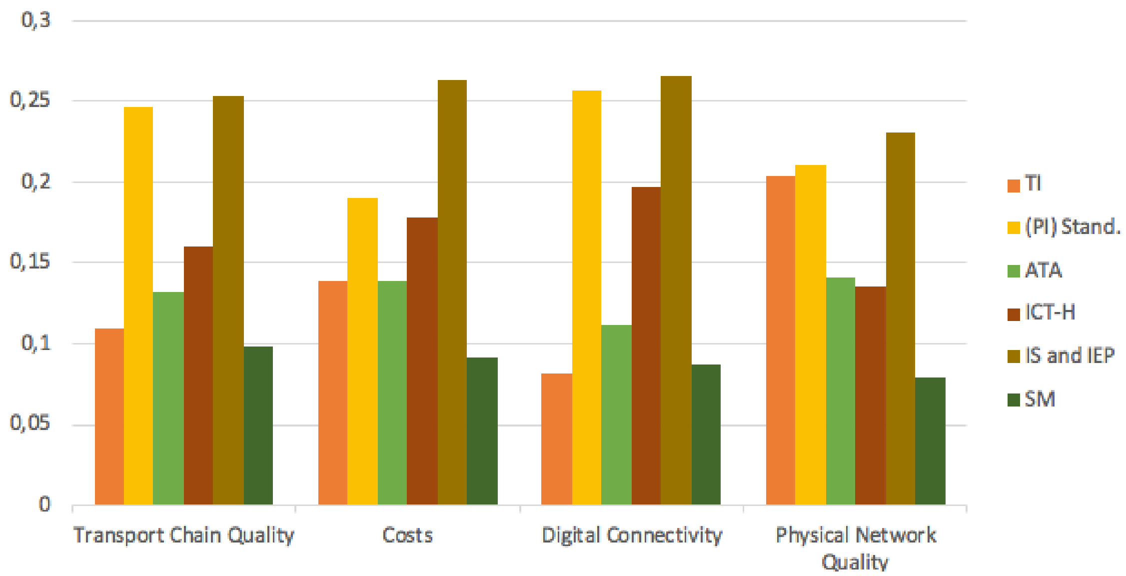

Figure 5.3: Histogram PI port scenario 'Technologically driven advancement'

PI port scenario 4: 'No PI'
In table 5.4, the 'best-fit' focus distributions of the different PI policy directions for the different KPIs in the PI port scenario 'No PI' are presented.

Table 5.4: 'best-fit' focus distributions policy directions on the different KPIs in PI port scenario 4: 'No PI'

	Transport Chain Quality	Costs	Digital Connectivity	Physical Network Quality
Transport Infrastructure	0.202	0.260	0.107	0.271
(PI) Standardisation	0.173	0.182	0.194	0.154
Advanced Terminal Areas	0.172	0.163	0.117	0.176
ICT Hardware	0.151	0.131	0.230	0.131
Information systems and Information exchange platforms	0.188	0.168	0.255	0.160
Sustainability Management	0.115	0.096	0.097	0.107
Total	**1**	**1**	**1**	**1**

The PI policy direction *Transport Infrastructure* is the most impactful PI policy direction for the KPI Transport Chain Quality. The confidence this PI policy direction is more impactful, in comparison to PI policy direction *Information System and Information exchange platforms* is only moderate (between 0.6 and 0.7). This, second most impactful PI policy direction, furthermore, only has moderate confidence, it is more impactful in comparison to the PI policy directions *(PI) Standardisation* and *Advanced Terminal Areas*. The confidence levels between these last two mentioned PI policy directions is significantly low (between 0.5 and 0.6), it cannot be stated that one PI policy direction is more impactful, in comparison to the other.

For the KPI Costs, the PI policy direction *Transport Infrastructure* is the most impactful PI policy direction. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The PI policy direction *(PI) standardisation* only has a moderate confidence (between 0.6 and 0.7), it is more impactful in comparison to the PI policy direction *Information systems and Information exchange platforms*. The confidence level of PI policy direction *Information systems and Information exchange platforms* being more impactful, in comparison to the PI policy direction *Advanced Terminal Areas* is significantly low (below 0.6), it cannot be stated *Information systems and Information exchange platforms* is more impactful.

For the KPI Digital Connectivity, the PI policy direction *Information systems and information exchange platforms* is the most impactful PI policy direction. The PI policy direction *Advanced Terminal Areas* only has a moderate confidence (between 0.6 ad 0.7), it is more impactful in comparison to the PI policy direction *Transport Infrastructure*. The same applies for the confidence level of the PI policy direction *Transport Infrastructure* being more impactful in comparison to the policy direction *Sustainability Management*.

For the KPI Physical Network Connectivity, the PI policy direction *Transport Infrastructure* is the most impactful PI policy direction. This PI policy direction has a very high confidence, it is more impactful in comparison to the other PI policy directions. The PI policy direction *Advanced Terminal Areas* only has a moderate confidence (between 0.6 and 0.7), it is more impactful in comparison to the PI policy direction *Information systems and Information exchange platforms*. Furthermore, the confidence level of PI policy direction *Information systems and Information exchange platforms* being more impactful in comparison the PI policy direction *(PI) Standardisation* is significantly low (below 0.6), it cannot be stated that *Information systems and Information exchange platforms* is more impactful.

In figure 5.4 the 'best-fit' focus distributions of the PI policy directions in PI port scenario 'No PI' for the different KPIs are presented in a histogram.

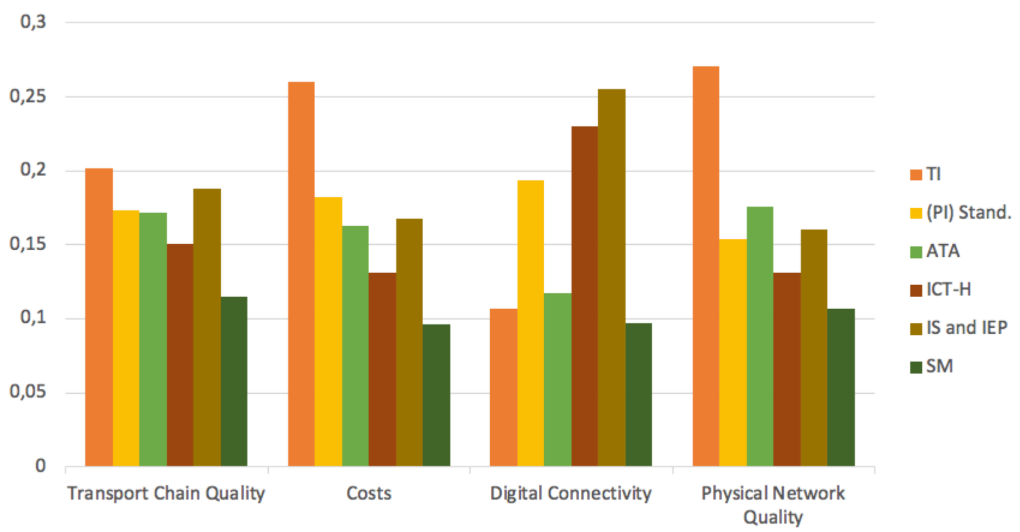

Figure 5.4: Histogram PI port scenario 'No PI'

Overall 'best-fit' focus distribution PI port scenarios
Based on the following assumptions the 'best-fit' focus distribution of the PI policy directions for the entire PI port scenarios are estimated:

- The (potential) improvement of a KPI is relatively the same to the (potential) improvement of the other KPIs across the different PI port scenarios.
- The weights of Fahim (2020) for the criteria classes are representative for the KPIs and consistent across the different PI port scenarios.

This provides the following results for the container perspective (see table 5.5) and the vessel perspective (see table 5.6).

Table 5.5: Estimated 'best-fit' focus distribution PI policy directions in the different PI port scenarios from the container perspective

	'Big PI'	'Institutionally driven advancement'	'Technologically driven advancement'	No PI'
Transport Infrastructure	0.165	0.156	0.137	0.222
(PI) Standardisation	0.202	0.197	0.221	0.175
Advanced Terminal Areas	0.146	0.159	0.133	0.162
ICT Hardware	0.168	0.171	0.165	0.151
Information systems and Information exchange platforms	0.234	0.234	0.253	0.185
Sustainability Management	0.088	0.083	0.090	0.104
Total	1	1	1	1

Table 5.6: Estimated 'best-fit' focus distribution PI policy directions in the different PI port scenarios from the vessel perspective

	'Big PI'	'Institutionally driven advancement'	'Technologically driven advancement'	No PI'
Transport Infrastructure	0.163	0.156	0.136	0.222
(PI) Standardisation	0.204	0.196	0.225	0.176
Advanced Terminal Areas	0.144	0.158	0.134	0.161
ICT Hardware	0.168	0.172	0.160	0.152
Information systems and Information exchange platforms	0.236	0.236	0.250	0.186
Sustainability Management	0.087	0.082	0.090	0.104
Total	1	1	1	1

As, the estimated 'best-fit' focus distributions of the PI policy directions (almost) not differ between the container perspective and the vessel perspective, the results are generally discussed below.

The PI policy direction *Information systems and Information exchange platforms* is very impactful across the different PI port scenarios, except in PI port scenario 'No PI'. This, also applies for the PI policy direction *(PI) Standardisation*, which is especially impactful in the PI port scenario 'Technologically driven advancement'. The impact of the PI policy direction *Transport Infrastructure* is low in all PI port scenarios, expect from the PI port scenario 'No PI'. The PI policy direction *Sustainability management* is across the different PI port scenarios the least impactful PI policy direction.

Sensitivity analysis

The sensitivity analysis is conducted by only including the first six respondents for the PI port scenarios 'Big PI' and 'No PI' and the first six respondents for the PI port scenarios 'Institutionally driven advancement' and 'Technologically driven advancement'. From this analysis can be concluded that the order of the different PI policy directions do in general not differ when only the first six respondents are considered. Nevertheless, still in fifteen of the sixteen (Bayesian) BWMs the order of two or three PI policy directions is different, as in these cases the confidence levels where moderate or lower.

Only, significant differences in order of PI policy directions are observed, due to the fact that the first six respondents for the PI port scenarios 'Big PI' and 'No PI' and the first six respondents for PI port scenarios 'Institutionally driven advancement' and 'Technological driven advancement' consider the

PI policy direction *(PI) standardisation* generally less impactful and the PI policy direction *Advanced Terminal Areas* generally more impactful. Other significant differences are observed, due to the first six respondents of the PI port scenarios ’Big PI’ and ’No PI’ consider the PI policy direction *Sustainability Management* more impactful in the PI port scenario ’No PI’, in comparison to all the respondents.

The figure 5.5 provides the percentage difference distribution of the impact weights of the different PI policy directions between all the respondents and the first six respondents.

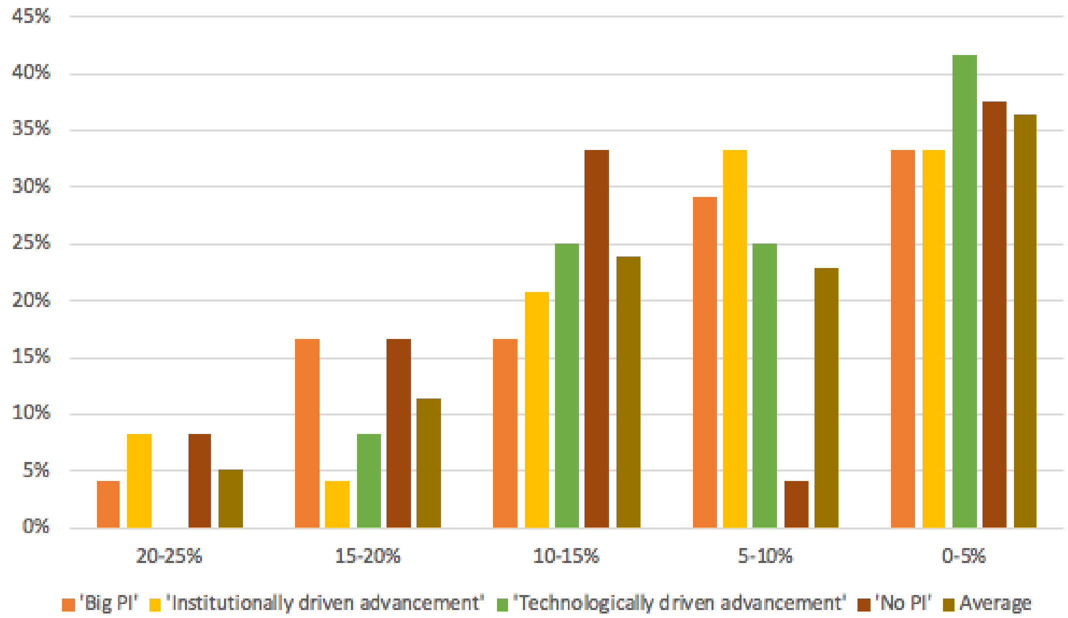

Figure 5.5: Percentage difference distribution between the (relative) impact weights of all respondents and the (relative) impact weights of the first six respondents

The differences between both the total group of respondents and the first six respondents are explainable, as with only six respondents the (Bayesian) BWM results are more sensitive for one or two outliers. Besides, the differences in weights do not lead to different patterns in and between the ’best-fit’ focus distributions outlined in chapter 6. For this reason, the performed sensitivity analysis supports the results of the thesis. It is already assumed that the exact focus distributions of the different PI policy directions cannot be determined with this application of the Bayesian BWM.

6

Future policy making Port Authority

In this chapter, recommendations are provided to the PA to make the maritime port attractive in the uncertain future of PI. The chapter is structured as follows:

- In section 6.1, different opportunities and vulnerabilities for the Port Authority (hereafter: PA) to improve the attractiveness of the maritime port are discussed.
- In section 6.2, the path-dependency and sell-by dates of the different PI policy directions are treated.
- In section 6.3, general recommendations regarding future (adaptive) policy making for the PA are provided.

6.1. Opportunities & vulnerabilities

In this section, opportunities and vulnerabilities to improve a particular KPI are discussed. Also, opportunities and vulnerabilities, which can be drawn from the (overall) 'best-fit' focus distribution of the PI policy directions of the different PI port scenario are presented.

6.1.1. Transport Chain Quality

To improve the KPI Transport Chain Quality, the *Information systems and Information exchange platforms* is impactful[1] (see figure 6.1). Nevertheless, this PI policy direction is less impactful, in the PI port scenarios with slow technological development and is especially low in the PI port scenario 'No PI'.

The PI policy direction *(PI) standardisation* is impactful in all PI port scenarios and especially in the PI port scenarios 'Technologically driven advancement'. In this PI port scenario, the respondents consider an important role for the PA to stimulate the development and usage of (PI) standards, as development of (PI) standards and stakeholders willingness to collaborate lack behind and the effective use of the PI policy direction *Information systems and Information exchange platforms* and the *Advanced Terminal Areas*, made possible by the fast technological development in this PI port scenario, depends on it.

The PI policy direction *Transport Infrastructure* generally has a low impact on the Transport Chain Quality. In the PI port scenario 'No PI', this PI policy direction is relatively impactful, as other PI policy directions, like the *Information systems and Information exchange platforms* and *(PI) Standardisation* become less effective.

In table 6.1, an overview of the 'best-fit' focus distributions of the different PI policy directions on the KPI Transport Chain Quality is provided.

[1]Note: when referred to impact, it is really about the relative impact of the PI policy direction in comparison to the other PI policy directions.

Table 6.1: 'best-fit' focus distribution PI policy directions on KPI Transport Chain Quality in the different PI port scenarios

	'Big PI'	'Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.130	0.126	0.110	0.202
(PI) Standardisation	0.195	0.214	0.247	0.173
Advanced Terminal Areas	0.141	0.169	0.132	0.172
ICT Hardware	0.179	0.179	0.160	0.151
Information systems and Information exchange platforms	0.255	0.219	0.253	0.188
Sustainability Management	0.100	0.094	0.098	0.115
Total	1	1	1	1

6.1.2. Costs

To reduce the costs for the port user, the PI policy direction *Information systems and Information systems* is in general impactful, except for the PI port scenario 'No PI'. This is also observable for the PI policy direction *ICT Hardware*, however this PI policy direction generally has a lower impact. This is comparable to the results of the KPI Transport Chain Quality. Furthermore, like for the Transport Chain Quality, the PI policy direction *Transport Infrastructure* has a relatively high impact in the PI port scenario 'No PI', in comparison to the other PI port scenarios. The difference, however is that, the impact of the *Transport Infrastructure* on the KPI Costs across the different PI port scenarios is higher.

The higher impact of the PI policy direction *(PI) Standardisation* in the PI port scenario 'Technologically driven advancement' is less observed for the KPI Costs. From this, it can be concluded that the respondents consider this effect being less important for reducing the costs of the port user.

In table 6.2, an overview of the 'best-fit' focus distribution of the different PI policy directions on the KPI Costs is provided.

Table 6.2: 'best-fit' focus distribution PI policy directions on KPI Costs in the different PI port scenarios

	'Big PI'	'Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.167	0.179	0.139	0.260
(PI) Standardisation	0.222	0.175	0.190	0.182
Advanced Terminal Areas	0.134	0.165	0.139	0.163
ICT Hardware	0.165	0.158	0.178	0.131
Information systems and Information exchange platforms	0.241	0.242	0.263	0.168
Sustainability Management	0.073	0.082	0.092	0.096
Total	1	1	1	1

6.1.3. Digital Connectivity

For the KPI Digital Connectivity, the PI policy direction *Information systems and information exchange platforms* is across the different PI port scenarios the most impactful PI policy direction. The PI policy direction *(PI) Standardisation* and *ICT Hardware* are also impactful. In which, the PI policy direction *ICT Hardware* is significantly less impactful in PI port scenarios, where the technologically development is fast. This is especially observed in the PI port scenario 'Technologically driven advancement'. The PI policy direction *Transport Infrastructure* and to a somewhat lesser degree the PI policy direction *Advanced Terminal Areas* are seen as low impactful for the KPI Digital Connectivity.

In table 6.3, an overview of the 'best-fit' focus distributions of the different PI policy directions on the KPI Digital Connectivity is provided.

Table 6.3: 'best-fit' focus distributions PI policy directions on KPI Digital Connectivity in the different PI port scenarios

	Big PI'	Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.085	0.080	0.082	0.107
(PI) Standardisation	0.228	0.226	0.257	0.194
Advanced Terminal Areas	0.108	0.099	0.112	0.117
ICT Hardware	0.207	0.232	0.197	0.230
Information systems and Information exchange platforms	0.286	0.285	0.266	0.255
Sustainability Management	0.087	0.078	0.087	0.097
Total	1	1	1	1

6.1.4. Physical Network Connectivity

To improve the KPI Physical Network Connectivity of the port, the PI policy direction *Transport Infrastructure* is impactful across the different PI port scenarios. The PI policy direction *Advanced Terminal Areas* is particularly impactful in the PI port scenarios with progressive institutional development, as for this PI policy direction it is important that stakeholders are willing to share data and goods, there are limited legal restrictions to share data and goods and far developed (PI) standards. This PI policy directions, also scores relatively high in the PI port scenario 'No PI'.

The PI policy direction *Information systems and Information exchange platforms* is impactful in both the 'Technologically driven advancement' and the 'Institutionally driven advancement'. For the PI port scenario 'Technologically driven advancement', it can be argued that the technological opportunities are available to implement this PI policy direction and because the institutional development is restrictive, the PA could play a more important role in providing services outside the port to stimulate more efficient hinterland/maritime operations, compensation the lack of information systems and information exchange platforms provided by other stakeholders. For the PI port scenario 'Institutionally driven advancement', it can be argued that the different stakeholders are willing to use information systems and information exchange platforms, however the availability of these systems are limited due to lack of technological development. In this, the PA could provide services possible with the current available information systems and improve the agility to respond to changes/disruptions in the hinterland operations and/or maritime operations. This would, also be an explanation why this PI policy direction is particularly less impactful in the PI port scenario 'Big PI'. In this PI port scenario, the PA has less a role in providing these services, as these systems are also developed by other stakeholders.

The impact of the PI policy direction *(PI) Standardisation* for the KPI Phyiscal Network Connectivity across the PI port scenario are in line with the KPI Transport Chain quality, however somewhat less impactful. A possible explanation for this could be that the standards required for the physical connectivity are considered less in the sphere of influence of the PA.

In table 6.4, an overview of the 'best-fit' focus distribution of the different PI policy directions on the KPI Physical Network Connectivity is provided.

Table 6.4: 'best-fit' focus distributions PI policy directions on KPI Port Network Connectivity in the different PI port scenarios

	'Big PI'	'Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.260	0.214	0.204	0.271
(PI) Standardisation	0.166	0.190	0.211	0.154
Advanced Terminal Areas	0.196	0.175	0.141	0.176
ICT Hardware	0.132	0.141	0.135	0.131
Information systems and Information exchange platforms	0.152	0.210	0.231	0.160
Sustainability Management	0.095	0.072	0.079	0.107
Total	1	1	1	1

6.1.5. Overall 'best-fit' focus distributions

From the estimated overall 'best-fit' focus distributions of the PI policy direction on the different KPIs for the PI port scenarios, presented in section 5.3, can be concluded that the PI policy directions *Information systems and Information exchange platforms* is impactful across the different PI port scenarios. However, this PI policy direction is significantly less impactful in PI port scenario 'No PI', as both the restrictive institutional development and slow technological development limits the effectiveness and the applicability of this PI policy direction. This same effect is observed for the PI policy direction *(PI) Standardisation*, which is especially impactful in the PI port scenario 'Technologically driven advancement'. This is the other way around for the PI policy direction *Transport Infrastructure*, which is especially impactful in the PI port scenario 'No PI.

The PI policy direction *Sustainability Management* is the least impactful PI policy direction across the different PI port scenarios. This, however, does not say anything about the importance of performing the port operations in a sustainable way, as more efficient port operations accomplished by e.g. improving the KPI Transport Chain Quality by the policy directions *Information systems and Information exchange platforms* and *Advanced Terminal Areas* also leads to more sustainability.

6.2. Path-dependency & sell-by dates

In this section, indications of sell-by dates and path-dependencies of the different PI policy directions relevant for policy making by the PA are, subsequently discussed.

6.2.1. Transport Infrastructure

The PI policy direction *Transport Infrastructure* is not path-dependent on other PI policy directions. Furthermore, it can be argued that the sell-by dates of the policy measures clustered in this PI policy direction are not dependent on which PI port scenario will unfolds in the future.

6.2.2. (PI) Standardisation

The PI policy direction *(PI) standardisation* is not path-dependent on other PI policy directions. The sell-by dates of the *(PI) standardisation* differ between the scenarios with progressive institutional development and restrictive institutional development. In a PI port scenario with progressive institutional development, the development of (PI) standards is fast and, therefore the PA could in an earlier stage focus on enforcing/stimulating the use of particular standards. Still, regardless of the PI port scenario, the PA could start best use cases and pilots to show what (PI) standardisation could bring to the port community.

6.2.3. Advanced Terminal Areas

This PI policy direction is path-dependent on the PI policy directions *(PI) standardisation* and *Information systems and information exchange platforms*. The *Advanced Terminal Areas* could work without (physical) standards. Nevertheless, it would work less efficient. Also, certain standards for digitalisation and customs should be set, before reshuffling of goods between different stakeholders could take place in an efficient way. And, information exchange platforms should be in place, before reshuffling activities could take place. The sell-by dates of the policy measures clustered in this PI policy direction strongly depends on the institutional development. When the institutional development is progressive, the *Advanced Terminal Areas* become useful in an earlier stage, as different logistics stakeholders are willing to share data and share assets. Still, regardless of the PI port scenario, the PA could directly start pilots and best use case to show what sharing of physical assets could bring to the port community.

6.2.4. ICT Hardware

This PI policy direction is path-dependent on the PI policy direction *Information systems and information exchange platforms*. The sensors and wireless communication technology required in the port depends on the level and which type of information systems and/or information exchange platforms will be developed. The sell-by dates of this PI policy direction depend on the technological development. In a PI port scenario with fast technological development in an earlier stage certain sensors (e.g. RFID tags) and wireless communication technologies (e.g. 5G) can be installed in the port.

6.2.5. Information systems and information exchange platforms

This PI policy direction is path-dependent on the PI policy directions *ICT Hardware* and *(PI) standardisation*. The right data should be available, before the information systems and information exchange platforms can become useful. Standardisation is required to effectively share information between stakeholders in the maritime port. The sell-by dates of the policy measures clustered in this PI policy direction differ due to the institutional development and the technological development. When the technological development in e.g. IoT, Big Data and Blockchain is fast, (effective) information systems and information exchange platforms can in earlier stage be developed. And, when the institutional development is progressive, stakeholders are willing to use these information systems and information exchange platforms. This implies that these systems become more effective in an earlier stage. Still, regardless of the scenario the PA could start with pilots and best use cases to show what data and data sharing could bring to the port community.

6.2.6. Sustainability Management

This PI policy direction is path-dependent on the PI policy direction *(PI) standardisation* and to a lower degree *ICT Hardware*. Before, the monitoring and controlling systems for safety, air and water quality and, nuisance become effective digital and administrative standard should be set. For the monitoring and controlling systems to receive adequate data there should be ICT hardware installed in the port. The sell-by dates for this PI policy direction change with the institutional development. When the institutional development is progressive, there are a lot of incentives to implement *Sustainability Management* and other stakeholders are willing to cooperate in implementing sustainability policy. To a lower degree the monitoring and controlling systems depend on technological developments. The development of IoT, Big Data and Blockchain should be at a certain level, before the monitoring and controlling systems become effective. Nevertheless, it can be argued that this is currently already the case.

6.3. Recommendations future (adaptive) policy making PA

This section provides recommendations to the PA to make the maritime port attractive in the uncertain future of PI, based on the previous sections:

Main focus points for the PA

The PA should mainly focus on the PI policy direction *Information systems and Information exchange platforms*, especially to improve the KPI Digital Connectivity. Nevertheless, in the PI port scenario 'No PI', it is advised, the PA should focus less on this PI policy direction, as it is less effective. This also applies for the *(PI) Standardisation*, which, however should generally be less focused in the different PI port scenarios. Still, it is advised to the PA to play an active role in developing (PI) standards in an early stage and dependent on the PI port scenario enforce/stimulate the usage of certain (PI) standards by the port community in a later stage. It is especially advised to focus on this PI policy direction in the PI port scenario 'Technologically driven advancement', as the PA in this case could have an extra important role in developing and stimulating/enforcing standards, as other stakeholders are less willing to do so and the effective use of e.g. the *Information systems and Information exchange platforms*, technologically far developed in that particular PI port scenario, depends on it.

The PA should in the different PI port scenarios apply the PI policy direction *Transport Infrastructure*, especially to improve the KPI Physical Network Connectivity. In the PI port scenario 'No PI', the PA should focus a lot on this PI policy direction, as other PI policy directions become less effective.

Different policy focus of the PA outside the port territory
To improve the KPI Physical Network Connectivity, the PA should to a lesser degree focus on the PI policy directions *Information systems and Information exchange platforms* and *(PI) Standardisation*. These PI policy directions are considered to be less impactful on maritime operations and hinterland operations, as these operations are outside the port territory and less in the influence sphere of the PA. The PI policy direction *Information systems and Information exchange platforms* is, still impactful on the KPI Physical Network Connectivity in the 'Institutionally driven advancement' and 'Technologically driven advancement'. In the PI port scenario 'Technologically driven advancement', it is advised to stimulate efficient maritime operations and hinterland operations by providing more information system services and information exchange platform services outside the scope of the port, compensating the lack of interest of other stakeholders providing (or using) these services. In the PI port scenario 'Institutionally driven advancement', it is advised to provide, as much services by information systems and information exchange platforms as possible, to improve the hinterland operations and the maritime operations, as other systems providing these services lack behind due to slow technological development.

General recommendations for the PA
The PA could regardless of which scenario unfolds itself start pilots and best use cases to show what standardisation and sharing of assets, both physically and digitally (data) could bring to the port community. In general, for future (adaptive) policy making, it is always important to consider a broad perspective: what is the added value of the maritime port to the (global) logistics system and what could the PA influence with its policy, rather than the competitive approach: how can I attract the most companies to the port. This broader perspective will, regardless of which PI port scenario unfold itself make the maritime port attractive and make the implemented (PI) policy effective.

Other recommendations for the PA
It is advised to the PA to consider *Advanced Terminal Areas*, especially as the institutional development is progressive. Otherwise, logistics stakeholders will only make limited use or will not use these facilities. This PI policy direction is particularly effective in improving the KPI Physical Network Quality. Nevertheless, the focus of the PA should be less on this PI policy direction, as it is considered not entirely up to the PA to develop the terminal areas. This strongly depends on the terminal operators.

The PA should advance the installation of *ICT Hardware*, as the effective usage of the *Information systems and Information exchange platforms* depends on it. This PI policy direction is especially effective to improve the KPI Digital Connectivity and should be less focused on to improve the KPI Physical Network Connectivity.

On the PI policy direction *Sustainability Management* the PA should focus the least. A possible explanation for this is that this PI policy direction is considered a bit outside of the scope of PI. It does not mean the policy suggested is not sustainable. Other PI policy directions improve the sustainability by better asset utilization, including the PI policy directions *Information systems and Information exchange platforms* and *Advanced Terminal Areas*.

7 Conclusion

In this chapter, the conclusions from the performed research in the thesis are discussed.

The chapter is structured as follows:

- In section 7.1, the research questions are answered.
- In section 7.2, the scientific contributions of the thesis are described.

7.1. Answering the research question(s)

Based on the research gap identified, the following research objective is formulated:

Supporting the maritime port in designing policy to be attractive in the future, given the uncertain development of Physical Internet.

To accomplish this objective the Main Research Question (hereafter: MRQ) is formulated as:

How could a maritime port be attractive in the future, given the uncertain development of Physical Internet?

To completely answer the MRQ, this question is divided into six Research Sub Questions (hereafter: RSQ). In the following subsection 7.1.1, these RSQs are, subsequently answered for the PA of the PoR and recommendations for this PA are provided. This fulfils the social objective of the thesis. Afterwards, in subsection 7.1.2, general recommendations for other PAs are discussed.

7.1.1. The Port Authority of the Port of Rotterdam

In this section, the six RSQs are answered for the PA of the PoR and based on these answers the answer to the MRQ is provided.

1. What are the external factors influencing the attractiveness of the maritime port in the uncertain future?
With a thorough literature review, the applications of the theoretical frameworks *Political- economy model of transport innovations* and *Dynamic multi-level perspective on technological transitions* and a stakeholder analysis, 39 different external factors are identified. These 39 external factors are clustered into the following eight external factor classes:

A Economic growth: Includes the growth of the (world) GDP.

B Demographic changes: Are the changes in size, growth and structure of the population.

C Flow patterns: Are logistics developments, which influences the trade flows through the maritime port, by affecting where goods are handled, stored and could be transported from and to.

D Global institutional integration: Refers to the 'rules of the game' for global trade, set by formal institutions.

E Regulatory frameworks: Refers to regulation, set by formal institutions, which influences the breakthrough or development of (technological) innovations.

F Technological innovations: Are other technological innovations than PI that affect the attractiveness of the maritime port.

G Logistics market structure: Refers to tangible social structures between companies in logistics which have evolved specific role behaviour towards one another.

H Sustainability: Refers to a plan or a set of ideas of what to do about environmental, economic and social unsustainable effects of the port operations and the port related activities.

2. What are the PI port scenarios?
To develop four realistic, consistent, easy to understand and comprehensive external scenarios are the external factor classes aggregated into two driving forces. The external factor classes A, B, C and D are excluded, as these classes are rather about the uncertainty on the demand side, than about the uncertain development of PI. The four remaining external factor classes are clustered into the following two driving forces:

- **Technological development:** includes the external factor class F: *Technological innovations* and represents the development of the innovations, like IoT, Big Data and Blockchain.
- **Institutional development:** includes the external factor classes E: *Regulatory frameworks*, external factor class G: *Logistics market structure* and external factor class H: *Sustainability* and represents the restrictions and/or support from institutions for implementing PI policy by the PA.

Based on the two driving forces the following four PI port scenarios are developed:

1. **'Big Physical Internet':** Incorporates the scenario, in which the *institutional development* is progressive and the *technological development* is fast.
2. **'Institutionally driven Advancement':** Incorporates the scenario, in which the *institutional development* is progressive and the *technological development* is slow.
3. **'Technologically driven advancement':** Incorporates the scenario, in which the *institutional development* is restrictive and the *technological development* is fast.
4. **'No Physical Internet':** Incorporates the scenario, in which the *institutional development* is restrictive and the *technological development* is slow.

3. What are the Key Performance Indicators for the attractiveness of the maritime port?
As, it is considered that containers and vessels are the most important entities in the future of PI, the port choice criteria classes of these entities, determined by Fahim (2020) are used to develop the following four Key Performance Indicators (hereafter: KPI) for the attractiveness of the maritime port:

A Transport Chain Quality (TCQ): Refers to the effectiveness of the port operations, including the speed, reliability and quality of operations, and the agility to respond to changes/disruptions in the port operations.

B Costs: Refers to the costs for the port users.

C Digital Connectivity (DC): Refers to the digital connectivity in the port and the seamless digital integration of the port in the supply chains.

D Physical Network Connectivity (PNQ): Refers to the physical connectivity of the port, the reliability of the maritime operations and the hinterland operations, and the agility to respond to changes/disruptions in the maritime operations and the hinterland operations.

4. Which PI policy directions can improve the attractiveness of the maritime port?
With an in-depth literature review and 14 conducted expert interviews the following six different PI policy directions are developed:

1. **Transport Infrastructure (TI)**
2. **(PI) standardisation ((PI) Stand.)**
3. **Advanced Terminal Areas (ATA)**
4. **ICT Hardware (ICT-H)**
5. **Information systems and information exchange platforms (IS and IEP)**
6. **Sustainability Management (SM)**

5. Which focus distribution of PI policy directions is the best-fit to improve the attractiveness of the maritime port in the different PI port scenarios?
With the use of the Bayesian BWM, the 'best-fit' focus distributions of the different PI policy directions on the defined KPIs in the different PI port scenarios are assessed. In table 7.1, an overview of the results is presented.

Table 7.1: 'best-fit' focus distributions policy directions on KPIs in the different PI port scenarios

	'Big PI'				'Institutionally driven advancement'				'Technologically driven advancement'				'No PI'			
	TCQ	Costs	DC	PNC	TCQ	Costs	DC	PNC	TCQ	Costs	DC	PNC	TCQ	Costs	DC	PNC
TI	0.130	0.167	0.085	0.260	0.126	0.179	0.080	0.214	0.110	0.139	0.082	0.204	0.202	0.260	0.107	0.271
(PI) Stand.	0.195	0.222	0.228	0.166	0.214	0.175	0.226	0.190	0.247	0.190	0.257	0.211	0.173	0.182	0.194	0.154
ATA	0.141	0.134	0.108	0.196	0.169	0.165	0.099	0.175	0.132	0.139	0.112	0.141	0.172	0.163	0.117	0.176
ICT-H	0.179	0.165	0.207	0.132	0.179	0.158	0.232	0.141	0.16	0.178	0.197	0.135	0.151	0.131	0.230	0.131
IS and IEP	0.255	0.241	0.286	0.152	0.219	0.242	0.285	0.210	0.253	0.263	0.266	0.231	0.188	0.168	0.255	0.160
SM	0.100	0.073	0.087	0.095	0.094	0.082	0.078	0.072	0.098	0.092	0.087	0.079	0.115	0.096	0.097	0.107
Total	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Based on the following two assumptions the overall 'best-fit' focus distributions of the different PI policy directions for the different PI port scenarios is estimated for the Container Perspective (CP) and Vessel Perspective (VP) (see table 7.2):

- The (potential) improvement of a KPI is relatively the same to the (potential) improvement of the other KPIs across the different PI port scenarios.
- The weights of Fahim (2020) for the criteria classes are representative for the KPIs and consistent across the different PI port scenarios.

Table 7.2: Estimated Overall 'best-fit' focus distribution PI policy directions in the different PI port scenarios

	'Big PI		'Institutionally driven advancement		'Technologically driven advancement'		'No PI'	
	CP	VP	CP	VP	CP	VP	CP	VP
TI	0.165	0.163	0.156	0.156	0.137	0.136	0.222	0.222
(PI) Stand.	0.202	0.204	0.197	0.196	0.221	0.225	0.175	0.176
ATA	0.146	0.144	0.159	0.158	0.133	0.134	0.162	0.161
ICT-H	0.168	0.168	0.171	0.172	0.165	0.160	0.151	0.152
IS and IEP	0.234	0.236	0.234	0.236	0.253	0.250	0.185	0.186
SM	0.088	0.087	0.083	0.082	0.090	0.090	0.104	0.104
Total	1	1	1	1	1	1	1	1

6. What can be recommended to the maritime port to further develop (adaptive) policy in the uncertain future of Physical Internet?
With the patterns in and between the 'best-fit' focus distributions of the PI policy directions for the different KPIs in the different PI port scenarios, and the researched sell-by dates and path-dependencies of the different PI policy directions the following recommendations are provided to the PA of the PoR:

- **Main focus points for the PA:** The PI policy directions *Information systems and information exchange platforms* and *(PI) standardisation* are the most important PI policy directions to focus on, except in PI port scenario 'No PI'. In this PI port scenario, the PA should put more emphasizes on the PI policy direction *Transport infrastructure*. Also, the PA should put more focus on this PI policy direction to improve the KPI Physical Network Connectivity.
- **Different policy focus outside the port territory:** To improve the KPI Physical Network Connectivity, the PA should to a lesser degree focus on the PI policy directions *Information systems and Information exchange platforms* and *(PI) Standardisation*. These PI policy directions are considered to be less impactful on maritime operations and hinterland operations, as these operations are outside the port territory and is less in the influence sphere of the PA.
- **General recommendations:** It is recommended to the PA to regardless of which PI port scenario will unfold itself start pilots and best use cases to show what sharing of assets could bring to the port community. Also, the PA should consider a broad perspective in further developing (PI) policy: what is the added value of the maritime port to the global logistics system and what could the PA influence with its policy.
- **Other recommendations:** The PA should less focus on the PI policy direction *Advanced Terminal Areas*, as it is considered not entirely up to the PA to develop the terminal areas. This strongly depends on the terminal operators. The PA should advance the installation of *ICT Hardware*, as the effective usage of the *Information systems and Information exchange platforms* depends on it and the PA should focus the least on the PI policy direction *Sustainability Management*.

Main Research Question: How could a maritime port be attractive in the future, given the uncertain development of Physical Internet?
The MRQ is answered by, subsequently performing the RSQs. This provides the following answer: Dependent on how PI will develop, different policy focus for the PA of the PoR is recommended. However, in general the PA should focus on developing and providing information systems and information platforms, and the PA should focus on developing and stimulating the usage of (PI) standards.

7.1.2. Recommendations for other PAs and maritime ports

As, the PI port scenarios and the PI policy directions are generally defined for PAs of a landlord port, the recommendations provided to the PA of the PoR can also be provided to other PAs of landlord port. Particularly for PAs of landlord port in the North-Europe, as the respondents of the (Bayesian) BWM all came from this geographical area. For PAs of other types of maritime port the recommendations are less applicable, as they have different roles and therefore other relevant PI policy directions.

7.2. Scientific contribution

The overall scientific objective of improving the knowledge regarding the implications of PI on the future development of maritime ports is filled by providing the following scientific contributions (see section 1.6):

Scientific contribution 1: Recommendations to the PAs to make the maritime port attractive in the uncertain future of PI
Based on patterns in and between 'best-fit' focus distributions of PI policy directions for different KPIs of the attractiveness of the maritime port in different PI port scenarios, sell-by dates and path-dependencies of PI port directions, for the first time recommendations are provided to the PAs about making the maritime port attractive in the uncertain future of PI.

Scientific contribution 2: First set of theoretical backed PI policy directions
Until now, only Voster (2019) identified some policy measures the PA could apply in the context of PI. Nevertheless, these policy measures lack theoretical background and did not directly have to objective to improve the attractiveness of the maritime port. In this thesis, with the use of in-depth literature review and 14 expert interviews, theoretical backed PI policy directions are formulated, which improve the attractiveness of the maritime port in context of PI.

Scientific contribution 3: A new case of the (Bayesian) BWM, specifically to determine 'best-fit' focus distribution for policy, in different (future) context
Currently, the Bayesian BWM is not widely applied. Only, Fahim (2020) applied this methodology in context of maritime ports and PI. This thesis adds a new case in this context. However, more importantly, to the best of the writer's knowledge, it is the first (Bayesian) BWM application, which is used to provide recommendations for policy making, based on patterns in and between 'best-fit' focus distributions of policies, being in this thesis PI policy directions, in/for different (future) contexts, being in this thesis different KPIs and different PI port scenarios. From this research can be concluded that the (Bayesian) BWM is a useful methodology to find these patterns and provide recommendations based on these patterns. Thereby, it is important to note that, the (Bayesian) BWM uses experts perspectives and it is for this reason, especially recommended to use this methodology in highly hypothetical (future) contexts, when other methodologies are less applicable due to lack of (quantitative) information.

Scientific contribution 4: Applications of theoretical frameworks
Unless, the limited scope of the applications of the theoretical frameworks *Political- and economy model* of Feitelson and Salomon (2004) and the *Dynamic multi-level perspective for technological transition* of Geels (2004) on providing insights in external factors for the PA to make the maritime port attractive, some general conclusions from these applications for future opportunities and bottleneck for the adoption of PI (in the maritime ports) can be distinguished.

8 Thesis reflection & Recommendations

In this final chapter, the thesis is reflected on and recommendations for future research are provided.

The chapter is structured as follows:

- In section 8.1, the thesis approach is reflected on.
- In section 8.2, the result of the thesis are reflected on.
- In section 8.3, recommendations for future research are formulated.

8.1. Reflection on the methodologies

In chapter 3, the different methodologies, which combined formed the thesis approach used to answer the Main Research Question (hereafter: MRQ) and the Research Sub Questions (hereafter: RSQ) are treated. In this section, the usage of each of these methodologies are reflected on.

8.1.1. Basis overall thesis approach

To develop the overall thesis approach and provide a structured way to answer the MRQ and the RSQs, insights from the adaptive policy making approach Dynamic Adaptive Policy Pathway (hereafter: DAPP) approach are used. This method provides a logical step wise approach. The final five steps are not considered as these steps are about implementing a policy plan.

8.1.2. Literature review

This methodology is used throughout the entire thesis. Literature review is applied to provide the research foundations in chapter 2. Literature review is applied to provide the theoretical background for the applications of the theoretical frameworks and the stakeholder analysis, which are used to determine and define the external factors in chapter 4. Literature review is used to determine policy measures for the PA to improve the attractiveness of the maritime port and define the PI policy directions in chapter 5. All these applications are, subsequently reviewed.

Research foundations

In chapter 2, literature review is conducted to the two main concepts of this thesis: PI and maritime ports. The literature review to both the concepts is discussed below.

As, PI is still in the infancy stage, a lot of important elements have to be further researched and consensus regarding the main characteristics of PI is lacking. Nevertheless, in this thesis the defined PI characteristics of Martinez de Ubago (2019) and Voster (2019) are used in the interviews, as these are easy to understand. It should be mentioned that these characteristics, as Martinez de Ubago (2019) reflects in his thesis are more based on logic reasoning, than on theoretical background. In total 25 publications are used to describe the concept of PI in chapter 2 (see appendix B).

The literature review performed to the maritime port only grasped the surface of all the literature available about maritime ports. However, due to the focus of the thesis only certain literature is selected. In the rest of the thesis a more in-depth literature review is conducted to determine and define the different external factors and the PI policy directions. In total 36 publications are used to describe the concept maritime port (see appendix B).

In general, a more thorough and systematic literature review to both these concepts could have provided a more clear description of the concepts and their relations. However, the conducted literature review in this thesis is considered to be sufficient for the research foundation.

External factors
Both, literature review and desk research are used to support the applications of the theoretical frameworks and stakeholder analysis in determining and defining the external factors. The majority is literature, complemented with some desk research, as this kind of research is related to the real world. In total 44 scientific publications are used to substantiate the external factors (see appendix 4.1).

The theoretical background of the external factors is considered to be sufficient. However, a more thorough literature review could have provided a more robust substantiation for both the applications of the theoretical frameworks and the stakeholder analysis.

PI policy directions
Both, literature review and desk research are applied to determine policy measures the PA could apply to make the maritime port attractive and define the PI policy directions. In total 42 scientific publications are used (see appendix E). A more systematic and in-dept literature review could have provided more insight. However, the conducted literature review is considered to be sufficient, as also knowledge from the experts interviews is used to determine and define the PI policy directions.

8.1.3. Theoretical frameworks
This methodology is only partially applied, as a full application of either the *Political- Economy model of transport innovation* or the *Dynamic multi-level perspective on technological transitions* could be a study on its own. For this reason, these theoretical frameworks are only applied to determine external factors for the PA to make the maritime port more attractive and to improve the framework from which, the PI port scenarios are formulated. This fulfils the recommendation from Martinez de Ubago (2019) thesis for further research. Still, some general conclusion useful for the future adoption of PI in general and the adoption of PI in the maritime port specific can be drawn from these applications.

8.1.4. Stakeholder analysis
The stakeholder analysis is conducted to identify external factors for the PA to make the maritime port attractive. Nevertheless, the support/resistance specific for the PI policy directions is not analysed, due to limited available knowledge in literature about the perspective of the different stakeholders regarding PI.

8.1.5. Expert interviews
Based on the criteria discussed in section 3.5, in total 20 experts are approached for interviews, from which in total 14 experts are interviewed. This is more than the recommended 8-12 interviews required to get a full picture and cross check opinions of different experts (Enserink et al., 2010). Due to COVID-19, all these interviews are performed online via, either Teams, Zoom or Skype. In general, the online interviews were very efficient. However, it provided less time for a bit of small talk, which was unfortunate.

As, more experts around the world could be interviewed due to the online setting, more knowledge could be gathered to determine policy measures, the PA could apply to improve the attractiveness of the maritime port and develop the PI policy directions.

The interviews had a semi-open structure, in which the experts were stimulated to talk in their field of expertise. This provided much enriching knowledge about different policy measures the PA could apply, in context of PI. However, sometimes the PI port framework was used to guide the discussion. This might have steered the conversation in a certain direction.

8.1.6. PI port scenario operationalisation

To conform with the objective of this thesis *Supporting the PA in designing policy to be attractive given* ***the uncertain development of Physical Internet***, only the external factor classes affecting this development are used to further develop the PI port scenarios. These external factor classes are clustered into two driving forces the *'Technological development'* and the *'Institutional development'*. Which, with the use of the scenario logic of Enserink et al. (2010) are operationalised into four distinct PI port scenarios. This is considered to be a structural way to develop four extreme scenarios describing the uncertain development of PI.

8.1.7. Bayesian Best Worst Method

The Bayesian Best Worst Method (hereafter: BWM) is used to analyse patterns in and between the 'best-fit' focus distributions of the different PI policy directions on the Key Performance Indicators (hereafter KPI) for the attractiveness of the maritime port in the different PI port scenarios. In this, it is assumed that the experts can make their judgments from the perspective of the PA. And, it is assumed that the experts base their judgments for the PA of a general landlord port, rather than a particular port. This could be tested by only including experts from a certain geographical area. Nevertheless, as these respondents groups will become very small, this analysis is not performed.

Besides, as only the 'best-fit' distribution of the PI policy directions is analysed the absolute contribution of the PI policy directions on the KPIs lack. This, however, differ for each port, as it depends on how far a particular port is developed and what the objective of the particular port is. Furthermore, this research lack insight in the investment cost of the PI policy directions for the PA. This is considered to be out of the scope of this research.

During the questionnaires, it was observed that some respondents struggled to perform the comparison between the most impactful or the least impactful PI policy directions and the other PI policy directions on a particular KPI, when they had to consider a certain PI port scenario in their head. This complexity was also strengthened by the relatively general defined PI policy directions.

8.1.8. Sensitivity analysis

The sensitivity analysis, performed by only including the first six respondents of both respondents groups for the PI port scenarios 'Big PI' and 'No PI' and the PI port scenarios 'Institutionally driven advancement' and the 'Technologically driven advancement' in the last step of the Bayesian BWM. This provides very useful insight about the consistency of the conclusions drawn in chapter 6.

8.2. Reflection on the results

In this section, the resulted external factors, PI port scenarios, KPIs and PI policy directions are reflected on. Also, the recommendations provided to the PA to make the maritime port attractive are reflected.

8.2.1. Resulted external factor classes

In RSQ 1, the external factors for the PA to make the maritime port attractive are identified and clustered into eight external factor classes. This clustering is based on insights from the *Dynamic multi-level perspective on technological transitions* and insights from the driving forces of Martinez de Ubago (2019). This provides a clear, relatable overview of external factors with a strong theoretical base. However, a limitation of this clustering is its interrelations. A more theoretical approach of, for example only using the *Dynamic multi-level perspective on technological transitions* could have reduced the interrelations. However, this would have provided far less relatable definitions of the classes.

8.2.2. Resulted PI port scenarios

In RSQ 2, the PI port scenarios are developed, based on the external factor classes in line with the research objective. These scenarios have two limitations. First of all, as the research objective of this thesis is about the uncertain future of PI the external factor classes regarding the demand side are not considered. Secondly, the scenarios only provide insight in four potential future outcomes of PI.

8.2.3. Resulted PI policy directions

In RSQ 3, with an in-depth literature review and 14 expert interviews, policy measures for the PA to make the maritime port more attractive are identified and aggregated into six PI policy directions. Due to this aggregation, the PI policy directions are quite generally defined and contain a lot of specific policy measures. Due to the different backgrounds of the interviewees and the semi-open structure of the interviews, it is considered to be inexpert to partly define the PI policy directions based on the methodology coding. For this reason, for each interview a summary is written, which is used in combination with literature review to define the (overarching) PI policy directions. This methodology could lead to some conformation bias in the resulted PI policy directions (Nickerson, 1998). This is considered during the process and tried to be prevented.

8.2.4. Resulted Key Performance Indicators for the attractiveness of the maritime port

In RSQ 4, the KPIs for the attractiveness of the maritime port are based on the port choice criteria classes for containers and vessels in the context of PI, determined by Fahim (2020). These criteria classes are considered relevant for the attractiveness of the maritime port, based on the following reasoning: in this thesis, the focus is on handling/transporting/storing containers rather than on bulk, which ensures vessels and containers are always playing a role in the transshipment between vessels and land modes. And, as can be stated that all activities and stakeholders in the maritime port are related to the transshipment of goods between vessels and land modes, can be stated that vessels and containers are the only two entities relevant for the attractiveness of the maritime port. Furthermore, a certain stakeholders' perspective is less relevant, as it is uncertain which stakeholder will play a role in the future of PI and in what form.

In defining the KPIs of the attractiveness of the maritime port, only general definitions of the criteria classes of the port choice of Fahim (2020) are used. This might have led to excluding some more specific information. One of the respondents of the questionnaire mentioned missing the KPI sustainability. This is in the port choice analysis a criterion within the criteria class: Transport Chain Quality. Nevertheless, this criterion is not used in the definition of the KPI, as this criterion only has a marginal influence within the criteria class Transport Chain Quality. Furthermore, it was suggested that an extra KPI for sustainability should be added, as this is becoming more important. Nevertheless, in this case double-counting will be rather high and sustainability is not a goal of PI, but rather a side-effect.

8.2.5. Resulted 'best-fit' focus distributions PI policy directions

The resulted 'best-fit' focus distributions of the PI policy directions, across the different PI port scenarios seem generally logical and reasonable conclusion can be drawn from it. This is backed by the performed sensitivity analysis, as only performing the (Bayesian) BWM for the first six respondents did not undermine the recommendations provided in chapter 6.

Nevertheless, the struggle of some respondents to perform the comparison between the most impactful or the least impactful PI policy directions and the other PI policy directions on a particular KPI, when they had to consider a certain PI port scenarios in their head could have led to some biasness in the results. This, however, is considered to be, if it had an effect, only a marginal effect, not influencing the patterns in and between the 'best-fit' focus distribution.

The resulted estimated overall 'best-fit' focus distribution of the PI policy directions in the PI port scenarios are less valid, as it is based on the two following assumptions:

- The (potential) improvement of a KPI is relatively the same to the (potential) improvement of the other KPIs across the different PI port scenarios.

- The weights of Fahim (2020) for the criteria classes are representative for the KPIs and consistent across the different PI port scenarios.

Nevertheless, it still provides useful insight for recommendations to the PA to make the maritime pot attractive in the uncertain future of PI.

Respondents with a research background rather have the upper hand in the respondents group of the questionnaire. This analysis is not perceived as a problem, as all the respondents are considered to have enough knowledge regarding policy making by the PA and still one third of the questionnaires is performed by practitioners. Also, it can be checked, whether there are significant difference between the groups. However, as the respondents groups become too small, this is not performed in this thesis.

8.2.6. Recommendations future (adaptive) policy making PA

PI is still in its infancy stage, which means it is rather unclear which direction it will go. Nevertheless, the conclusions from this thesis, provide rather a broad insight in what could happen and what the PA could generally focus on in the different PI port scenarios. To further specify an actual adaptive policy plan, the sell-by dates of the specific policy measures clustered in PI policy directions in the different scenarios lack.

8.2.7. General reflection on the results

Generally, the results of the thesis only take into account a PA of landlord port and in particular ports in North-west Europe. Also, only the container and vessel perspective is used in analysing the attractiveness of the maritime port.

8.3. Recommendations for further research

In this section, recommendations for future research are provided. These are grouped into three categories: recommendations for future PI literature, recommendations for future research regarding (adaptive) policy making by the PA and general recommendations.

Recommendations for future PI literature

It is recommended to perform a more systematic and thorough literature review to the concepts of PI and maritime ports. In this way, the possibility of missing important elements might be lower.

As, PI is still in its early stage of development a significant number of further research can be recommended to this concept. This includes research to clearly define the PI characteristics. Research to align the vision of PI with Synchromodality. At this moment, these research areas develop rather detached, while they are closely related. Furthermore, a general stakeholder analysis can be conducted to gain insight in what PI exactly mean for the different logistics stakeholders and whether they are resistant against this change or are supportive. An application of a theoretical framework, like the *Political- economy model of transport innovations* or the *Dynamic multi-level perspective on technological transitions* could provide insight in bottlenecks and opportunities relevant for the future adoption of PI. This could be applied for a specific element in logistics, like the maritime port, but also on PI in general. In this thesis, only a partial application of the frameworks is conducted, specifically to determine external factors for the PA to make the maritime port attractive.

A design study of the maritime port, as a π-hub is recommended. Currently, design studies are conducted to most other potential hub locations in PI. A well-suited starting point for this research is the multi-layer perspective developed by Martinez de Ubago (2019). The performed design study could provide further insight in, among others more specific policy measures the PA or other stakeholders in the port community could apply in the future.

Recommendations for future research regarding (adaptive) policy making by the PA

It is recommended to analyse more different scenarios to really get insight required for adaptive policy making. These scenarios could, for example, incorporate the external factor classes (A - D) about the demand side.

In this research, the attractiveness of the maritime port is based on the criteria classes used for the port choice of containers and vessels. In future research, it might be valuable to also consider bulk transport and the industry in the maritime port.

More research is recommended to the specific policy measures contained in the PI policy directions. This research could use the information provided by the literature review and the expert interviews conducted in this thesis (see appendix E and appendix F). It is recommended to research the effects of these specific policy measures on the attractiveness of the maritime port in the different PI port scenarios and perform research to the path-dependencies between the specific policy measures and what there more precise sell-by dates are in the different PI port scenarios. And, it is recommended to further research the support and/or resistance of the stakeholders to the particular policy measures and PI policy directions.

It is recommended to research the cost-effectiveness of the policy measures/ PI policy directions by performing additional research to the investment cost. Or, further analyse the impact of policy measures/ PI policy directions in a more quantitative way, by e.g. determining the effects of these measures/directions on the container throughput in the different PI port scenarios.

It is recommended to develop an indicator on which in the future, the PA could determine in which PI port scenario the real world is developing and in this way could take appropriate action.

It is recommended to perform a *Gap analysis* for a particular port to determine to which extend in this port the different KPIs can be improved in the different PI port scenarios. In combination with the results of this thesis, the absolute contribution of PI policy directions in the PI port scenarios can be determined. This provides valuable information for the PA to develop an actual policy plan. Alternatively, research can be recommended to determine the relative improvement of the KPIs in the PI port scenarios, by e.g. a (Bayesian) BWM. This can in combination with the results from this study and Fahim (2020), better estimate the overall 'best-fit' focus distribution of the PI policy directions in the different PI port scenarios.

To verify and validate the results and conclusions drawn from the applied Bayesian BWM it is recommended to perform a workshop or in times of COVID-19 organize a webinar. Also, it is recommended to perform a similar Bayesian BWM with experts with other geographical backgrounds. And, as PI is still in its infancy stage it is recommended to perform a similar analysis in two to five years. This might provide different results, as in the future the clarity of the concept of PI and the shared understanding of this concept by experts improves. Furthermore it might be valuable to perform research to the validity the (Bayesian) BWM with a questionnaire with more complexity.

It is recommended to further develop adaptive policy making for the PA by performing e.g. step 5 until step 10 of the DAPP approach. In this, it might be relevant to first consider the recommendations provided above.

General recommendation
This research is performed for a landlord port and in particular from the perspective of the PA. For this reason, it can be recommended to perform a comparable research to the other types of maritime ports, to perform a comparable research from a different stakeholders perspective and to perform a comparable research to other system components of logistics, like airports.

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A

Main components Physical Internet

In this appendix the main components considered in the latest definitions of Physical Internet by Montreuil (2016) are further discussed.

A.1. Modularity

Modularity refers in the context of PI to the combining and separating of the π-containers (see figure A.1). The π-containers are the physical elements in the PI, in which the goods are encapsulated (see section A.2). These π-containers come in sizes from small packages to large maritime containers (see figure A.1).

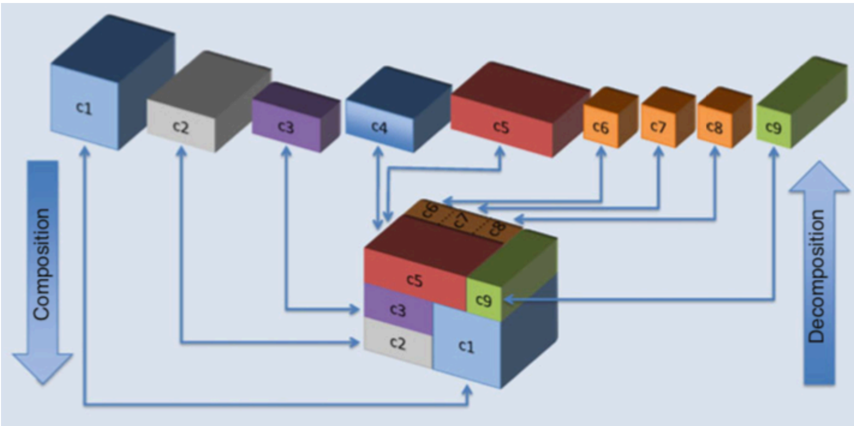


Figure A.1: Example of separating and recombining the π-containers (Montreuil, 2011)

Easy separating and recombining requires standardisation of the sizes and other characteristics of the π-containers (Treiblmaier et al., 2016). In figure 4.1 an overview of the most important characteristics of the π-containers is given. Until now, there is, unfortunately, no global standard set of modular π-containers. The design is currently being researched (Landschützer et al., 2015). In designing the π-containers, it is, thereby, important to consider the relation of the π-containers to the other two main physical elements of the PI network: the π-nodes and the π-movers (see table 2.1 adopted from Montreuil, Meller, and Ballot (2010)).

The π-containers should be easily handled and stored at the π-nodes and should be easily loaded and unloaded on and from the π-movers. Therefore, the design of the other two main physical elements of PI should also be standardised and aligned to the π-containers. Meller, Montreuil, et al. (2012), already, researched the functional design of road-based π-transit centres. More research to other more complex π-nodes and the π-movers is lacking (Oktaei, Lehoux, & Montreuil, 2014; Walha et al., 2016).

Unless, this lack of research a simulation study, using π-transit centres instead of the current logistics approach in the logistics system shows a huge potential as the delivery time was reduced with 50% for a shipment from Quebec to Los Angeles (Meller, Montreuil, et al., 2012).

A.2. Encapsulation

There is a lot of inconsistency in the literature about this PI component, mainly because it is so related to the previous component Modularity. These two components are in different papers used for the same purpose. This leads to ambiguity (Oktaei et al., 2014; Treiblmaier et al., 2016).

To make a distinction between the two components, in this thesis, the metaphor with DI is used. In this metaphor, the encapsulation refers to the assignment of the information to the data packages. This means for PI that the encapsulation refers to the assignment of the physical objects to the π-containers and the component modularity refers to the actual design and characteristics of the π-containers itself (Montreuil, Meller, & Ballot, 2012). To illustrate the relation, in figure A.2, the encapsulation of physical objects into the three different types of modular π-containers is shown.

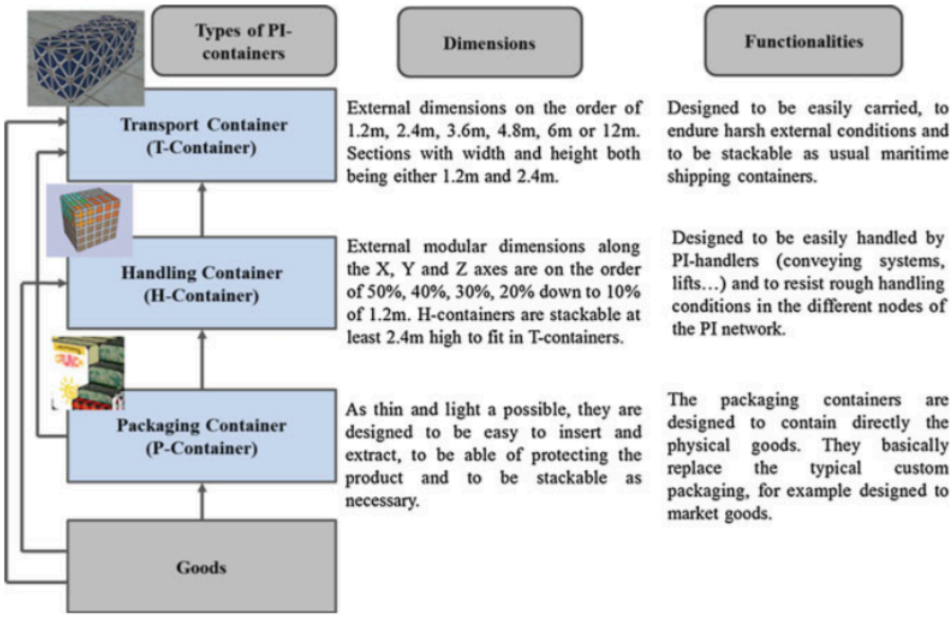


Figure A.2: π-container types and their relations (Krommenacker et al., 2016)

Using the π-container will increase the handling and storing efficiency, however there might be a disadvantage of using π-container during the transport. The encapsulation of the physical objects into the three different π-containers leads to an increase in volume. Meller, Lin, and Ellis (2012) showed with a mathematical model, that there is no negative effect on the total transport volume, in comparison with the current way of transport, as long as there is flexibility in the number of items per π-container and/or flexibility in the item dimensions. The main reason for this conclusion is the higher volume utilization rate or in other words due to the encapsulation of the goods in the three π-containers, the empty volume transported decreases and at least compensates for the volume increase due to material of the three π-container themselves.

A.3. Standard protocols

In literature, there is no clear definition for standard protocols. In general, this component refers to a set of rules that guide the operations and structure the decision making in PI. The aim of the standard set of rules is to make collaboration between logistics stakeholders, between physical elements and logistics stakeholders, between physical elements possible (Ambra, Meers, Caris, & Macharis, 2017). In this way, the standard protocols will guide the π-containers and π-movers through the PI network in the most efficient and sustainable way (Montreuil, Meller, Thivierge, & Montreuil, 2013).

Unfortunately, until now, it is uncertain how these standard protocols will look like. In literature, there are different studies suggesting standard protocols for one or more parts of PI. For example, Oktaei et al. (2014) suggests negotiation protocols for simple PI transit centers that manages the planning. Another study, conducted by Sarraj, Ballot, Pan, Hakimi, and Montreuil (2014), shows the potential impact of using standard protocols for routing between π-hubs. Furthermore, Sallez et al. (2015) discusses in their paper that in designing standard protocols, it is important to consider the unpredictability of PI. This unpredictability descend from the constant changes in finding the most efficient and sustainable way goods are transported, handled and stored.

Despite, the lack of research to the actual design of the standard protocols, research is conducted to which types of protocols there should be and how these protocols should relate to each other. Montreuil, Meller, and Ballot (2012), for example, distinguishes two main types of protocols:

- **Basic Protocols:** ensures the physical integrity of the π-containers and guide the transfer from one π-mover to another. Like, in the IoT-guidelines, each π-container and π-mover has an unique identification number assigned.
- **Higher-level Protocols:** focusses on the performance and integrity of the PI-network itself. For example, the routing of π-containers through the PI-network.

On the assumption that there should be basic and higher-level protocols, the Open Logistics Interconnection model (hereafter: OLI-model) is suggested for the different protocol layers in PI (Montreuil, Ballot, & Fontane, 2012). In this model is, as with the description of other components the analogy with the DI used. The model is based on the Transmission Control Protocol/Internet Protocol (hereafter: TCP/IP) reference model for DI and the Open Systems Interconnection reference model (Open Systems Interconnection: OSI-model) for data networks (Colin, Mathieu, & Nakechbandi, 2016).

However, there is a problem with this analogy, because as already discussed in section 2.1, there is a significant difference between sending a data package and sending a physical object. To cope with these issues Colin et al. (2016) suggested the New Open Logistics Interconnection (hereafter NOLI) model. This NOLI-model is also based on the TCP/IP reference model and the OSI-model. However, in the NOLI reference model there is no single layer that defines all the physical elements. In this model, physical characteristics play a role in all the protocol layers: from the top layer, where the products that could be transported in π-containers are defined, to the lowest layer were the physical characteristics of the π-movers are described. In table A.1 the layers of all models are presented.

A.4. Standard interfaces

The standard interfaces in PI provide the safe, transparent and reliable transfer of physical objects through the entire PI network. Furthermore, the standard interfaces take care of the preservation of the physical objects during the transfer. As, with the other PI components the standard interfaces are not designed yet. Nevertheless, literature made some distinctions between different types of standard interfaces.

A commonly used distinction of interfaces is the distinction between the standard handling interfaces and the standard digital interfaces (Ballot et al., 2013; Meller, Montreuil, et al., 2012). An example of the first type in the current supply chain, is the universal interlocking system for containers. Through this revolutionary system the container transport has seen a tremendous development in the last decades (Ballot, Montreuil, & Meller, 2014). The same standardisation is suggested in PI, however on a larger scale. This implies that the interfaces required for handling and transporting the π-containers by the π-movers should be aligned for all types of π-containers and all types of π-movers (see figure 2.1).

Table A.1: Layers of TCP/IP, OSI, OLI and NOLI model adapted from Colin et al., 2016

TCP/IP layer Name (Internet)	**OSI reference Model Layer Name**	**OLI Layer Name (Montreuil et al.)**	**NOLI Layer Name (Colin et al.)**
Application	7. Application	7. Logistics Web	7. Product
	6. Presentation	Encapsulation	6. Container
	5. Session	5. Shipping	5. Order
Transport	4.Transport		4.Transport
Network	3. Network	4. Routing	3. Network
		3. Network	
Network access	2. Data Link	2. Link	2. Link
Physical	1. Physical	1. Physical	1. Physical handling

The other type of interfaces, the standard digital ones, are required to enable the fast and fact-based exchange of meaningful information to enable efficient and sustainable decision making. To achieve this, the performance and status of the π-containers, the π-movers and the π-nodes have to tracked and controlled. For this kind of information RFID and GPS kind of technology is required. Thereby, these information systems should be harmonised and combined (Crainic & Montreuil, 2016).

Another distinction between different standard interfaces is made by Montreuil, Meller, and Ballot (2012). This distinction is not only based on the physicality or digitality of the interface, but also on the operational level the interface operates. The four types of interfaces distinguished are the π-fixtures, the π-devices, the π-nodes, and the π-platforms. These types of interfaces are briefly discussed below:

- **Physical fixtures:** are the standard interfaces at the basic physical level. These standard interfaces ensure smooth flow of the π-containers through the PI network by providing the π-containers and the other physical elements with fixtures to easy interlock, store and snap the π-containers in the PI network.
- **Devices:** are the standard interfaces at the basic communication and information level. These interfaces include the smart sensors that each π-container and π-movers have to provide the required information to make efficient and sustainable decisions. The so-called smart tags provide the correct information to ensure the identification, the integrity, the routing, the conditioning, the monitoring, the traceability and the security of each π-containers
- **π-nodes:** are the standard interfaces at the higher operational level. The different types are shown in figure 2.1. Each π-node type has different functionalities: for example at the π-gateway the goods enter the PI network, at the π-transits the π-containers are redirected and at the π-hubs the π-containers can switch from one mode to another (Meller, Montreuil, et al., 2012).
- **π-platforms:** are the standard interfaces at the higher communication and information level. These platforms should, both enable an open market for logistics and a smooth operation of all the physical elements in PI. The business models for π-transit centers created by Oktaei et al. (2014) are examples of this type of standard interface.

B
Literature overview

In this appendix an overview of the literature used to describe the main concepts of the thesis: Physical Internet (hereafter: PI) and maritime ports and used to substantiate the methodology is provided.

In table B.1 an overview of the PI literature used is given their main used methodology applied. In table B.2 an overview of the literature on maritime port is shown. In table B.3 an overview of the literature used for the methodology is presented.

Table B.1: PI literature methodology applied

Methodology	Number	Publications
Conceptualisation	6	Crainic and Montreuil (2016); Montreuil (2011); Montreuil, Meller, and Ballot (2012); Montreuil et al. (2010); Ambra et al. (2017); Ballot et al. (2014)
Simulation	4	Ballot, Gobet, and Montreuil (2012); Montreuil (2016); Oktaei et al. (2014); Sarraj et al. (2014)
Design	8	Landschützer et al. (2015); Meller, Montreuil, et al. (2012); Ballot, Montreuil, and Thivierge (2012); Walha et al. (2016); Krommenacker et al. (2016); Sallez et al. (2015); Montreuil, Ballot, and Fontane (2012); Colin et al. (2016)
Literature review	3	Treiblmaier et al. (2016); Ambra et al. (2019); Pan et al. (2017)
Quantitative research	1	Sarraj et al. (2014)
Modelling	1	Meller, Lin, and Ellis (2012)
Survey	2	Martinez de Ubago (2019); Fahim (2020)

Table B.2: Literature used to substantiate the research foundations of the maritime ports

Category	Number	Publications
The role of the maritime port	9	Ligteringen (1999); Zondag et al. (2010); Flynn et al. (2011); Notteboom and Rodrigue (2005); Rodrigue and Notteboom (2010b); P. T. W. Lee and Cullinane (2016); Rodrigue and Notteboom (2010a); Rodrigue (2010); Dooms et al. (2013)
Definitions	3	Ibrahimi (2017); Roso et al. (2009); Stopford (2008)
Stakeholders	17	Notteboom and Winkelmans (2002); Min et al. (2017); Verhoeven (2010); Dooms et al. (2013); Martin and Thomas (2001); Heaver (2002); Fahim (2020); Strandenes (2000); Saeed (2013); Henesey et al. (2003); Brooks (2004); Van der Lugt et al. (2013); Daamen and Vries (2013); Van der Lugt et al. (2014); Zondag et al. (2010); Van der Lugt et al. (2017); Centin (2012); Panayides and Song (2013)
PI in maritime ports	9	Fahim (2020); Voster (2019); Martinez de Ubago (2019); Montreuil (2019); Sallez et al. (2016); Walha et al. (2016); Krommenacker et al. (2016); Montreuil et al. (2018); Zhang and Pel (2016)

Table B.3: Literature used for each methodology

Methodology	Number	Publications
Overall thesis approach	6	Van der Heijden (2011); Börjeson et al. (2006); Duinker and Greig (2007); Haasnoot et al. (2013); Walker et al. (2001); Evers et al. (1994)
Literature review	3	Rowley and Slack (2004); Wohlin (2014); Jalali and Wohlin (2012)
Application of Theoretical framework	5	Feitelson and Salomon (2004); Geels (2004); Geurs and Van Wee (2004); Woolthuis et al. (2005); Williamson (1998)
Stakeholder analysis	4	Peters (2015); Bryson (2004); Notteboom and Winkelmans (2002); Brugha and Varvasovszky (2000)
Expert interview	4	Weiss (1995); Gubrium and Holstein (2001); Gopinath and Hoffman (1995); Enserink et al. (2010)
Scenario operationalisation	3	Postma and Liebl (2005); Amer et al. (2013); Enserink et al. (2010)
(Bayesian) Best Worst Method	10	Rezaei (2015); Rezaei et al. (2019); Apparcel (2019); Rezaei (2020); Cheraghalipour and Farsad (2018); Ahmadi et al. (2017); Sadeghi et al. (2016); Mi et al. (2019); Mohammadi and Rezaei (2019); Fahim (2020)
Sensitivity Analysis	2	Saltelli et al. (2004)

C

Stakeholder analysis

In this appendix the power and interest of the different stakeholders is shown in a Power/Interest grid (hereafter: P/I grid) and the stakeholders influence diagram the most important influence relations.

C.1. Power/Interest grid

Based on the power and interest of the different stakeholders is the P/I grid composed in figure C.1. In the P/I grid four different groups of stakeholders are identified. These different groups have the following meaning:

- **Players:** are the stakeholders that have a high interest in the attractiveness of the maritime port and have significant power to influence the attractiveness of the maritime port. For the PA, it is important to work closely together with these stakeholders. This group include the stakeholders: the terminal operators, the shipping lines companies, the EU and the Dutch government.
- **Subjects:** are the stakeholders that have a high interest in the attractiveness of the maritime port. However, have less power to influence the attractiveness of the maritime port. It is important for the PA to satisfy these stakeholders. This group include the stakeholders: the municipality of Rotterdam, the freight forwarders, the ship brokers and the carriers.
- **Context setters:** are stakeholders that have a less significant interest in the attractiveness of the maritime port, but have a lot of power to influence the attractiveness of the maritime port. It is important for the PA to inform these stakeholders. This group include the stakeholders: the customs.
- **Crowd:** are stakeholders that have, both, no significant interest in the attractiveness of the maritime port and little power to influence the attractiveness of the maritime port. For this reason, these stakeholders should only be monitored. This group include other maritime ports and local residents.

C.2. Stakeholder influence diagram

A stakeholder influence diagram shows the most important influence relations between the different stakeholders on a P/I grid (Bryson, 2004). In figure C.2 the P/I grid shown in figure C.1 is used to construct the stakeholder influence diagram. The relations between the stakeholders are based on the stakeholders discussion in section 4.1.2.

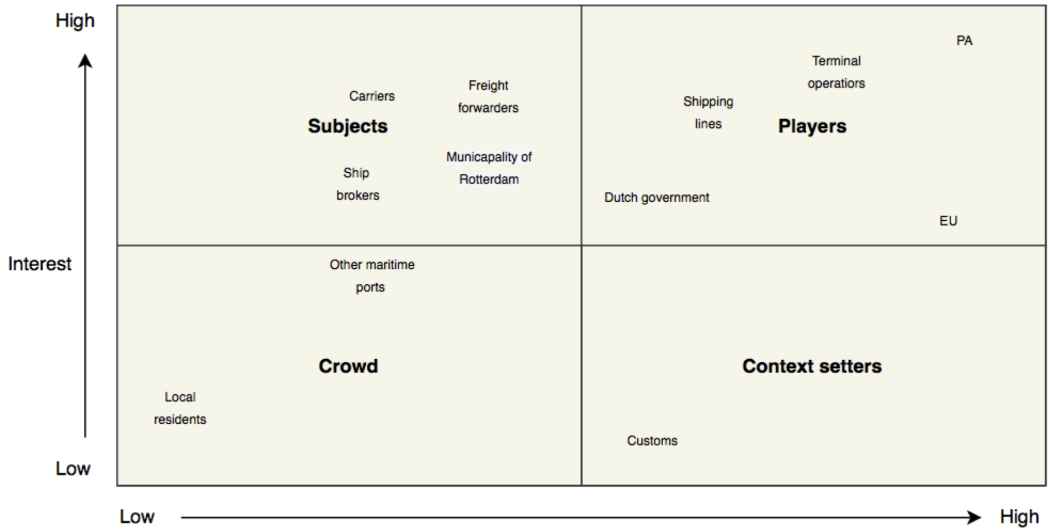


Figure C.1: P/I grid for decision making in the maritime port

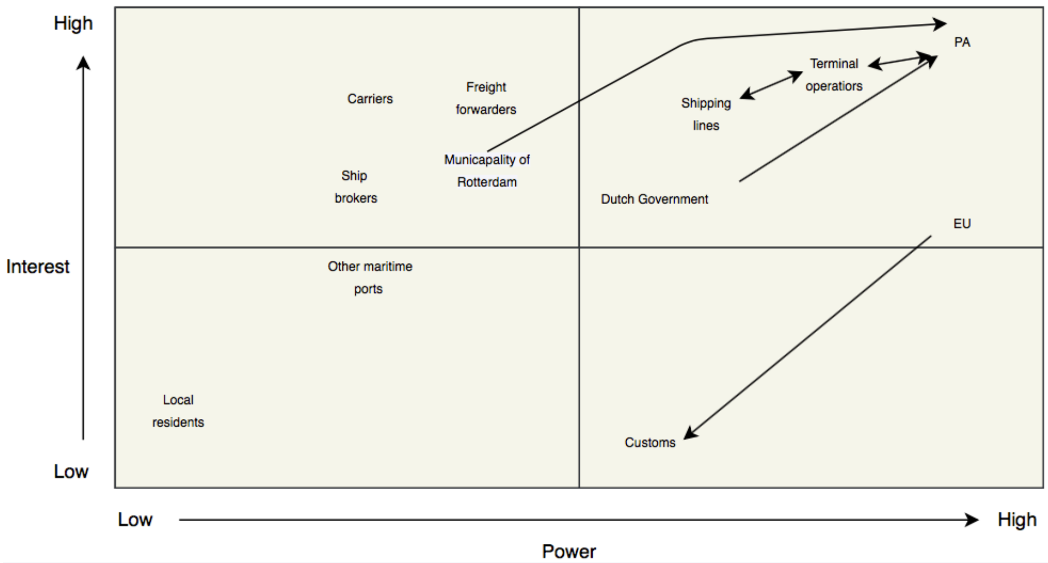


Figure C.2: Stakeholder influence diagram for decision making in the maritime port

D External factor classes

In this appendix an overview of the identified external factors for the Port Authority (hereafter: PA) to make the maritime port attractive is presented.

The external factors identified with literature review, stakeholder analysis and theoretical frameworks are clustered into eight external factor classes. This clustering is, both based on the *Dynamic multi-level perspective on technological transitions* from Geels (2002) and the eight driving forces from Martinez de Ubago (2019) (see section 4.1.3).

Below, the external factors classes and external factors are described. Furthermore, an overview of the used sources to determine and define the external factors is provided in tables.

A Economic growth: Includes the growth of the (world) GDP (Henderson et al., 2012).

Table D.1: Source(s) used for each external factor clustered in external factor class A: Economic growth

Number	Policy measure	Source(s)
1	Economic growth	Henderson et al. (2012)

B Demographic changes: Are the changes in size, growth and structure of the population (IMF, n.d.). This class includes the following external factors:

1. *Population growth:* Is the change in population due to the natural causes of birth and dead.
2. *Migration: 'Is an event in which a person changes his or her place of usual residence'* (Poulain, 2008). This has a major effect on regional demographics.
3. *Urbanisation: 'Involves the shift in population from rural areas to urban settlements'* (McGranahan & Satterthwaite, 2014). This development will have significant economically, social and environmentally impact in the 21^{st} century (McGranahan & Satterthwaite, 2014).

Table D.2: Source(s) used for each external factor clustered in external factor class B: Demographic changes

Number	Policy measure	Source(s)
1	Population growth	
2	Migration	Poulain (2008)
3	Urbanisation	McGranahan and Satterthwaite (2014)

C Flow patterns: Are logistics developments, which affects the trade flows through the port, by affecting where goods are handled, stored and could be transported from and to. This class includes the following external factors:

1. *Nearshoring & Backshoring:* Is the development of reallocating business activities back to the home country or to the nearby countries in the region (Stentoft, Olhager, Heikkilä, & Thoms, 2016). This phenomena could be further stimulated by the COVID-19 outbreak, as this has shown vulnerabilities in the global supply chain.
2. *Safety stock:* Is a potential consequence of the COVID-19. Companies might increase their safety stock at strategic places to adequately respond to disruption in the supply chain.
3. *Increase in vessel size:* The sizes of the container vessels have increased significantly over the last decades. Whether this development will continue and at what rate is uncertain. Therefore, it is uncertain whether the PA have to make new changes to the port infrastructure, maritime access, equipment and hinterland transport connections (Notteboom, 2016).
4. *New trade routes:* Due to investments by governments in infrastructure, trade routes around the world are affected. For example, the 'Belt and Road Initiative' by China has the objective to improve the land connectivity of Asia with Europe. This could significantly impact the maritime trade flows (PoR, 2018). Furthermore, as the North pole is melting in the coming decades a new maritime trade route between East-Asia and Europe will emerge. The economic impact of this new trade route is uncertain (Liu & Kronbak, 2010).
5. *Digitalisation of society:* is defined as *'The way many domains of social life are restructured around digital communication and media infrastructures'* (Brennen & Kreiss, 2016). It is uncertain how this phenomenon will affect the logistics in the future. On the one hand, it has tremendous advantages, like the increased ability to integrate services, but on the other hand this phenomenon could have tremendous disadvantages, like the increase in job losses (Degryse, 2016). Also, in this external factor are developments like e-commerce and the use of social media included. This developments affect the way people order their goods (Yu, Wang, Zhong, & Huang, 2016; Liang & Turban, 2011). This external factor could be stimulated by the current outbreak of COVID-19, as people have less face-to-face interaction. This external factor is actually a development at landscape level, affecting the logistics. Nevertheless, this external factor is clustered in this class for clarity reason.
6. *Mass individualism:* Is the development of customizing the product by the buyers (Ince, 2017). This could significantly affect the logistics activities in the supply chain in the future. This is, like the digitalisation of society a development at landscape level. However, for the same reason this external factor is clustered here.
7. *Hinterland infrastructure:* The PA is for the hinterland accessibility dependent on local, regional and national government to make investment in the basic infrastructure. This is the part of the supply chain that has a major contribution to the total logistics costs and is of key importance for the competitiveness of the maritime port (Elsayeh, 2015).

Table D.3: Source(s) used for each external factor clustered in external factor class C: Flow patterns

Number	Policy measure	Source(s)
1	Nearshoring & Backshoring	Dachs et al. (2019); Slepniov et al. (2013); Stentoft et al. (2016)
2	Safety stock	NOS (2020)
3	Increase in vessel size	Notteboom (2016); Merk (2018)
4	New trade routes	Liu and Kronbak (2010); PoR (2018)
5	Digitalisation of society	Brennen and Kreiss (2016) Degryse (2016); Yu et al. (2016); Liang and Turban (2011)
6	Mass individualism	Ince (2017)
7	Hinterland infrastructure	Rodrigue and Notteboom (2006); Elsayeh (2015)

D Global institutional integration: Refers to the 'rules of the game' for global trade, set by formal institutions. This class includes the following external factors:

1. *Trade agreements:* Involves two or more countries that agree on terms to perform trade with each other.
2. *Import tariffs & quotas:* As trade agreements stimulate trade between countries, limit import tariffs & quotas trade between countries. Import tariffs include taxes payed by the importer of the goods and quotas are a limit on how much goods can be imported into a country.
3. *Different tax environment:* Each country has his own rules and regulation, which implies difficulties with importing and exporting goods. Each time goods are transferred between different tax environments new formal documents have to be submitted. Furthermore, customs might be performed when entering a new region. This could lead to disruptions in the supply chain. This is even a bigger bottleneck in PI, as the goods are encapsulated in three different π-containers.

Table D.4: Source(s) used for each external factor clustered in external factor class D: Global institutional integration

Number	Policy measure	Source(s)
1	Trade agreements	Eicher and Henn (2011)
2	Import tariffs & quotas	Eicher and Henn (2011)
3	Different tax environment	

E Regulatory frameworks: Refers to regulation set by formal institutions, which influences the breakthrough or development of (technological) innovations. This class includes the following external factors:

1. *Cybersecurity: 'Is the organisation and collection of resources, processes, and structures used to protect cyberspace and cyberspace-enabled systems from occurrences that misaligned de jure from de facto property right.'* (Craigen, Diakun-Thibault, & Purse, 2014). The EU and the Dutch government have implemented laws to protect the privacy and confidential information of companies (Wettenbank, 2000, 2018). These laws could be a bottleneck for implementing new innovations.
2. *Antitrust policies:* Are policies concerned with the distribution of economic power to ensure healthy competition. This could also has a negative effect, as mostly large companies, are restricted in their actions (Posner, 2009). This could potentially limit the adoption of new (technological) innovations (Ordover & Willig, 1985). On the contrary, the expansion of the CBER or similar regulation could lead to flexible cooperation between companies without extensive market power.
3. *Labour protectionism:* Due to the adoption of new technological innovations, it is expected that people will lose their jobs. This are mostly people from lower classes (Forbes, 2019). To prevent this from happening governments might implement labour protection laws.
4. *(PI) standardisation:* At this moment, there are no standards for the physical elements, the protocols and the interfaces in PI. This is a bottleneck for the widespread adoption of PI and the adoption of PI in the maritime port. Also, other standards are required for e.g. digitalisation. The development of standardisation required could be stimulated by large institutions like the EU, WTO, ISO, IMO, GS1 and UN by two means: firstly by bringing different stakeholders in logistics together and secondly by enforcing standardisation by regulation (WTO, n.d.; UN, n.d.; ISO, n.d.; IMO, n.d.; GS1, n.d.). They should consider the high sunk made the many stakeholders in logistics, before implementing (PI) standards. A step in the right direction could be the adoption of the Rotterdam Rules and new standardised Incoterms.

Table D.5: Source(s) used for each external factor clustered in external factor class E: Regulatory frameworks

Number	Policy measure	Source(s)
1	Cybersecurity	Craigen et al. (2014)
2	Antitrust policies	Wettenbank (2000); Wettenbank (2018); Ordover and Willig (1985); Posner (2009)
3	Labour protectionism	Aaronson and Phelan (2019); Forbes (2019)
4	(PI) standardisation	Landschützer et al. (2015) WTO (n.d.); UN (n.d.); ISO (n.d.); IMO (n.d.); GS1 (n.d.)

F Technological innovations: Are other technological innovations, which affect the attractiveness of the maritime port.

1. *Internet of Things:* Is about combining physical objects and digital components. It allows for human decision makers and automated controllers to constantly track and control the performance of equipment, energy usage and environmental conditions in real time, anywhere and anytime. This is one of the key elements of PI. IoT could improve the decision making in maritime ports in general.
2. *Big data:* Is a term used to describe the storage and analysis of big and complex data sets using a series of techniques (Ward & Barker, 2013). This could enable the analysis of larger data sets, for example required to enable fast and fact-based decision making in PI and/or for the decision making in maritime ports in general.
3. *Artificial intelligence:* Is a *'field of computer science and engineering concerned with the computational understanding of what is commonly called intelligent behavior, and with the creation of artifacts that exhibit such behaviour'* (Korb & Nicholson, 2010). This research field could potentially help develop standard protocols and interfaces for PI or better communication systems in the maritime port (Barr & Feigenbaum, 2014).
4. *Blockchain: 'Enables immutable data records and facilities a shared data view in the supply chain'* (Treiblmaier, 2019). This technology could enable safe and reliable data transmission, which is crucial for PI and communication system in the maritime port.
5. *Drones:* Are unmanned aerial vehicles and micro aerial vehicles. Drones are capable of filling the gap between weather dependent and low-resolution images from satellites and limited human-level perspective (Floreano & Wood, 2015). Drones have many applications in logistics, for example for last-mile delivery (Murray & Chu, 2015). Drones are useful in maritime ports for surveillance and detection (of incidents) and delivering small packages between land and vessels (Frederiksen & Knudsen, 2018).
6. *Hyperloop:* Is a new transportation system concept in which a vehicle travels with a *'high speed through a low-pressure tunnel to minimize the aerodynamic drag'* (Braun, Sousa, & Pekardan, 2017). This significantly reduces the travel time and could for a maritime port potentially improve the hinterland connection for the distribution of containers.
7. *3D printing:* Is used to produce three dimensional objects according to computer design. In the future this innovation could be widely used to produce goods closer to the customer or by the customer themselves. This could significantly impact the trade flows around the world (Abeliansky, Martinez-Zarzoso, & Prettner, 2015).
8. *Machine learning:* Improves the performance of a measure by learning form experience (Mitchell, 1997). This innovation could stimulate the development of standard protocols and interfaces in PI and better communication systems in the maritime port.
9. *5G network:* Is the fifth generation of cellular networks, which enables large data transmissions between physical objects. This could significantly improve the decision making in PI and maritime ports.
10. *Industry 4.0:* can be best described, as the organisation of production processes based on technology and devises autonomously communicating with each other along the value chain (Maslarić, Nikoličić, & Mirčetić, 2016). This innovation can be seen as the application of e.g. IoT, Big data and AI technologies in the production and operations environment to

develop an integrated Cyber-Physical system. The main advantages of 'Industry 4.0' are the increased efficiency, flexibility, productivity and quality standards. This will enable mass customization, allowing companies to better meet customer's requirements and create value due to constantly updating the products and services. This innovation will also have a lot of impact on the logistics processes in the entire supply chain (Tjahjono, Esplugues, Ares, & Pelaez, 2017). To enable these changes Maslarić et al. (2016) describes PI as the logistical response to 'Industry 4.0'. Both these innovations are highly complex and dependent on each other's development.

11. *Automated guided Vehicles/equipment/vessels:* Automated Guided Vehicles (hereafter: AGV) and other automated equipment, like Automated Yard Cranes (hereafter: AYCs) could play an important role in synchronizing operations of among others, transshipment of goods from vessels to a land mode (K. H. Kim & Bae, 2004; Carlo, Vis, & Roodbergen, 2014). Furthermore, currently tests are running to automate vessels (see interview in appendix F.8)

Table D.6: Source(s) used for each external factor clustered in external factor class F: Technological innovations

Number	Policy measure	Source(s)
1	Internet of Things	Wortmann and Flüchter (2015); I. Lee and Lee (2015); Montreuil, Meller, and Ballot (2012); Treiblmaier et al. (2016); Khan and Salah (2018)
2	Big data	Ward and Barker (2013); Zhong et al. (2017);
3	Artifical Intelligence	Korb and Nicholson (2010); Barr and Feigenbaum (2014)
4	Blockchain	Treiblmaier (2019); Khan and Salah (2018)
5	Drones	Floreano and Wood (2015); Murray and Chu (2015); Frederiksen and Knudsen (2018)
6	Hyperloop	Braun et al. (2017)
7	3D printing	Abeliansky et al. (2015)
8	Machine learning	Mitchell (1997)
9	5G network	Ni et al. (2018); Forbes (2019)
10	Industry 4.0	Tjahjono et al. (2017); Maslarić et al. (2016)
11	Automated guided Vehicles/ equipment/ vessels	K. H. Kim and Bae (2004); Carlo et al. (2014)

G Logistics market structure: Refers to tangible social structures between companies in logistics which have evolved specific role behaviour towards one another. This class includes the following external factors:

1. *(Vertical) Alliances:* Are collaborations between shipping line companies, terminal operators and/or carriers to get a competitive advantage. This is a bottleneck for implementing policy measures, as the PA is dependent on these stakeholders to make the maritime port attractive.

2. *(Long-term) Terminal contracts:* The PA has long-term contracts with terminal operators regarding operating the superstructure of the maritime port. This, however implies that the PA almost have no power over the terminal operators during the contract period. Furthermore, as the terminal operators made high sunk cost, it is likely that they are not willing to change their operations very quickly.

3. *(New) business models:* Currently, there are different business models developed for PI. However, stakeholders are only likely to change to these new business models when they get a competitive advantage (Geels, 2004). These different business models have to fit in the regulation. And, (new) business models changes financial streams, which has to be accepted by financial institutions, like banks and insurers.

4. *Network externalities:* The number of stakeholders involved in PI increases the functionality of PI. For instance, the logistics cost will significantly decrease by the number of transactions made in a network (Tavasszy, 2018). Therefore, the more stakeholders willing to enter PI will stimulate the adoption of PI in the maritime port.

5. *Willingness to share assets:* The adoption of PI and other new technological innovations are dependent on the willingness of stakeholders in logistics to share assets. In this context are assets, both physical and digital (information) are considered.

Table D.7: Source(s) used for each external factor clustered in external factor class G: Logistics market structure

Number	Policy measure	Source(s)
1	(Vertical) Alliances	Zhu et al. (2019); Van der Horst and De Langen (2008); De Langen (2009)
2	(Long-term) Terminal contracts	Van der Lugt et al. (2014)
3	(New) business models	Geels (2004)
4	Network externalities	Tavasszy (2018)
5	Willingness to share assets	

H Sustainability: Refers to a plan or a set of ideas of what to do about environmental, economic and social unsustainable effects of the port operations and the port related activities (Glavič & Lukman, 2007). This class includes the following external factors:

1. *Environmental regulation:* Is regulation that provide protection to the environment (Qc, 1995). This includes regulation to reduce the following negative externalities of logistics: air pollution, water pollution, climate change and nuisance.
2. *Land-use planning:* Are measures taken by the government to e.g. reduce the (excessive) land-use required to perform logistics activities. This is, especially, an issue by maritime ports in urban areas, as there is only limited land available near the waterfront.
3. *Traffic measures:* Are measures taken by the government to reduce congestion, causalities and injuries due to transport.
4. *Work condition regulation:* is regulation taken by the government to deal with occupational safety and health.
5. *National subsidies:* Is financial support to implement measures to deal with environmental, economic and social unsustainable issues.

Table D.8: Source(s) used for each external factor clustered in external factor class H: Sustainability

Number	Policy measure	Source(s)
1	Environmental regulation	Qc (1995)
2	Land-use planning	Lindholm and Behrends (2012)
3	Traffic measures	Lindholm and Behrends (2012)
4	Work condition regulation	
5	National subsidies	

E

Literature review policy measures

In this appendix, policy measures the Port Authority (hereafter: PA) could implement to improve the attractiveness of the maritime port are identified by literature review. Furthermore, information from several webinars from Port Technology International are used to identify policy measures.

This appendix first discusses the policy measures related to the traditional role of the PA in a landlord port in section E.1 and afterwards treats policy measures related to the following research areas:

- Hinterland (section E.2).
- Foreland (section E.3).
- Smart port and port digitalisation (section E.4).
- Green and Sustainable port (section E.5).
- Port city interface (section E.6).
- Port centric logistics (section E.7).
- (PI) standardisation (section E.8).

Some of the above-mentioned research areas have overlap with each other. For this reason, certain policy measures are mentioned more than once.

E.1. Traditional role of a Port Authority in a landlord port

In a landlord port, the PA is responsible for the port safety, economic exploitation, the long-term development of the land, maintenance of basic port infrastructure, like access roads and berths, and providing waterside access by e.g. dredging. The PA also has a regulator function, which includes the licensing, the permitting, the vessel traffic safety, the customs and the immigration, the port monitoring, the emergency services, the protection of public interest on behalf of the community, the determination of port policy and environmental policies. (Baltazar & Brooks, 2001; Brooks, 2004).

The regulator functions immigration and emergency services are considered to be out of the scope of the thesis and not further discussed. Besides, as the functions customs and port monitoring have similarities with research areas the Smart port and port digitalisation, these functions and related policy measures are further discussed in section E.4 (see for more on customs in section 4.1.2). This also applies for the regulatory functions: protecting the public interest and environmental policies with the research areas Green port, Sustainable port and the Port city interface. For this reason, these regulatory functions and their corresponding policy measures are further discussed in section E.5 and section E.6. Regarding the other traditional functions of the PA in a landlord port the following policy measures can be distinguished:

The PA has the power to lease out the land via tendering processes. In this, the PA could set certain conditions or incentives to enforce or stimulate certain behaviour, like the modal shift targets set by the PA of the PoR (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; Lam & Notteboom, 2014). In context of PI, this could include conditions or incentives to develop a shared warehouse and enable *Automated crossdocking and reshuffling operations* (see figure 2.2). The PA could also show with pilots and best use cases what the effect of a shared warehouse could be or even develop these sites themselves (Franklin & Spinler, 2011; Van der Heide, Buijs, Roodbergen, & Vis, 2018; Voster, 2019; Thijsen, 2020; Port Call Optimization, n.d.; ALICE, 2019; Daamen & Vries, 2013; PoR, 2019; Van den Boogaard, Feys, Overbeek, Le Poole, & Hekkenberg, 2016). Furthermore, the PA could shorten the lease contracts to force more competition and enable faster adaptation of the conditions in the concessions (Wiegmans & Louw, 2011). The PA could collaborate with the terminal operators and other leasers of the land to intensify the land use (Wiegmans & Louw, 2011). This could include providing the leasers money, research or permission for certain port activities in certain areas (Brooks & Cullinane, 2006). The PA could also decide to redevelop areas, which are currently underutilised (Wiegmans & Louw, 2011).

Nevertheless, the PA is also dependent on other major stakeholders, like the municipality, and port regulation (Daamen & Vries, 2013; Wiegmans & Louw, 2011). In port regulation, it can be, for example stated that there are restriction for port expansion due to the impact on the environment (Wiegmans & Louw, 2011). For this reason, the PA should collaborate with other stakeholders to look for sustainable solutions and create, as the PA of the PoR calls it 'environmental space' for growth of port activities (Wiegmans & Louw, 2011; PoR, 2019) (see section E.5 for more specific policy measures to create the 'environmental space'). More general, it is important for the PA to actively reach out to the port community (P. T. W. Lee & Cullinane, 2016).

The PA is responsible for the waterside access and the port infrastructure (Brooks, 2004). The port infrastructure could be improved by increasing its capacity (Voster, 2019; Brooks, 2004). In this, the PA is highly dependent on national, regional and local governments, as the infrastructure in the port should be accommodated to the hinterland infrastructure (Rodrigue & Notteboom, 2006). Therefore, it is important to collaborate with these stakeholders in developing adequate infrastructure. In the future, the PA could enable the usage of Hyperloop infrastructure or stimulate this development by running pilots (Braun et al., 2017). To improve the waterside access, the PA could take several policy measures, like deepening the access by sea (Notteboom, 2016), developing indented berths (Arduino et al., 2013) and dredging the river and performing canal maintenance (Brooks & Cullinane, 2006).

The PA collects port duties, by charging the shipping line companies for using the services provided by the PA (Van der Lugt et al., 2013; Fahim, 2020). This policy measure could be used to stimulate certain behaviour, like the usage of greener vessels by the Environmental Ship Index (hereafter: ESI) (Mocerino & Rizzuto, 2019; Lam & Notteboom, 2014; Bergqvist & Egels-Zandén, 2012; Aregall, Bergqvist, & Monios, 2018). Also, the PA could deny entry of a vessel/truck/train in the port under certain conditions (Brooks & Cullinane, 2006; De Langen, 2009; Lam & Notteboom, 2014).

The PA has a role in providing the vessel traffic safety. This is an increasingly important for the PA, as the traffic in the maritime port is growing and how this growth is managed influences the capacity of the maritime port (Shu, Daamen, Ligteringen, & Hoogendoorn, 2013). For the PA, it is important to asses the current vessel traffic safety and estimate the effects of implementing certain new policy measures. Specific policy measures could include traffic control to reduce the traffic congestion in the rush hours, reducing the vessel handling difficulties and enabling the usage of autonomous vessels in the maritime port (Inoue, Park, Usui, Sera, & Masuda, 2002; Van den Boogaard et al., 2016).

All the above described policy measures should be within the rules and regulation set by the local-, regional-, national governments and the EU. In this, it is wise for the PA to communicate with these governments about their policy plans and implement the seaport laws and regulations set by these institutions (Ibrahimi, 2017). In table E.1 an overview is presented of the identified policy measures related to the traditional functions.

Table E.1: Source(s) used for each policy measure related to the traditional functions

Number	Policy measure	Source(s)
1	Lease out land via tendering procedures	Brooks (2004)
2	Stimulate certain behaviour by incentives in the concessions	Wiegmans and Louw, (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
3	Enforce certain behaviour by rules in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
4	Stimulate or enforce the development of shared warehouses	Franklin and Spinler (2011), Van der Heide et al. (2018), Voster (2019)
5	Start pilots and show best use cases (of shared warehouses)	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013)
6	Develop their own shared warehouses	Franklin and Spinler (2011) Van der Heide et al. (2018) Brooks (2004) Voster (2019)
7	Reduce the length the lease period	Wiegmans and Louw (2011)
8	Intensify land use	Wiegmans and Louw (2011)
9	Permit certain port activities	Brooks and Cullinane (2006)
10	Redevelop existing port area	Wiegmans and Louw (2011)
11	Collaborate with other stakeholders to create 'environmental space' for expansion of port activities	Wiegmans and Louw (2011) PoR (2019)
12	Actively reach out to the port community	P. T. W. Lee and Cullinane (2016)
13	Improve the (land) infrastructure capacity of the port	Voster (2019), Brooks (2004)
14	Collaborate with local/regional/national governments to align the infrastructure expansion in the port with the hinterland infrastructure	Rodrigue and Notteboom (2006)
15	Improve the waterside access	Notteboom (2016), Arduino et al. (2013), Brooks and Cullinane (2006)
16	Perform maintenance on the land infrastructure and maintenance required for the waterside access	Brooks (2004)
17	Monitor the vessel traffic safety and assess the effects of policy measures on the vessel traffic safety	Inoue et al. (2002)
18	Raise awareness to take policy measures for the vessel traffic safety	Inoue et al. (2002)
19	Traffic control	Inoue et al. (2002)
20	Reduce vessel handling difficulties	Inoue et al. (2002)
21	Stimulate and enable the usage of autonomous vessels	Van den Boogaard et al. (2016)
22	Collect port duties	Van der Lugt et al. (2013)
23	Stimulate certain behaviour with higher or lower charges for certain vessels	Mocerino and Rizzuto (2019), Lam and Notteboom (2014), Bergqvist and Egels-Zandén (2012), Aregall et al. (2018)
24	Collect rent from the concessions	Wiegmans and Louw (2011)

Number	Policy measure	Source(s)
25	Permit access to the port or deny access when certain conditions are not met	Brooks and Cullinane (2006), De Langen (2009), Lam and Notteboom (2014)
26	Implement the seaport laws and regulation set by the local, regional or national governments	Ibrahimi (2017)

E.2. Hinterland

In this thesis, is referred to hinterland as the landside area of which (a large part of) the goods moving from and to the port passes through (Weigend, 1958). This incorporates, among other things the inland terminals, the extended gates and the inland infrastructure. This part of the supply chain is accountable for a large part of the total logistics costs (Zondag et al., 2010; Iannone, 2012). For this reason, the inland accessibility has become an important element for the port competitiveness, hence the emergence of the port regionalization development and the broader focus of the PA to its hinterland (Notteboom & Rodrigue, 2005; De Langen, 2009; PoR, 2019). The PA has less direct power in this area, as it does not operate or owns the land and/or the infrastructure. Nevertheless, the PA should play an active role in the hinterland to make the port community benefit from synergies with other transport nodes and other stakeholders in the network (Notteboom & Rodrigue, 2005). For this the PA could apply the following policy measures:

The PA can collaborate with local/regional/national governments in developing the appropriate infrastructure required for the hinterland transport (Voster, 2019; Rodrigue & Notteboom, 2006; PoR, 2019). This could involve cooperation in traffic management, environmental protection, marketing and research (Notteboom & Rodrigue, 2005). The PA could contribute by introducing a dedicated inland waterway or rail service to an inland terminal in collaboration with railway companies, rail operators, terminal operators, shipping line companies and/or large shippers (Notteboom & Rodrigue, 2005; De Langen, 2009). In general, the PA should encourage collaboration of the port community stakeholders and the stakeholders in the hinterland to create wealth (Brooks, 2001). The PA could in this be a facilitator, using pricing or other incentive policies to ensure the efficiency and sustainability of the hinterland operations (P. T. W. Lee & Cullinane, 2016; Rodrigue & Notteboom, 2006).

In this role, the PA could promote intermodal transport and the modal shift from road to rail and/or inland waterways (Van den Berg, 2015). This will increase the efficiency and sustainability of the hinterland freight transport system (Notteboom & Rodrigue, 2005; Lindholm & Behrends, 2012; Wiegmans & Louw, 2011; PoR, 2019). An example of such a policy measure is setting modal shift targets in the concessions for the terminal operators (Wiegmans & Louw, 2011; Notteboom & Lam, 2018) or for that matter stimulate/enforce certain behaviour with their concession power (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; De Langen, 2009; Lam & Notteboom, 2014). Furthermore, the PA could permit or deny access to the port and use this as a policy measure to encourage certain behaviour (Brooks & Cullinane, 2006; De Langen, 2009; Lam & Notteboom, 2014).

Besides, the PA should encourage bundling concepts to develop a collaborative network with consolidated flows (see figure E.1). Policy measures for the PA include using the concession power and the right to permit or deny access to the port to stimulate or enforce certain behaviour (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; De Langen, 2009; Brooks & Cullinane, 2006; Lam & Notteboom, 2014) The PA could promote the development of inland terminals by other stakeholders and/or invest in inland terminals via joint ventures or subsidiaries (Notteboom & Rodrigue, 2005; Van der Lugt et al., 2014; De Langen, 2009). This could also include collaboration with other ports in the region in developing a joint hinterland strategy.

An advantage of inland terminals is the transfer of the collection and distribution function from the port to its hinterland, preventing the pressure on land use in the port area. Furthermore, by using dedicated services via inland waterway or rail corridors congestion could be significantly reduced (Slack, 1999; Notteboom & Rodrigue, 2005). There are also developments in the other direction, like the port-centric logistics (see section E.7).

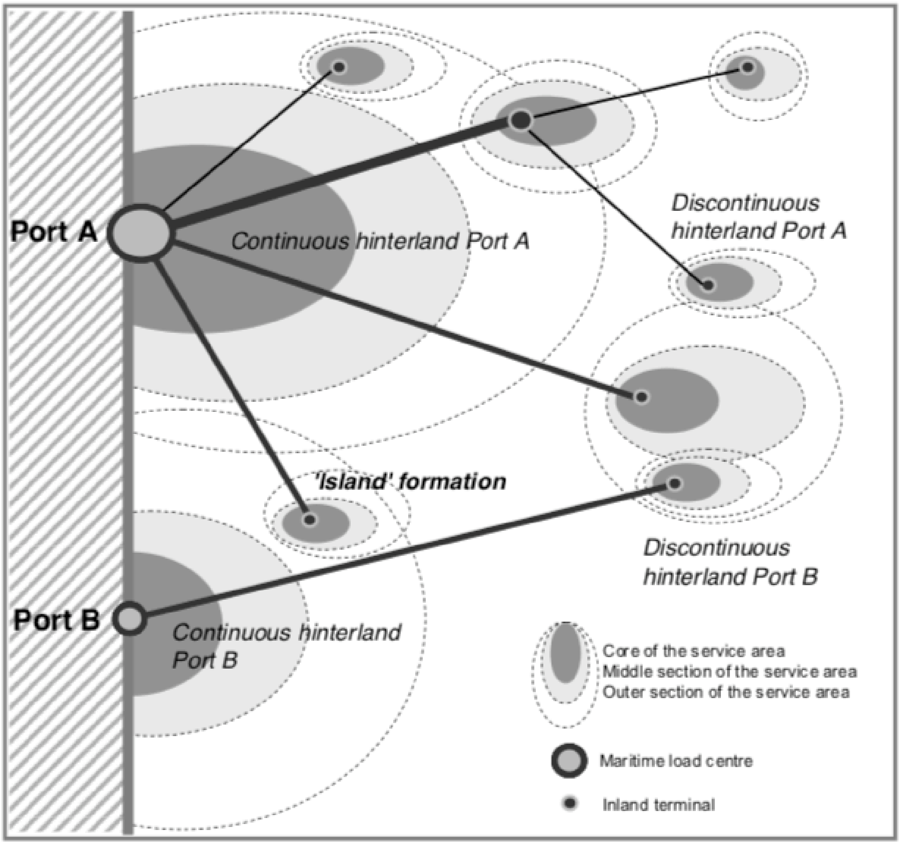


Figure E.1: Port Hinterland Regionalization (Nottenboom Rodrigue, 2005)

The PA could, as a neutral stakeholder play a significant role in advancing the concept of Synchromodality in its hinterland. They could show the benefits of this concept and start pilots. Or, they could stimulate/enforce the collaboration and information sharing between the stakeholders. (Thijsen, 2020; Port Call Optimization, n.d.; ALICE, 2019; Daamen & Vries, 2013; PoR, 2019; Van den Boogaard et al., 2016). This is currently lacking due to e.g. the absence of shared data standards and the incompatibility of the company Information systems (hereafter: IS) (Tavasszy, Behdani, & Konings, 2015). In this, the PA could play a role in developing digital platforms or integrating the ISs in the port with the hinterland (Voster, 2019). In general, the PA could advance the sharing of information within the port community and its hinterland as this avoids unnecessary costs (Groothedde, Ruijgrok, & Tavasszy, 2005; Notteboom & Rodrigue, 2005) (see section E.4). The concept of Synchromodality requires reshuffling activities taking place in the port (Voster, 2019; Martinez de Ubago, 2019) (see section E.1). The PA could more efficiently exploit its resources by looking at the added value of their port operations to the total port region (Ibrahimi, 2017).

Also, it is important to understand that the relevancy of all these policy measures in the hinterland of a port depends on the ports specific function. If the port function is, for example being a transshipment hub to other more regional ports and less on the hinterland, the investments in its hinterland will be less relevant (De Langen, 2009). Nevertheless, advancing bundling concepts, like Synchromodality is also applicable for these kind of ports.

In table E.2 an overview is presented of the identified policy measures related to the ports hinterland.

Table E.2: Source(s) used for each policy measure related to the hinterland or port regionalization

Number	Policy measure	Source(s)
1	Collaborate with local/regional/national governments in developing hinterland infrastructure	Voster (2019), Rodrigue and Notteboom (2006), PoR (2019)
2	Collaborate with local/regional/national governments in traffic management, environmental protection, marketing and research	Notteboom and Rodrigue (2005)
3	Collaborate with stakeholders from the port community and hinterland in creating efficient and sustainable hinterland operations	Notteboom and Rodrigue (2005), De Langen, (2009), Brooks (2001)
4	Stimulate certain behaviour by incentives in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
5	Enforce certain behaviour by rules in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
6	Permit access to the port or deny when certain conditions are not met	Brooks and Cullinane (2006), De Langen (2009), Lam and Notteboom (2014)
7	Promote intermodal transport	Notteboom and Rodrigue (2005), Lindholm and Behrends (2012), Wiegmans and Louw (2011), PoR (2019)
8	Encourage bundling concepts	Notteboom and Rodrigue (2005), Groothedde et al. (2005)
9	Promote or invest via joint ventures or subsidiaries, into inland terminals	Notteboom and Rodrigue (2005), De Langen (2009), Van der Lugt et al. (2014)
10	Collaborate with other ports in the region in developing a joint hinterland strategy	PoR (2019)
11	Start pilots and show best use cases (of Synchromodality)	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013), Tavasszy et al. (2015)
12	Advance the concept of Synchromodality	Tavasszy et al. (2015), Voster (2019), Martinez de Ubago (2019)
13	Encourage sharing of information between stakeholders in the port community and hinterland	Notteboom and Rodrigue (2005), Groothedde et al. (2005)
14	Integrate the PCS with the hinterland	Voster (2019)
15	Improve the resource allocation of the port by looking at the total port region	Ibrahimi (2017)

E.3. Foreland

The foreland of a maritime port can be best described, as the land area with which the port is connected by shipping line companies for trade (Weigend, 1958). Like hinterland regionalization, there is foreland regionalization. In this development, large intermediate port hubs are starting to appear and connecting smaller ports with the global shipping network. This kind of networks could reduce the investment in the waterside access for smaller ports, as they no longer have to welcome large vessels. For larger ports, it means more traffic stability and on a network level the service frequency can be maintained with fewer assets (Rodrigue & Notteboom, 2010b).

The foreland regionalization development is different for each region in the world. Currently, in China, for example, the development of foreland regionalization is limited, due to export orientation. Also, the development of foreland regionalization in the Hamburg - Le Havré area is limited due to its strong hinterland orientation (Rodrigue & Notteboom, 2010b). However, around the Mediterranean area intermediate hubs are appearing, like the port of Algeciras (Port of Algeciras, n.d.). Furthermore, the port of Singapore is a large intermediate hub in South-east Asia (Notteboom, 2012). In advancing this development the PA could focus on becoming an intermediate hub by building strong connections with other large ports around the world. Or, as a smaller port try to connect the port with as many different intermediate hubs as possible to have a better connection to the global shipping network (Rodrigue & Notteboom, 2010b).

To improve the foreland connection of the port, the PA could attract more traffic flows by outgoing trade missions or commercial representation. The PA could build strong relationships by consultancy or by participation in projects with other ports. The PA could actively invest by starting joint ventures or by subsidiaries (Dooms et al., 2013). Currently, the PA of the PoR is, for example, exchanging its knowledge and trying to connect different ports with the use of the project PortXchange (Port Call Optimization, n.d.) (For more information about this project see section E.4). In context of PI, this could even be taken a step further by developing certain (PI) standards or protocols together to optimize the streams in the network (see section E.8). Nevertheless, the foreland strategy of a PA all dependents on the resources of the PA. For a smaller port investing with joint ventures in other ports might be step to far (Dooms et al., 2013).

In table E.3 an overview is presented of the identified policy measures related to ports foreland.

Table E.3: Source(s) used for each policy measure related to the foreland

Number	Policy measure	Source(s)
1	Go on outgoing trade missions	Dooms et al. (2013)
2	Build strong relations by commercial representation	Dooms et al. (2013)
3	Build strong relations by providing consultancy and participating in projects	Dooms et al. (2013), Rodrigue and Notteboom (2010b)
4	Invest in other ports by joint ventures or subsidiaries	Dooms et al. (2013)
5	Collaborate with other maritime ports to set (PI) standards	Port Call Optimization (n.d.), Voster (2019), ALICE (2019)

E.4. Smart port/Port digitalisation

Both the concepts Smart port and Port digitalisation are about improving the port operations with the use of data. The difference is that the Smart port concept is about the adoption of (smart) technologies to better manage operations of the port (Molavi, Lim, & Race, 2020) and Port digitalisation is only about the digital exchange of information (between different stakeholders and physical objects) in the port (Hambletion, 2020). Therefore, all considered policy measures related to port digitalisation are integrated in the more broad Smart port concept.

The Smart port concept is, in literature often mentioned in relation to the concept of Smart logistics and Industry 4.0 (Douaioui, Fri, & Mabrouki, 2018; Yang et al., 2018). Industry 4.0 was a new concept introduced by the German government to deal with the changing needs of customers by using technologies, like IoT, to enable devices autonomously communicating with each other along the value chain (C. Lee, Lv, Ng, Ho, & Choy, 2018; Maslarić et al., 2016). This new concepts also requires changes in logistics, which caused the term Smart logistics to appear. Furthermore, as the maritime port is an important element in logistics chains the research area Smart port developed (Douaioui et al., 2018). To define the Smart port concept, it is important to consider what it used for (Molavi et al., 2020). For this reason, in the context of PI the Smart port in this thesis is defined as: *the adoption of (smart) technologies to improve the efficiency and sustainability of the port operations and the port related activities.* To achieve the goal contrived from the definition the PA could apply the following policy measures:

The PA should for a Smart port develop intelligent infrastructure in the port (Molavi et al., 2020). This intelligent infrastructure enables the usage of, among others IoT like Applications (I. Lee & Lee, 2015; Belfkih, Duvallet, & Sadeg, 2017; Yang et al., 2018) Intelligent infrastructure includes: sensors, wireless communication technologies and data centres (Yang et al., 2018; Douaioui et al., 2018):

- *The sensors:* These are required to monitor the port operations (Yang et al., 2018). Sensors include among others cameras, liders, infrared radiation sensors and RFID tags. In this, the PA could apply such sensors to monitor their operations. They could encourage other stakeholders in the port to apply these sensors by incentives in the concessions or enforce application of these sensors by rules in the concessions (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; Lam & Notteboom, 2014).
- *The wireless communication technologies:* are required for the fast and fact-based exchange of meaningful information between the physical elements and the stakeholders, between the stakeholders and between the physical elements themselves (Yang et al., 2018; I. Lee & Lee, 2015; Montreuil, Meller, & Ballot, 2012; PoR, 2019). These technologies include, among others 4G/5G,RFID, Bluetooth and GPS (P. T. W. Lee & Cullinane, 2016; Yang et al., 2018; Molavi et al., 2020).
- *Data centres:* Smart requires a lot of computer power to store and analyse all the data (Douaioui et al., 2018). In this the PA could build their own data centre or use cloud computing (Botti, Monda, Pellicano, & Torre, 2017; Molavi et al., 2020; Brooks, 2004; Douaioui et al., 2018). The PA could also outsource such activities via, for example concessions (Brooks, 2004).

The PA could play a role in developing ISs, which enable the efficient and sustainable port operations and port related activities (Douaioui et al., 2018; Fernández et al., 2016). Currently, the two most important information systems of a maritime ports are the Port Management System (hereafter: PMS) and the PCS. These are often owned and operated by the PA. The PMS, in the PoR called PortMaster, focuses on providing a detailed overview of the operations in the maritime port and improving the port planning. The PCS focus is to improve the port efficiency by connecting the different stakeholders digital systems and facilitating their mutual communication (Carlan, Sys, & Vanelslander, 2016). The PCS is defined by Srour, Van Oosterhout, Van Baalen, and Zuidwijk (2008) as a *'holistic, geographically bounded information hubs in global supply chains that primarily serve the interest of a heterogeneous collective of port related companies.'* The most cited reason for the further advancement of PCS is to reduce the communication cost through digitalization and to develop a reliable, efficient and paperless data flow (Carlan et al., 2016; PoR, n.d.). Currently, most information flows are still executed physically. For example, the Bill-of-Lading is still transferred manually (Thijsen, 2020). This has many disadvantages, like a high business risk of loss, forgery, delay in delivery of the physical document, commercial disputes, high handling time and cost due to compare, validate and process the documents.

Nevertheless, there are also examples which improve the advancement of the Smart port concept. A first example is the FIWARE platform in Las Palmas de Gran Canaria that provides the port users to explore the data collected by port sensors and processed by internet applications (Fernández et al., 2016). A second example is the smart service system in the port of Salermo, which is also connected to an inland port (Botti et al., 2017). A third example is the use of Blockchain for smart contracts in the PCS of Israel ports, which show the administrative documents only to the authorized people and make the adjustment of the required documents more easy (Benmoshe, 2020). The PA of the PoR is also improving their ISs. Recently, Nextlogic is connected with the PCS. Nextlogic is a digital system that optimizes the inland waterway operations of the port. By connecting this system with the PCS, the planning of the port operations and the inland waterway operations can be more easily adjusted to each other (Portbase Nextlogic, n.d.). The PA is advancing digitalization with the Port Call Optimization project. In this, the PA is sitting down with several stakeholders to improve, among other things the planning of arrival and departure time by the PortXchange platform. In this digital platform the location, the estimated arrival time and departure time of vessels are shared to optimize the real arrival and departure time of vessels in the port (Heilig & Voß, 2017). This system is currently in operation in the PoR and also in other ports, like the port of Algeciras (PoR, n.d.; Port Call Optimization, n.d.) Also, the PA of the PoR is showing with best practices what works and what not. A current example is the experimentation of digitizing the Bill-of-Lading between the PoR and the port of Singapore with the use of Blockchain. This will provide more visibility and more easy checking and adjusting the documents. Nevertheless, current regulation in the Netherlands doesn't allow for this experiment to start (Thijsen, 2020).

In further advancing the Smart port concept, the PA could show best use cases, like currently the PA of the PoR is doing with the digitalising of the Bill of Lading (Thijsen, 2020; Port Call Optimization, n.d.). The PA could apply IoT applications (Douaioui et al., 2018; Fernández et al., 2016; Yang et al., 2018), Big data analysis (Fernández et al., 2016; Belfkih et al., 2017), Artifical Intelligence (hereafter: AI) (Barr & Feigenbaum, 2014), Blockchain (Treiblmaier, 2019) and Machine Learning (Mitchell, 1997) on the data provided by the sensors and communicated via the wireless communication technologies. This could also be outsourced to other stakeholders (Fernández et al., 2016). Nevertheless, the PA, as a neutral party could have a critical role in ensuring the availability, traceability, integrity and confidentiality of the information stored and transmitted (PoR, n.d.). To further advance Smart port in the port the PA could stimulate certain behaviour by incentives in the concessions (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; Lam & Notteboom, 2014), enforce certain behaviour by rules in the concessions (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; Lam & Notteboom, 2014) or stimulate certain behaviour by incentives in port duties or permit/deny access to the port when certain conditions are met (Brooks & Cullinane, 2006; De Langen & Chouly, 2009; Lam & Notteboom, 2014; Mocerino & Rizzuto, 2019; Bergqvist & Egels-Zandén, 2012; Aregall et al., 2018)

The PA could align their ISs and align the different ISs operated by the different stakeholders in the maritime port (PoR, n.d.c). Also, the PA could integrate the different ISs in the port with the hinterland. This will provide more visibility of services and improve the orchestration of the overall workflow (Srour et al., 2008). An example of such an ISs is a digital platform, which enables stakeholders to share and book hinterland transport services. This digital platform in combination with a shared warehouses enables *Automated crossdocking and reshuffling operations* (Martinez de Ubago, 2019; Voster, 2019; Franklin & Spinler, 2011; ALICE, 2019). The next step could be to connect the ISs with the entire global logistics chain (Srour et al., 2008). This development would be very much in line with the objective of PI (Montreuil, 2011) or level 4 of the PI port framework *Global hub hyperconnectivity* (Voster, 2019; PoR, 2019). Also, ISs could be developed for air pollution control, Noise pollution control, Waste management, energy control and safety (Molavi et al., 2020; PoR, 2019) (see for more policy measures related to these ISs in the section E.5).

Unless, the crucial role of the PA in developing ISs, it is important for the PA to understand that they are dependent on many different stakeholders in, for example setting data definitions, nautical standards and standards required for PI (PoR, 2019) (for more information on the policy measures the PA could apply to advance the standardisation see section E.8).

Other than the ISs, it is important for the PA to develop forecasting and policy analysis tools, as a lot of the policy measures described in this entire appendix require a level of forecasting. This is especially important in the context of large investments in land and infrastructure (Zondag et al., 2010).

Also, automation is often considered part of being Smart (Douaioui et al., 2018). To achieve more automation in the port operations, it is important to develop the following equipment:

- *Smart/Automated vessels:* Earlier discussed in context of vessel traffic safety. Automated vessels also have a positive effect on the sustainability, as it reduces the emissions of the vessels and improves the predictability of when a vessel will arrive (Van den Boogaard et al., 2016).
- *Smart containers*: In context of PI called a π-container (Montreuil, Meller, & Ballot, 2012; Montreuil, Ballot, & Tremblay, 2015) (see section A.1 for more specific characteristics of the π-container)
- *Automated Yard Cranes (hereafter: AYC) and Automated Guided Vehicles (hereafter: AGV)* (K. H. Kim & Bae, 2004; Carlo et al., 2014; Douaioui et al., 2018; Molavi et al., 2020)

In advancing the automation of the port operations the PA has limited power the terminal operators are responsible for the superstructure in the port (Brooks, 2004). Nevertheless, the PA could encourage these stakeholders by collaborating (Notteboom & Rodrigue, 2005; Groothedde et al., 2005; Brooks, 2001; De Langen, 2009) or enforce certain behaviour by rules in the concessions (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; Lam & Notteboom, 2014).

The PA could advance the concept op Smart port by developing an innovation ecosystem. Trying to attract companies with a specialisation in developing platforms, AI, 3D printing, industry 4.0 and Blockchain technology (PoR, 2019).

In table E.4 an overview is presented of the identified policy measures related to the Smart port.

Table E.4: Source(s) used for each policy measure related to the Smart port concept

Number	Policy measure	Source(s)
1	Implement own sensors and wireless communication technologies	Yang et al. (2018)
2	Encourage other stakeholders to implement sensors and use the wireless communication systems	Notteboom and Rodrigue (2005), Groothedde et al. (2005)
3	Stimulate certain behaviour by incentives in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
4	Enforce certain behaviour by rules and regulation in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
5	Permit access to the port or deny access when certain conditions are not met	Brooks and Cullinane (2006), De Langen (2009), Lam and Notteboom (2014)
6	Stimulate certain behaviour with higher or lower charges for certain vessels	Mocerino and Rizzuto (2019), Lam and Notteboom (2014), Bergqvist and Egels-Zandén (2012), Aregall et al. (2018)
7	Build data centre or use cloud computing	Botti et al. (2017), Molavi et al. (2020), Brooks (2004), Douaioui et al. (2018)
8	Start pilots and show best use cases (of ISs)	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013)
9	Use IoT applications	Douaioui et al. (2018), Fernández et al. (2016), Yang et al. (2018)
10	Use AI technologies	Barr and Feigenbaum (2014)
11	Apply Big data analysis	Fernández et al. (2016), Belfkih et al. (2017)
12	Use Blockchain technology	Treiblmaier (2019)
13	Apply Machine Learning	Mitchell (1997)
14	Align the information systems of the different stakeholders	PoR (n.d.)
15	Develop a single window system	PoR (n.d.c), P. T. W. Lee and Cullinane (2016)
16	Connect the PMS & PCS with the port hinterland	Srour et al. (2008), PoR (2019), Benmoshe (2020)
17	Connect the PMS & PCS with the entire global logistics chain	Srour et al. (2008), PoR (2019), Voster (2019)
18	Create a digital platform to book and over services	Voster (2019), Martinez de Ubago (2019), Franklin and Spinler (2011), ALICE (2019)
19	Develop IS for environmental control of the port operations and the port related activities	Molavi et al. (2020), PoR PoR
20	Develop forecasting and policy analysis tools	Zondag et al. (2010)

Number	Policy measure	Source(s)
21	Advance port automation	Uckelmann (2008), Kao, Chen, Wang, Kuo, and Horng (1995), Douaioui et al. (2018), Yang et al. (2018)
22	Developing an innovation ecosystem	PoR (2019)

E.5. Green port and Sustainable port

The Green and Sustainable port concepts are about reducing the negative externalities of the port operations and the port related activities, without endangering economic growth. The difference in terminology between the Sustainable port and the Green port concept is the focus. The Green port focus is on sustainable and climate friendly development of the port infrastructure and the Sustainable port has a more broader perspective of the behaviour of all the working structures, from the port management to the individual employee (Pavlic, Cepak, Sucic, Peckaj, & Kandus, 2014). As, the PA is responsible for protecting the public interest on behalf of the community and is responsible for the environmental policies of the maritime port, the PA has an important role in advancing these concepts (Baltazar & Brooks, 2001; Brooks, 2004). In context of both concepts, the PA could apply the following policy measures:

The PA should conform to the environmental regulation set by the local/regional/national governments (Di Vaio & Varriale, 2018; Verhoeven, 2010). An example of such regulation is the Dutch Climate Act (PoR, 2019).

The PA should measure the environmental impact of the port operations and the port related activities (Lam & Notteboom, 2014; Pavlic et al., 2014; Aregall et al., 2018; Chiu, Lin, & Ting, 2014). This include, among others the measurement of the air quality, water quality and the nuisance. With this information more specific policy measures can be developed. The PA could set environmental performance indicators, including efficiency targets and standards (Puig, Wooldridge, & Darbra, 2014; Pavlic et al., 2014; Di Vaio & Varriale, 2018; Molavi et al., 2020) and develop an Environmental Management System (hereafter: EMS) (Puig et al., 2014; Pavlic et al., 2014; Molavi et al., 2020; PoR, 2019; Lam & Notteboom, 2014; Di Vaio & Varriale, 2018). An EMS is an framework for evaluating, monitoring and reducing the environmental impact of the maritime port (Molavi et al., 2020; PoR, 2019). It provides an effective benchmark of the environmental sustainability of a maritime port (Lam & Notteboom, 2014). Other management systems that could be implemented are the energy management system, providing insight in the energy performance and the safety and security management system (Molavi et al., 2020).

The PA could take policy measures to reduce the negative externalities of the port operations and the port related activities. This includes many policy measures either related to the (traditional) role of the PA of a landlord port (discussed in E.1) or the research area hinterland of the maritime port (discussed in E.2):

- In relation to the traditional function of the PA it includes the policy measures: intensify the land use, reduce the length of the lease period, monitoring of vessel traffic safety, reduce the vessel handling difficulties and stimulate and enable the autonomous vessels (see section E.1).
- In relation to the research area hinterland it includes the policy measures: encourage bundling concepts, promote intermodal transport, develop dedicated infrastructure, collaborate with local/regional/national governments in traffic management, environmental protection, marketing and research and collaborate with stakeholders from the port community and hinterland in creating efficient and sustainable port operations and hinterland operations (see section E.2).

Other, not before mentioned policy measures include, the cleaning of polluted land areas, the creation of ecozones, careful handling of dangerous goods (PoR, 2019; Wiegmans & Louw, 2011). Specific policy measures to improve the air quality. This could among others include the reduction of vessel speed in the port (Wiegmans & Louw, 2011; Chiu et al., 2014; PoR, 2011; Molavi et al., 2020). Policy measures to specifically improve the water quality. This include, among others, the management of ballast water (Wiegmans & Louw, 2011; Chiu et al., 2014; PoR, 2011; Molavi et al., 2020). Noise control (Wiegmans & Louw, 2011; Chiu et al., 2014; PoR, 2011; Molavi et al., 2020). Waste management

(Molavi et al., 2020; Chiu et al., 2014) And the improvement of energy efficiency (PoR, 2019; Pavlic et al., 2014). The PA could stimulate/enforce the usage of alternative fuels by vessels and land modes, by certain incentives or rules in the concessions, certain incentives in the port duties or permitting/denying access (Wiegmans & Louw, 2011; Notteboom & Lam, 2018; P. T. W. Lee & Cullinane, 2016; Lam & Notteboom, 2014; Brooks & Cullinane, 2006; De Langen, 2009; Mocerino & Rizzuto, 2019; Bergqvist & Egels-Zandén, 2012; Aregall et al., 2018).

In general, to advance the concepts of Green and Sustainable port, it is important for the PA to raise awareness in the port community (Pavlic et al., 2014). This is achieved by improving its own knowledge and providing training to its own workforce on these subjects (Di Vaio & Varriale, 2018). Also, it is important to collaborate with the other stakeholders in the port community and the local/regional/national governments in developing, among other things, sustainable spatial planning and environmental space (PoR, 2019; Lam & Notteboom, 2014; Van den Berghe, Jacobs, & Boelens, 2018; P. Hall, 2008). The PA should communicate the environmental impact of the port operations and how this is managed (Lam & Notteboom, 2014). More generally speaking, the PA should in all cases try to improve the port image. This could also be done by social strategies (Daamen & Vries, 2013).

In table E.5 an overview is presented of the identified policy measures related to the Green port and/or Sustainable port concept.

Table E.5: Source(s) used for each policy measure related to the Green port or Sustainable port concept

Number	Policy measure	Source(s)
1	Stimulate certain behaviour by incentives in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
2	Enforce certain behaviour by rules and regulation in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
3	Permit access to the port or deny access when certain conditions are not met	Brooks and Cullinane (2006), De Langen (2009), Lam and Notteboom (2014)
4	Stimulate certain behaviour with higher or lower charges for certain vessels	Mocerino and Rizzuto (2019), Lam and Notteboom (2014), Bergqvist and Egels-Zandén (2012), Aregall et al. (2018)
5	Start pilots and show best use cases	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013)
6	Stimulate resident areas for innovative businesses	PoR (2019)
7	Stimulate port workers to live in nearby area	PoR (2019)
8	Conform with the environmental regulation set by the local/regional/national governments	Di Vaio and Varriale (2018), Verhoeven (2010)
9	Develop an Environmental/Energy/Saftey/Security Management System	Puig et al. (2014), Pavlic et al. (2014), Molavi et al. (2020), PoR (2019), Lam and Notteboom (2014), Di Vaio and Varriale (2018)
10	Intensify the land use	Wiegmans and Louw (2011)
11	Reduce the length the lease period	Wiegmans and Louw (2011)
12	Monitor the vessel traffic safety and asses the effects of policy measures on the vessel traffic safety	Inoue et al. (2002)

Number	Policy measure	Source(s)
13	Raise awareness to take policy measures for the vessel traffic safety	Inoue et al. (2002)
14	Reduce vessel handling difficulties	Inoue et al. (2002)
15	Stimulate and enabling the usage of autonomous vessels	Van den Boogaard et al. (2016)
16	Collaborate with local/regional/national governments in developing hinterland infrastructure	Voster (2019), Rodrigue and Notteboom (2006), PoR (2019)
17	Collaborate with local/regional/national governments in traffic management, environmental protection, marketing and research	Notteboom and Rodrigue (2005)
18	Collaborate with stakeholders from the port community and hinterland in creating efficient and sustainable hinterland operations	Notteboom and Rodrigue (2005), De Langen, (2009), Brooks (2001)
19	Promote intermodal transport	Notteboom and Rodrigue (2005), Lindholm and Behrends (2012), Wiegmans and Louw (2011), PoR (2019)
20	Encourage bundling concepts	Notteboom and Rodrigue (2005), Groothedde et al. (2005)
21	Implement dedicated policy measures to improve the air, water and land quality and reduce the nuisance	PoR (2019), Wiegmans and Louw (2011), Chiu et al. (2014), Molavi et al. (2020), PoR (2019)
22	Raise awareness	Pavlic et al. (2014)
23	Improve their knowledge regarding the Sustainable port concept	Di Vaio and Varriale (2018)
24	Collaborate with port community and the local/regional/national governments	PoR (2019), Lam and Notteboom (2014), Van den Berghe et al. (2018), P. Hall (2007)
25	Communicate the environmental impact and how this is managed	Lam and Notteboom (2014)
26	Improve port image	Daamen and Vries (2013)

E.6. Port city interface

Maritime ports and port cities have been geographical and functional bounded with each other since the beginning of maritime trade (Polanyi, 1963). Many maritime ports and cities have grown on the basis of mutual benefits, including employment for the inhabitants of the city (Hayuth, 1982; PoR, 2019). Nevertheless, port activities and port related activities also have some negative effects on the port city, like the excessive land use, nuisance, congestion and air pollution, further discussed in section 4.1.1.

The wide land-maritime interrelations between the port city and the maritime port is described by the port city interface (Hoyle, 1989). The PA as a public stakeholder and in case of the PoR partly owned by the municipality requires a sustainable relation with the local governments. For this reason, the PA should try to find a balance between reducing the negative effects of the port on the city and advance the ports competitive position (Daamen & Vries, 2013). This is very much in line with the green and sustainable port concept, discussed in section E.5. To achieve a sustainable port city interface the PA could apply the following policy measures:

The PA could implement policy measures related to the land-use in and nearby the port area. The PA in this sense has significant influence, as it is the owner of the land in the port area. Nevertheless, it is also dependent on among others the municipality, and port regulation (see section E.1). It is commonly known by urban planners and politicians that waterfront areas are well-suited areas live and to work. For this reason, this area is the place of constant battles between the port and the city. Lately, in a lot of West-European port-cities urban areas expanded to old port areas (Daamen & Vries, 2013; Wiegmans & Louw, 2011). The PA of the PoR recognizes these residential areas as places where people who work in the maritime port could live. This reduce the pressure on the local infrastructure. Furthermore, the PA of the PoR recognizes these areas as places where new innovative business can resident, as this will improve the competitive position of the maritime port (Van den Berg, 2015). It is important to create a win-win situation, in which the housing needs, economic development, leisure and cultural amenities go hand in hand (PoR, 2019; Daamen & Vries, 2013). To do so, the PA of the port of Amsterdam and Rotterdam are creating experimental zones to try new land-use combinations (Daamen & Louw, 2016). Also, the PA could stimulate the usage of warehouses outside the direct port areas. This, nevertheless, has other negative external effects, like the increase of transport movements (Wiegmans & Louw, 2011). Other policy measures related to the land-use in the port are already discussed in section E.1.

The PA could apply policy measures regarding the consequences of its hinterland transport. Investment in hinterland infrastructure to reduce the congestion in the future (PoR, 2019; Van der Lugt et al., 2014; Lindholm & Behrends, 2012). In this the PA is highly dependent on local, regional and national governments. For this reason, it is important to collaborate with these governments in, for example optimizing the urban movement of goods. Furthermore, the EU recommends cities to develop a Sustainable Urban Transport Plan (hereafter: SUTP) (European Commission, 2019). In this the PA should also actively play a role by for example further advancing the more sustainable rail and inland waterway transport (Lindholm & Behrends, 2012; Wiegmans & Louw, 2011). The PA could enforce or stimulate certain behaviour by higher or lower port duties or denying access all together (Brooks & Cullinane, 2006; De Langen, 2009; Lam & Notteboom, 2014; Mocerino & Rizzuto, 2019; Bergqvist & Egels-Zandén, 2012; Aregall et al., 2018). The PA could apply policy measures to reduce the negative externalities of the port activities (see section E.5 for more specific policy measures).

It is important for the PA to understand that it is dependent on several different stakeholders to implement policy measures related to the port city interface (Van den Berghe et al., 2018). Therefore, the PA should develop a vision with ecological requirements of urban sustainability with, the municipality and other stakeholders in the port community (P. Hall, 2008).

In table E.6 an overview is presented of the identified policy measures related to port city relation.

Table E.6: Source(s) used for each policy measure related to the port city relation

Number	Policy measure	Source(s)
1	Create more 'environmental space' (see section E.5 for more concrete policy measures)	Wiegmans and Louw (2011), PoR (2019)
2	Encourage other stakeholders to implement sensors and use the wireless communication systems	Notteboom and Rodrigue (2005), Groothedde et al. (2005)
3	Stimulate certain behaviour by incentives in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
4	Enforce certain behaviour by rules and regulation in the concessions	Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
5	Permit access to the port or deny access to the port when certain conditions are not met	Brooks and Cullinane (2006), De Langen (2009), Lam and Notteboom (2014)
6	Stimulate certain behaviour with higher or lower charges for certain vessels	Mocerino and Rizzuto (2019), Lam and Notteboom (2014), Bergqvist and Egels-Zandén (2012), Aregall et al. (2018)

Number	Policy measure	Source
7	Stimulate resident areas for innovative businesses	PoR (2019)
8	Stimulate port workers to live in nearby area	PoR (2019)
9	Create win-win situations for housing needs, economic development, leisure and cultural amenities	Daamen and Vries (2013), PoR (2019)
10	Start pilots and show best use cases (Develop experimental zones to try new land-use combinations)	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013)
11	Redevelop existing port area	Wiegmans and Louw (2011)
12	Intensify land use	Wiegmans and Louw (2011)
13	Reduce the lease period	Wiegmans and Louw (2011)
14	Stimulate local/regional/national governments to invest in the hinterland infrastructure	PoR (2019), Van der Lugt et al. (2014), Lindholm and Behrends (2012)
15	Develop a SUTP in collaboration with the municipality	European Commission (2019), Lindholm and Behrends (2012)
16	Stimulate modal shift	Lindholm and Behrends (2012), Wiegmans and Louw (2011)
17	Implement policy measures that reduce the negative externalities congestion, nuisance and air pollution	PoR (2019), P. V. Hall (2007)
19	Measure the air and noise quality to pinpoint policy measures	Lam and Notteboom (2014)
20	Communicate the environmental impact and how this is managed	Lam and Notteboom (2014)
21	Improve port image	Daamen and Vries (2013)
22	Develop a vision about ecological requirements of urban sustainability with the municipality and other stakeholders of the port community	Van den Berghe et al. (2018), P. V. Hall (2007)

E.7. Port-centric logistics

Port-centric logistics is about logistics and distribution services provided at the maritime port where the goods arrive (PTI, 2020). Currently, a lot of goods arriving at the terminal are directly transported to another area for handling and consolidation. One of the main reasons for this extra movement is the lack of space in the port to perform these activities. However, some industry parts are endangered, like the heavy industry, oil industry, coal and construction. This might provide new space to perform logistics activities in the maritime port (Rúa, 2020). This has the following main advantages (Van den Bosch, 2020; Rúa, 2020):

- Less handling required.
- Reduces transportation cost.
- Reduces empty millage of trucks.
- Reduces road congestion.
- Release better utilization of terminal capacity (currently in Europe there is a lot of overcapacity).

Port-centric logistics, also, enables space to perform horizontal integration between different streams of containers in the port (see PI port framework operational dimension level 2: *Automated crossdocking and reshuffling operations* in figure 2.2). This development could include an Urban Distribution Centre (hereafter: UDC) providing consolidated transportation streams to more local cross-dock areas in the city centre or providing the goods directly to the final customer (Rúa, 2020). This could enable more economic, environmental and societal efficiency (Crainic & Montreuil, 2016). The PA has an important role in this development, as it is responsible for the land exploitation in the maritime port (Brooks, 2004; Baltazar & Brooks, 2001). The PA has to adopt its (physical and digital) infrastructure to enable this change (Brooks, 2004).

In table E.7 an overview is presented of the identified policy measures related to Port-centric logistics.

Table E.7: Source(s) used for each policy measure related to Port-centric logistics

Number	Policy measure	Source(s)
1	Include more space for (shared) warehouses or other logistic value-added services in tendering processes	Van den Bosch (2020)
2	Separate tendering process for UDC, shared warehouse areas and or other logistic value-added services	Franklin and Spinler (2011), Van der Heide et al. (2018), Voster (2019)
3	Develop own UDC or shared warehouses	Van der Heide et al. (2018), Franklin and Spinler (2011), Brooks (2004)
4	Develop digital platforms to enable reshuffling operations	ALICE (2019), Voster (2019), Martinez de Ubago (2019), Franklin and Spinler (2011)
5	Stimulate the use of the shared warehouses/urban distribution centre by incentives in concessions or higher/lower port duties	Mocerino and Rizzuto (2019), Lam and Notteboom (2014), Bergqvist and Egels-Zandén (2012), Aregall et al. (2018) Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
6	Enforce stakeholders to use the shared warehouses/urban distribution centre by rules and regulation in the concessions or denying access to the port	Lam and Notteboom (2014), Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
7	Adapt infrastructure for efficient use of the shared warehouses/urban distribution centre	Brooks (2004)
8	Start pilots and show best use cases	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013)

E.8. (PI) standardisation in the maritime port

Currently research is conducted to standardize the physical elements, protocols and interfaces in PI. However, it will probably take a long time before these standards and standards required for e.g. the digitalization are developed and used. The PA could play an active role in the process of developing and stimulating (PI) standards, by promoting the concept of PI with, among other means pilots and best use cases (Thijsen, 2020; Port Call Optimization, n.d.; ALICE, 2019; Van den Boogaard et al., 2016; PoR, 2019; Daamen & Vries, 2013). The PA could enforce port users to adopt to the Rotterdam rules. This include the digitalisation of the Bill-of-Lading (Thijsen, 2020). The PA could set their own (PI) standards and encourage other stakeholders in logistics to adapt these standards. However, the PA only has limited control over other stakeholders, and it might be better to cooperate. At this moment, the PA of the PoR is with the Port Call Optimization cooperating with other stakeholders in the port community improving the efficiency and sustainability of the port stay by setting certain data standards and standards for maximum draughts (Port Call Optimization, n.d.). The PA could actively collaborate with other PAs and stakeholders in the port community to develop certain (PI) standards and develop mutual understanding. Besides, the PA could lobby by the EU, ISO, GS1, IMO, UN and WTO to set nautical standards, set standards for digitalisation and set PI standards, new Incoterms and encourage these institutions to actively implement PI (Voster, 2019; Benmoshe, 2020).

In table E.8 an overview is presented of the identified policy measures for (PI) standardisation in the maritime port.

Table E.8: Source(s) used for each policy measure related to (PI) standardisation in the maritime port

Number	Policy measure	Source(s)
1	Setting own (PI) standards	Voster (2019), Port Call Optimization (n.d.)
2	Promote the use of PI	ALICE (2019)
3	Stimulate the use of the (PI) standards by incentives in concessions or higher/lower port duties	Mocerino and Rizzuto (2019), Lam and Notteboom (2014), Bergqvist and Egels-Zandén (2012), Aregall et al. (2018) Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014), ALICE (2019)
4	Enforce stakeholders to use of the (PI) standards by rules and regulation in the concessions or denying access to the port	Lam and Notteboom (2014), Wiegmans and Louw (2011), Notteboom and Lam (2018), P. T. W. Lee and Cullinane (2016), Lam and Notteboom (2014)
5	Start pilots and show best use cases	Thijsen (2020), Port Call Optimization (n.d.), ALICE (2019), Van den Boogaard et al. (2016), PoR (2019), Daamen and Vries (2013), ALICE (2019)
6	Lobby by the EU, ISO, GS1, IMO, UN and WTO to set nautical standards, standards for digitalisation, PI standards for interfaces, protocols and containers or new Incoterms	Voster (2019), ALICE (2019) WTO (n.d.), UN (n.d.), ISO (n.d.), IMO (n.d.), GS1 (n.d.)
7	Collaborate with other PAs and stakeholders in the port community in developing (PI) standards, protocols and mutual understanding	Port Call Optimization (n.d.), Voster (2019) Benmoshe (2020), ALICE (2019)

F Interviews

In this appendix an overview of all the performed interviews is presented. The appendix is structured as follows:

- Firstly, in section F.1 an overview of the interviewee's background is presented.
- Afterwards all the interviews performed are treated.
- Finally, in section F.16 some conclusion regarding the goals of the interviews are discussed.

F.1. Overview interviewee

In this section the background of each interviewee is given:

- Strategist at the PA of the PoR.
- Professor, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta.[1]
- Professor of Global Supply Chains and Ports, Erasmus University.
- Adjunct Professor of Logistics and Academic Director of Executive Education at Kühne Logistics University.
- Research Professor Transport, Logistics and Ports, University of Antwerp
- Chief Information Officer (hereafter: CIO) and manager digital innovation Groningen Seaports
- Full Professor, Freight & Logistics, Delft University of Technology.
- Technical Director of the technical Innovation Office of the Bahía de Algeciras and Port innovation manager by port of Algeciras.
- Dean of Industry Relations from Universitity Groningen.
- Teacher Systems Engineering, University Groningen.
- Professor at Mines ParisTech, PSL Research University, Director Centre de Gestion Scientifique.
- Senior Professor at Kedge Business School, Visiting Professor at the Shanghai Maritime University and at the World Maritime University.
- Director of Innovation and Port Cluster Development at Fundación Valencia port.
- Manager innovations at the Port of Amsterdam.

[1]This respondent, after repeated emails did not respond to whether they agree or disagree with the summary I use in my thesis. Nevertheless, during the interviews I asked whether they were fine with using their functions in this way.

F.2. Interview 1

Interview with a Professor in Freight and Logistics at the TU Delft (the Netherlands), who also worked with the Port Authority (hereafter: PA) of the Port of Rotterdam (hereafter: PoR) for quite some time and is currently part of the community innovation institute Smart port. Furthermore, he supervises one PhD student and a master student in the field of Physical Internet (hereafter: PI). The interview was conducted via Skype and lasted for about 80 minutes.

What is the PA currently doing in the field of Smart port and what are potential future policy measures they can take?
The PA is currently in the exploration phase. They currently don't have a clear vision and are trying to understand the concept by different experiments. Smart ports are in essence about digitalizing information and handling this information to improve the port performance. However, the PA has limited power in this area, as they don't own most of the information. They are only allowed to use the information from the service providers for certain purposes. They have in some way only an intermediate function via Port Community System (hereafter: PCS), they are not completely on the side, as they are a link in the chain where goods have pass through.

What could be the role of the PA in developing Synchromodality in the hinterland?
The PA has different layers of influence: They could change things where they have a mandate for, for example, who is allowed in the port (regulation), the port duties and leasing the land. However, the PA has no power over standardisation of containers over the entire world. The role in Synchromdality is in between, the PA has in some influence here as the port is the place where all the goods/containers are being transported from. The PA has an orchestrating role here. They can provide the means for the logistic service providers, by e.g. infrastructure, see the current Container Exchange Route (hereafter: CER) being built. Furthermore, there is a fair share of mergers and acquisitions outside the port going on and the port is lobbying and investing to improve the rail connection to Germany. The drive of the PA is to be able to guarantee as a port to its users that there are always three modes of transport available.

Also the PA is investing in hinterland Information Systems (hereafter: IS), however in the end it is up to the market to create these platforms. Nevertheless, the PA could play a role by investing in a company or creating a new company and taking more initiative than only small experiments.

What about the governance dimension? Currently the Rotterdam rules are set but not implemented, why not and what could the PA do to harmonize the rules as this is also an important part of PI?
In the end the stakeholders have to allow the PA, or any party in that matter to use their information. Sharing of information has to be seen in a commercial light, we are only willing to share information if we both benefit. However, if you want to share does not mean you are allowed to share or can share. This is determined by rules. The Rotterdam rules was an initiative to harmonize these rules, concerning the use of bills of lading. However, this change is very slow and it is hard to predict what is required in 20-30 years. This is also a long-term barrier for PI. Many Stakeholders do not want to change or cannot change. For this reason, a disruptive change is more likely to be effective, compare to AirBnB, Uber or Picnic, who are playing by different rules. The best thing the PA can do is experiment, exploring what this disruption could be and what it means.

What can the PA do for the Port digitalisation?
Currently there is a bit of an anarchy in the ecosystem. No one knows how much to pay for certain information and whether it is safe. There are no broadly agreed rules or protocols in place. For this reason, it is likely that the development of different ISs will take place in an unstructured way and different stakeholders in the maritime port will use different platforms. For this reason, the PA could play a role in synchronizing these platforms in the direction of PI needs. Furthermore, the PA could lay out requirements for PI like activities. To clarify things here for stakeholders, help them to understand the idea and guide them through the jungle. For example, lay out a roadmap for information system to allow investors in ISs to know how to join in the coming years, where they need to invest in, which data bases and communication lines etc. The PA is currently not taking this initiative.

Is it also important to make the physical infrastructure and land in the port ready for Physical internet like activities?
CER is a current example that helps to bundle flows. It could be that PI has more consequences for the layout of the port, for example cross dock places near the terminals could be required. This may imply changes in current concessions or other terms in new concessions. However, it is hard to predict what is required, this has to be further studied. For the PA it is important to think about these spatial consequences of PI, make plans and maybe in the long-term reserve land for these activities. Also, they have to look in the consequences for the customs, as currently they already cannot cope with the large stream of parcels from China. Which at this moment, they at least know a day in advance when it will arrive in the port. In the future with PI this could be only one hour. This could place new demands on ICT infrastructure, physical infrastructure and human infrastructure.

PI could enable more efficient and more sustainable transfer of goods. What could the PA do to make the port more sustainable?
PI is not an incentive to be more sustainable, only to boost efficiency, which of course leads to better use of assets and therefore could make the transfer of goods sustainable. Nevertheless, it could also create a new lock-in situation. To really achieve a lean carbonised sector another property of PI has to be used. The price setting of each activity could take into account the negative externalities of this activity (next to the efficiency incentive). In this, the PA could play an active role. As they are an important price setter in the supply chain, they could increase the price for port duties or land use. Furthermore, they could regulate who is allowed in the port. Which trucks, currently only Euro 6 trucks are allowed on the Maasvlakte, maybe in the future only Electrical trucks allowed. Furthermore, they could improve the usage of sustainable energy sources.

Concluding remark: What are the main policy directions for the PA?

1. Play a role in price setting and regulation about who is allowed in the port.
2. Play an active role in the development of the land to make the port ready for the future demand of land. The port should be strategically ready as the development can go really fast at ones. This is also required for the port digitalisation: bringing the ISs together.
3. Stimulate appropriate rules and protocols, and support the development of an IT landscape that is good for the PI.
4. The PA has to not only consult, but also bring the port community together, as it is highly uncertain what is going to happen in the future. Scenarios could help stakeholders to understand this uncertainty and be aware of optional course of action.

F.3. Interview 2

Interview with a Professor of Global Supply Chains and Ports, Erasmus University (The Netherlands). The interview was conducted via Zoom and lasted for about 1 hour.

General comment
Level 1 and level 2 of the operational dimension, being the *'Mode Hinterland Synchromodality'* and the *'Automated crossdocking and reshuffling operations'* develop at the same time. For this reason, it can be true that level 2 of this dimension is reached before level 1 is fully developed.

What could the Port Authority (PA) do to reach level 2 of the Governance dimension: the harmonized rules and standards for intraport connectivity?
They could set their own standards, however this is not very useful. The PA is, for example dependent on the EU. The PA could on their own show with best practises what works and what does not work. At this moment, the PA is already collaborating with shipping line companies to set standards for digitalisation. The PA really wants to play a role here, also for standardisation required for intermodal transport. You can better see their role as a facilitator opening the discussion between the different stakeholders.

What is the role of the PA in achieving Hinterland Synchromodality?
The PA has an important role in stimulating collaboration between the different stakeholders. At this moment, there is collaboration on certain corridors. Furthermore, the PA has set modal shift targets in the newest concessions. However, these modal shift goals play less a role for the terminal operators to invest in, for example the extended gate concept than avoiding congestion in the port.

Besides, the terminal operators are not performing the hinterland transport, but the carriers are. These Stakeholders in the end decide about the mode decision, which makes the modal shift targets in the concessions a bit confusing. Also, the effectiveness of these targets is questionable. In the future it could be true that road transport will be the most effective and most sustainable transport mode for hinterland transport, due too new innovations, like platooning.

The PA is also playing a role in the internal transport system connecting the different terminals in the port. However, they don't want to compete with transport operators currently performing these tasks.

Could the PA play an active role in providing digital information platforms, even to enable Synchromodality?
The goal of the PA and the Dutch government is to provide public sources, resources, public goods that can help develop advanced transportation systems. However, in case they provide information services on top of public infrastructure, they will actively compete with the market. This might be very sensitive. At this moment, for example not all the terminals are actively using the Portbase system. Data will in the future play even a more important role than now. In this, the PA could play an active role in providing and stimulating the exchange of data between Stakeholders to improve the port operations. Furthermore, the PA could check the data quality being exchanged. This would be useful feedback for the users of the digital platforms.

How should the PA cope with the future uncertainty?
Very interesting discussion. This is not only about the maritime port only, it is about the entire logistics system of the Netherlands or even the EU. Private organisations are looking at the government to handle these uncertainties. It is about making decisions under large uncertainty with no regrets. It is important that the PA works together with the local and regional government for making the right investments.

What is Nextlogic?
Nextlogic is a platform, which guide the planning of the barges through the port and the corridors. At this moment there is often a lot of congestion of barges in the port. This system could enable a more efficient visit of the barges in the port and thereby reducing the congestion. Furthermore, the PA is connecting the Nextlogic with the Portbase and in the future might build a similar system for the rail operations. However, this is somewhat a different market. So, maybe the PA is looking for another solution here. They started with Keyrail which is now part of ProRail.

What is the PA currently doing to make the port more sustainable and what could be policy measures in the near/mid/long term?
They have come up with the Port Vision 2030, in which the energy transition is an important subject. Another goal is to stimulate modal shift. However, to what extend this will be more effective and sustainable is uncertain. Furthermore, there is a bit of a self-fulfilling prophesy here as investing in a certain infrastructure will automatically make this infrastructure more attractive.

What is the relation between Portbase and the PA of the PoR?
Portbase is a daughter company of the PA and is also used by other Dutch port, like the port of Vlissingen, the Port of Amsterdam and the Seaports of Groningen.

We talked about the hinterland connectivity, what about the foreland connectivity, does the PA has partnerships with other international ports?
Yes, they do. They have coinvested in ports in the middle east and Brazil. Mostly by joint ventures, helping the port development. Furthermore, they are more and more exchanging knowledge and creating

an international network of ports to have some power in the negotiation with the large terminal companies and shipping liners. This could, furthermore, be a steppingstone in setting standards required to further develop the governance dimension of PI.

F.4. Interview 3

Interview with the technical director of the technical Innovation Office of the Bahía de Algeciras and Port innovation manager by port of Algeciras. The interview was conducted via Zoom and lasted for about 60 minutes.

How would you describe the Port of Algeciras?
Port of Algeciras is located in the strate of Gibraltar, which is a though environment, as there are many ports in the area. The port of Algeciras is mainly competing with other ports in Spain, ports in Portugal and the port of Tanger for the transhipment of cargo to the Mediterranean. Especially, the competition with Tanger is high, as the personal costs on the other side of the strate are much lower. For this reason, we have to provide better quality of services by innovations. The transhipment of cargo to the Mediterranean is the main focus of the port of Algeciras. There are also cargo flows by road and rail to the hinterland of Spain, but this is only a small part at this moment. Furthermore, the port has some industry flows and passengers' flows, however this is relatively small in comparison to the container transport.

What are current policy measures/innovations the Algeciras Port Authority (PA) of Algeciras is working on?
Currently, the Algeciras PA is building a management system to compare the innovations inside the port. Furthermore, open innovation framework is developed. The goal of this framework is to identify the main challenges to increase the competitiveness in the coming years. In this framework the Algeciras PA is collaborating with other stakeholders in the maritime port, but also start-ups and some universities.

The main focus of the Algeciras PA is to develop Synchromodality or in the shorter term to become a just-in-time port, by reducing the idle time: the time the vessels are occupied in the port. At this moment, the Algeciras PA is using the Portxchange platform developed by the PoR. In this platform, the shipping line companies, both the two large container terminal operators and the Algeciras PA are sharing information about the time of arrival, the time of departure and the current location to optimize the transport flows. All the stakeholders have access to the same information, which is updated each five minutes. Furthermore, the system uses predictors based on learning to estimate the arrival/departure time of a vessel. Nevertheless, this is less accurate data, which is also shown in the system.

Based on all the information provided by the platform the port planning can be improved and inefficiencies in the port operations can be detected. Besides, the vessels sailing to the port are actively updated on how fast they can travel to arrive at the right time. In this way, they don't have to wait at the port before they can enter the port or have to wait on pilotage. This also saves fuel and therefore is more efficient and sustainable.

The following step is to develop such a system for the hinterland transport and connect it with Portxchange. This is much more difficult to achieve as there are much more different and small stakeholders involved. These stakeholders also include third parties, who are much more reluctant to share data. However, when this barrier is overcome, setting operational standards is important and the Algeciras PA could play a role in managing the inland ports and cargo.

The ultimate vision of the Algeciras PA is to develop a digital platform in the port which is controlled from a 'control tower' by the Algeciras PA as a neutral party who wants to orchestrate all the port operations and related logistics activities. This digital platform consists of three layers:

1. *Internet of Things & Data layer:* Getting situational awareness (this is basically Portxchange)
2. *Advanced analytic layer:* In order to improve the predictability of among others, a delay. Provide this information to the stakeholders and improve the overall planning.

3. *Decision support system:* To, among others, advice when is the best time visit the port.

Do you think the stakeholders are willing to share the required data?
I think so, few years ago it was different, but now they realize that sharing data and getting data could improve their operations. If you can show them the value of sharing data, they will do it. That is important. We are not going to replace the port management system for the carrier. We are just providing data to improve the system performance.

What about the current Port Community System (hereafter: PCS)?
This is currently very basic, but we are developing a new one. In the new system we will get much more information about the cargo handling operations to provide the truckers better information about when they can off-load and load their trucks. At this moment, we are a bit blind. Furthermore, each large port in Spain has its own PCS.

How to harmonize the rules between the different stakeholders?
We are currently working with a start-up and the PoR to develop standardisation for port-call. This does not include the digitalisation of the bill-of-lading. From the inland perspective there was a pilot last year to set some standards for the exchange of data. In the future, in the perspective from PI there might come collaboration with other ports in the region. However, this depends on the type of cargo. At this moment, we are working together with the port of Tanger. This collaboration can be expanded by, for example connecting the digital platform/PCS.

What is the Algeciras PAs current vision on sustainability and what are potential policy measures the PA could implement in the future to become more sustainable?
The main vision is to save time and reduce congestion, which as a side effect reduces emissions. Furthermore, we are thinking about policy measures related to energy efficiency. Facilitating vessels to use LNG or electricity instead of diesel to produce its electricity in the port. However, this is a second layer of priority. Besides, we would like to increase the railway share, by first improving the physical infrastructure (working with local/regional governments) with the hinterland and later on promote rail transport with lower prices. Furthermore, stimulating the development of (new) inland dry ports to connect the cargo from Algeciras with the areas with demand.

F.5. Interview 4

Interview with an Adjunct Professor of Logistics and Academic Director of Executive Education at Kühne Logistics University and one of the cofounders of ALICE. The interview was conducted via Zoom and lasted for about 70 minutes.

How do you see the development of harmonized rules and standards required for Physical Internet (PI) and what could be the role of the Port Authority (PA) in achieving these harmonized rules?
My interest in PI is about the mechanisms and protocols that can be used to make operations in PI work and achieve its objectives, without lots of governmental oversight. Currently, this is an undeveloped research area.

Policy measures the PA could apply are developing standards for operations (long-term) and showing best practices. In general, mechanisms of control and management have to be set in such a way that the ports can pursue their local objectives while still maximizing the outcomes/objectives of the PI, in which both efficiency and sustainability are maximized. In this, we can learn from the Japanese by applying their principles for Lean manufacturing: reducing waste for example time, but also in the environmental consequences (of waste reduction/minimization).

The PA needs to think about creating incentives that make the governance take place in a cooperative fashion and not in a regulatory fashion. This requires market mechanisms and operating protocols (also including protocols for being sustainable, for example not dumping any waste in the water) and requires to a certain extent a shift in mindset to a broader perspective. Not including only the operations in the port, but also in the hinterland and the foreland of the port. The PA in this extent can in the short-term raise awareness by the stakeholders in the Port Community System.

Or even expand their vision even further. In general, PI is about collaboration. It would, therefore, be ideal when the PA understands that it is part of a larger network of ports. Currently the focus is on competition, which leads to overcapacity of the entire network and poor asset utilisation. To improve this, a logical distribution of trade flows between ports, also based on the environmental and social impact, is required.

How could the PA enable efficient and sustainable port operations and port related operations, like hinterland transport (managing the inbound and outbound flow)?
The port in general is a cross dock area, in which there is an incoming flow from sea and land and an outbound flow from sea and land. The PA has the responsibility to examine and facilitate the efficient handling of the inbound and outbound flows. This is its primary objective. It can decide whether they do this themselves or provide contracts with other stakeholders who perform these activities. For example, leasing out the land and setting regulation ensuring that the port community is aware of the goals and act accordingly.

From the hinterland and near sea perspective the PA should work with other entities to ensure the flows of the goods through the port. The goal here is to minimize the negative impacts and maximizing the benefits for the surrounding areas. Currently, the way of thinking is seeing the PA as a regulator working with other regulatory bodies to implement rules and other regulatory mechanisms when something is not working as expected. A new way of thinking is to see the role of the PA as controller of the flow through the port: trucks coming in are scheduled and slotted to minimize transit time, emissions of Green House Gasses (GHG) and so on. The same for vessels. In this way you control everything in an efficient and sustainable way. The protocols should enable this without implementing extra regulation.

For this, a Port information system is required that allows you to manage the flows of the goods (containers, bulk or liquid and so on) through the port. This is a more long-term vison. In the short term, the PA could implement regulation, like you cannot do this or stimulate this behaviour. It can use current mechanisms in a different way to make the stakeholders in the port community do what the PA wants them to do. For example, the PA could implement rules that requires all terminal operators to use shared warehouses even before having harmonized rules (level 2 Governance dimension) (companies will make it work). At this level 2 companies will work with companies they now see as their competitors.

However, to reach level 2: *Harmonized rules*, the PA should work together with other ports in setting these standards or maybe a third party will come and set these standards. Nevertheless, the PA is a major player in setting these standards. After setting the harmonized rules, you can think of level 3, integrating port operating across the globe.

The PA also plays an important role in the digital component: combining the information flows via the port operating system of, among others, the terminal operators and the shipping lines. However, currently the terminal operators are not really required to provide input or consistent integration into these systems. Regulation can be put in place to require them to do so.

What are concrete policy measures the PA could imply to improve its sustainability?
It is all about better use of assets: how can the port develop models where the asset utilisation rate is as high as possible. It should, therefore, manage the inbound and outbound flows and also include sustainable goals in doing so. To achieve this the port is required first of all, the capacity to deal with all the flows and secondly requires visibility in all the port related operations. For the second requirement sharing of information between the different stakeholders and investments by the PA in digital platforms is necessary.

How could the PA deal with the deep uncertainty of the future development of PI?
Change its mindset, think for example of the capacity of the entire North-European harbour system (from Le-Havre to Hamburg). Do I really need more capacity? At this moment the Port of Rotterdam (PoR) is restricted by its hinterland. Why not send vessels to Antwerp? As long as this mindset (me first) is not changing there will be no PI. Now it is all about optimizing the local objectives, which is often suboptimal for the bigger overall efficiency/sustainably.

Furthermore, the PA is spending our tax money, so they have to look at the optimum from a society perspective. This might, for example, be not adding new capacity. The Pa of the PoR are currently not graded in this way. They only have to maximize the return on their (local) investment money wise.

Patrick: How does it work with the terminal operators, because I think as long as there is competition in the chain it is hard to achieve such a world?
Collaboration between all entities from beginning to the end of the supply chain is required. There will always be competition between the ports with the same hinterland, but they should also consider maximizing the profit of the entire region. This will increase the profit of everyone. This is not how they think, they look at their own territory and their own hinterland. There should be a balance. Nevertheless, it is hard to find the optimum or the next best optimum, because there are so many stakeholders involved. It might be wise to look at the price of Anarchy: how can you reduce the gap between the actual performance and the best theoretical performance.

In the end, it is important you show them how they can collectively make more money. People don't care about whether your vessel/truck is used, they only care whether their goods are delivered when it is supposed to be delivered. It is about profit, right? So, in some cases sharing is a much better option. Why not creating the North European port monopoly? This isn't against compliance regulation. This regulation wants to avoid individual monopolies, but they don't care about a shared monopoly (Cartels). Look for example at the airline or ocean container shippers industries.

F.6. Interview 5

Interview with a senior Professor at Kedge Business School, visiting Professor at the Shanghai Maritime University and at the World Maritime University. The interview was conducted via Zoom and lasted for about 60 minutes.

What policy measures could the Port governments (hereafter: PA) apply to make the port and the port related activities more sustainable or green?
From my background, as a shipping and port economist, I look at trade patterns and trade characteristics. Where my main specialism is in translating this into applications for the port and shipping industry. I am not an expert in Internet of Things (hereafter: IoT) solutions, but I follow these developments. For the sustainability, the PA is already doing a lot. Nevertheless, many PAs don't have a clear view of their environmental impact or have a general overview of the operational aspect in the port. This should be first improved, by applying e.g. IoT solutions. Furthermore, the PA should use Physical Internet (hereafter: PI) and IoT applications to become more sustainable, to reduce the carbon footprint for example.

How could the PA improve the visibility and efficiency in the port, also regarding the many different stakeholders involved in the port?
First, the PA should focus on its own operations, where they have control. In the landlord model this means they should increase their visibility in the port safety and the port planning. The second, and much more difficult step is to collaborate with other stakeholders over parts they don't have full control. Of course, they are already doing this, but not to the extend required for PI. To achieve this collaboration they should use pilots, show best use cases about what, for example, a shared warehouse could mean for the efficiency or the general idea of the shared economy. They could, furthermore, show use cases of sharing information via a digital platforms. At this moment, many companies are very wary to share information.

We might go back to a more public controlled port, if this is more efficient. It doesn't make sense to split the terminals of the port into 5 or 10 pieces. Which is current practice in many landlord ports. This leads to a lot of inefficiencies. There is an important role of the PA to improve the port efficiency, by for example forcing the terminal operators to work together. This is, also, applicable for ports in the same region. An example, of a coffee company in Corona times: normally, vessels will go to a port in Italy, but due to Covid-19 the vessels were rerouted to the port of Le Havre. Nevertheless, this port did not have enough capacity. In the future, PI could solve this kind of problems by immediately checking at which port there is warehouse capacity for the Coffee. This also requires access to these warehouses. To achieve this, old silos built by most industries for the past 25 years have to be broken down. These silos are not a bad thing, it was another time when they were developed. This will, in the end, significantly reduce the time to market.

How do you see the role of the PA in the development of the governance dimension?
The governance dimension should be adjusted to the new way of doing business and in this respect the PA should become more an entrepreneur. This is already starting, as a lot of PAs are working with start-up trying to see what works and what not. Promoting the innovation and the new way of thinking. The PA has an important role here as it is a public entity. People don't often fully trust private companies with new innovations. Is this for their own benefit or for the benefit of the society? This is, also, the case with the reduction of emissions of Green House Gasses (hereafter: GHG) by shipping line companies. Even if they really reduce the emission of GHG, people don't often believe it. For this reason, the PA could play an important role in the development of the governance dimension.

I'm not an expert in the governance dimension of PI, but I think international institutions should change current regulations and set certain standards. This is also important for the exchange of data. This, will, I think take a long time, in which new best practice standards will be added and applied worldwide. In this the PA could play a role.

Furthermore, the PAs of different ports should change their own mindset by collaborating with each other and take a more societal perspective. At this moment, for example there is too much terminal capacity in the North-west region of Europe. Also, if you look from this narrow perspective and you want to compete as a port you need a lot of storage capacity, which doesn't make sense from a wider perspective. Two good examples of collaborations are:

1. The collaboration between the port of Marseilles and Le Havre in the rail connection from Lyon and Geneve. They have a shared interest here, as they compete for the transport to Lyon, but afterwards both ports have not enough transport demand to have a dedicated service to Geneve.
2. The merger of the port of Malmo and the port of Copenhagen across the border of Sweden and Denmark.

The PA's should stop competing on, for example, technology development of IoT or PI and share information from their own Port Community System (hereafter: PCS) with each other. At this moment, shipping line companies are working together to develop a shared portal as they understand it doesn't make sense to develop separate ones. This doesn't mean you are not competing. For example, there should be competition on services on the infrastructure, but not in developing two separate infrastructures for the same purpose. There should be a balance between competition and collaboration. This, also, includes thinking about more regional ports. What is their function in the network and provide them adequate solution to be more efficient and sustainable. It doesn't have to be big.

How do you think the PA could enable Synchromodality in its hinterland?
The PA has an important role here in showing by for example, pilots or best practices what this will bring to the society. Furthermore, the PAs are already investing in hinterland infrastructure and inland terminals to improve the hinterland connection. They could for example also invest in connecting the PCS with inland terminals to reduce the time to market. The digital connection is really important here.

Do you think the PA should play an active role in developing this digital platform?
They should, but also in informing people. It is 50% about the technology and 50% about the people. PAs and other stakeholders in general should spend money in making people understand why something is happening. Why is PI the future? Why is Synchromodality a good thing? Improving the awareness is really important.

F.7. Interview 6

Interview with the director of Innovation and Port Cluster Development at Fundación Valencia port. The interview was conducted via Zoom and lasted for about 60 minutes.

How would you describe the port of Valencia?
The Port Authority of Valencia manages three ports located along 80 km of the Valencian coast:

1. The port of Valencia is the biggest of the three ports and it is the main container port in Spain and the 5th in Europe. It is the natural port of the Madrid area and it combines transhipment with import and export operations (almost 50%-50%). It counts with three container terminals operated by CSP (COSCO), APM (MAERSK) and TIL (MSC). The new terminal in the North extension of the port will be developed in the following years and will duplicate the capacity of the port.
2. The port of Sagunto was originally developed for the iron and steel cluster located next to the port (currently Arcelor Mittal plant) and currently manages also manages the transhipment of e.g. cars and LNG.
3. The port of Gandia is a small port which in general handles conventional cargo and specialises.

What research are you currently working on in respect to Synchromodality and what is the Port Authority (hereafter: PA) of the port of Valencia doing in this direction?
I am the director of innovation and port cluster development at Fundación Valencia port (hereafter: FV). This organisation is a research and training centre for transport and logistics, which serves the port and logistics cluster of the port of Valencia involving all public and private stakeholders working around the port activity. FV, furthermore, provide technical assistance to other ports outside the port of Valencia. Currently, I am also chairing ALICE's 'Corridors, hubs and Synchromodality' thematic group and WATERBORNE's 'Port and Logistics IRAG'.

The port of Valencia fosters multi-modal transport and Synchromodality investing to improve railway infrastructures (inside and outside the port area – e.g. dry ports and key railway corridors with poor infrastructure) and developing information services through its Port Community System in order to improve the efficiency of road and railway operations at port and inland terminals through better coordination of the actors involved. Furthermore, the PA is advancing Synchromodality, by showing best practices and promoting the innovation. It has an important role in raising awareness.

At this moment, in the framework of different research projects, we are developing different kind of tools and proof of concepts in order to improve the ISs for the hinterland connections. They involve IoT, Artificial Intelligence and blockchain technologies and new processes and business models. For instance, we are doing research in a collaborative approach for specific port-hinterland railway corridors that could lead to improved service levels and improved flexibility to select the best transport option through the development of an intelligent shared shuttle service, where the PA or the terminal operator could play a new role deciding about the containers to be loaded in each train following the rules agreed.

Terminal operations could also be significantly improved this way, by reducing internal movements. (E.g. At this moment, a shipping company or a freight forwarder has a contract with a specific railway operator, who has a train to Madrid on Tuesday and Thursday. However, when one container cannot be transported on Tuesday it has to wait until Thursday, before being transported to Madrid. This doesn't make sense, as there are several train services every day and other operators would be capable of sending this container on Wednesday or even late Tuesday. The intelligent shared shuttle service will avoid these situations) Nevertheless, the PA has little power to force this kind of collaboration.

How could the PA further advance the operational dimension?
To achieve level 2 of the operational dimension: *Automated crossdocking and reshuffling operations* the PA could enforce automation in its concessions. This is also currently what the port of Valencia is doing with the new tendering of a terminal. However, in the end the terminal operators have to develop this. Furthermore, the PA could stimulate sharing different port, transport and logistics assets, like spaces in warehouses through their tendering requirements and developing new services and tools in their PCS or other information platforms. However, while sustainable requirements are always incorporated in any tender process, other approaches related to collaborative systems sharing logistics capacity is not common.

Is there collaboration with other ports in the region and how could the PA advance this?
There is some collaboration with other ports in the area, as they face the same problems and challenges. However, each port develops its plans, tools and actions individually, under the supervision of ‘Puertos del Estado’, and they are competitors. For instance, the PCS is something that differentiates one port from another and influences in its competitive position. Now there are multiple barriers that limit the flexibility to change the destination port of a loaded container once it is already in the vessel. Collaborative approaches to provide this flexibility could be something to explore. For example, it could happen that a vessel has to call first the Port of Barcelona, but this port is unavailable due to weather conditions. The captain could decide to change the route and go first to the port of Valencia. Now it is difficult to take this kind of decisions with no detailed information of the costs and consequences of the two options, and there is no flexibility to re-plan logistics unloading in Valencia containers that where expected to be unloaded in Barcelona or vice versa. This is against Synchromodality and PI principles. To improve this flexibility, the rules and regulation of the different ports/modes of transport and so on should be aligned. This is very hard to achieve. It is necessary to find the win-win situation between ports and have a balance between competition and collaboration.

What are digital innovations you are currently working on?
At this moment, we are advancing the Internet of Things concept (hereafter: IoT) with all type of sensors at port infrastructure, transport means and cargo providing as much real-time information about the port and logistics operations as possible. The objective is to make this information available through different platforms and data-sharing spaces, and develop all kinds of value-added services that improve the predictions, planning and finally the execution of the operations in the port. These services might in the future become available via the PCS or other platforms. At this moment, we are working on best practices to further develop this strategy and develop the port strategy for the coming 10 years. In this context, we are collaborating with other ports and international groups, like the Digital Logistics Transport Forum, IPCSA or the DCSA.

What are policy measures the PA could apply to improve the sustainability of the port?
Currently, we are developing the Strategic Plan for zero net-emissions in 2030 for the port of Valencia. This will include a detailed roadmap to achieve this objective with many different actions involving the use of renewable energy sources and the intelligent management of the energy grid, the on-shore power supply to vessels and the development of hydrogen for different port-related uses. Furthermore, there is collaboration with regional governments to define an ambitious plan in order to update the road transport providing services to port traffics according with the zero emissions objective.

F.8. Interview 7

Interview with the CIO and manager digital innovations of the Seaport of Groningen. The interview was conducted via Microsoft Teams and lasted for about 60 minutes. The interview had an open structured, however sometimes is the PI port framework used for guidance.

What is the role of Seaport of Groningen in the North of the Netherlands?
We describe ourselves as an industrial area with a port. There is a lot of supply of products that are processed in the port and later on transported into the hinterland. Furthermore, Offshore is an important element.

What is the Port Authority (hereafter: PA) of Seaport of Groningen doing in regard to the digitalisation?
The PA of Seaports Groningen has all its data collected in the cloud, which means that there is now time to focus on new innovations instead of running the technology and its maintenance. Unfortunately, there is almost no discussion about digitization yet. At this moment we are working on, among other things on:

- Autonomous vessels.
- Creating data platforms.
- Developing a new port information system with a connected data management tooling system

to better utilize the data. This is a first step in the direction of the digital dimension of Physical Internet (hereafter: PI).

- Running some pilots with 5G. This will however not fully cover what is required in the future. For this reason, we might develop a LTN network.
- Sensor projects and improving the radar systems.
- Participating in the national discussion about the connectivity in and around the port.

Ultimately, it is about the digital infrastructure being ready to take further steps towards PI. There are still many basic things to be done. My job is to convince people what the future will look like, that PI is for example coming. In the current Business Plan of the PA this is not covered. Furthermore, this is hardly discussed with other stakeholders in the port, only with customs and other service providers in the port. Only in the last few weeks have there been some initial discussions with shipping line companies, as these companies now also understand digitalisation is important.

In general, the role of the PA is to develop and maintain the infrastructure, issuing land concessions and some other services, however the PA could also play a role in creating awareness for the changes that are to come, for example with pilots.

What is Portbase? Could this be a first step in the direction of digital platforms required for PI?
Portbase is nothing more than a roundabout in which stakeholders insert information about the arrival time, the departure time and characteristics of hazardous substances. Portbase is used by almost all ports in the Netherlands. It is quite administrative. Often data is entered manually, which sometimes contains errors. This system still needs to be improved, before it is useful for PI. The Port Authority of the Port of Rotterdam is currently developing the Port call optimizing system, in which departure and arrival times are more visible.

As you describe, the Seaport of Groningen is an industry with a port. What could PI mean for the industry, for e.g. bulk goods or goods larger than a container, including for offshore?
So far there are only a few ideas about this. Logistical flows are also required for the construction and maintenance of offshore wind turbines. What would this look like. Could be a great new project.

How do you see the role of the PA of the Seaport Groningen in the consolidation of flows?
We are currently working on the accessibility of the hinterland. For example, discussions are being held with the regional governments about extending the N33. The aim is also to make this the greenest highway in the Netherlands, with a data management system. In addition, we have a rail port and some hinterland transport via inland barges. Until now, these have mainly been dedicated flows, but this may change in the future.

Are there any thoughts about harmonizing rules for all the different stakeholders in the port in order to enable developments towards PI?
Not really. However, standards for recycling flows such as steel and plastic are being considered. There are dozens of different types of plastic and only certain types can be processed in certain factories. PI could play an interesting role here.

What are policy measures you apply and could apply in the future to make the maritime port more green?
The main goal is to reduce CO_2 emissions. We are currently working on the energy transition to hydrogen. In which a smart platform makes decisions for the entire chain. There are two reasons why greening is so important for the Seaport of Groningen:

1. The port is located next to the Wadden area, which is UNESCO World Heritage protected area. For this reason, there is an active discussion with environmental groups about each expansion step of the port. This is also means we have a natural brake on the expansion of the port.
2. Our belief that growth should always be green.

Concrete policy measures are:

- Green shore-based power, which means that diesel is no longer used for the electricity supply on the vessels in the port.
- Cleaning ballast water: there are more and more exotic animals that threaten the ecosystem of the Wadden Sea Region (e.g. the Pacific oyster). This system cleans the ballast water by using ultraviolet radiation.
- A payment system in which greener vessels have to pay less to enter the port and the supply of hydrogen for hydrogen vessels are also being considered.

F.9. Interview 8

Interview with a Professor at Mines ParisTech, PSL Research University, Director Centre de Gestion Scientifique. The interview was conducted via Zoom and lasted for about 45 minutes.

How do you see the development of the Governance dimension in PI and what could be the role of the PA?
In a port you have different terminal operators and the PA is the big umbrella behind it. They provide a framework for the players that actually perform the operations. So, they can play an important role in setting rules/regulation or standards for IT systems, like the Port Community System (hereafter: PCS).

What is the role of a maritime port in the PI network?
Physical internet (hereafter: PI) is a network of network, which means when you go from one network to another you can still have some visibility on the services of the other network. An example is a maritime company with their own vessels and their own operations. They have full visibility of their own network. They can offer some services to their customers, but maybe for me as a shipper, I also use another company for the inland transport. Now you have to go to both systems to create an end to end route. The idea of PI is that you can plan from begin to end, regardless of the suppliers and also are able to change it according to your preferences during the transfer. In this, information has to flow from one system to another and a maritime port as a hub is an important place to link all the chain services. The port really is a place where they can gather, pool and broadcast offers to different players. This really would be a competitive advantage in the future. It, thereby, is important to increase visibility on services and to ease the connection between the services within the same port, even if these services are provided by logistic service providers and not by the port authority. They should play the role of a facilitator providing the digital and physical infrastructure (and land) to enable this. They, furthermore, could in the short-term start pilots to raise awareness and show best practices.

What about collaboration vs competition between ports?
There will always be competition between ports with the same hinterland. However, it is in the end important that the PA knows its role in the network and acts accordingly. This will make the maritime port far more attractive.

How do you see a design of a maritime port, in comparison to the rail-road hub you designed and what could be the role of the PA?
My knowledge of a maritime port is not sufficient to answer this question. However, currently one of my PhD students is developing an intermediate platform on truck level. This is a digital platform, in which all inbound flows are reshuffled to outbound flows and then offered to carriers for the right price. An example: you, as a trucker have some pallets for nearby Paris and a few pallets for inside Paris. What if you could go to our platform, offload the pallets for outside Paris and add some extra pallets that match your destinations in Paris, all for better prices. This could mathematically also be applied for a maritime port or other hub types, in which transshipment between different modes of transport takes place.

How do you see the development of future standards required for PI, what would this implicate for the maritime port and what could the PA do?
At this moment the rules between the different modes of transport really differ. Nevertheless, more agreements are being developed to more easily transferred goods from one system to another. For example, in Europe the same documents are used for road and air transport. In this way, you don't have to duplicate all documents or adapt it to the other system when changing from transport mode. There will also be difference in the future, due to difference in codes to refer to a specific vessel or airplane for example. However, at a certain moment a more aligned set of rules will be welcome so the flow of goods from one system to another is easier. This set of rules is easier to develop in one region (Europe/Asia/USA), but harder to align between these regions. It is important that large institutions related to these industries will work together, also on digitalisation of the paperwork. At this moment, the paperwork will after the Brexit already be digital for road transport between EU and the UK.

What are other research areas you are currently working on?
Currently, I am working on projects related to Internet of Things technology on traffic and cargo level. One of these projects is to track and trace assets with 5G technology. Using sim cards of truckers and Artificial Intelligence to develop a real-time freight traffic overview for France. The goal of this system is to develop a shared vision, check the effects of certain rules or new infrastructure. Nevertheless, there are some issues with privacy here.

Furthermore, I am working on an urban logistics project in Paris. In this project an interconnected system and new infrastructure are used to interconnect service to reduce the footprint of logistic activities in Paris and in the entire France region. Results will be published soon.

F.10. Interview 9

Interview with a research Professor Transport, Logistics and Ports at the University of Antwerp. The interview was conducted via Zoom and lasted for about 50 minutes.

What is the role of the Port Authority (hereafter: PA) of Antwerp in its hinterland and what role could they possibly play in the future?
In the past, the PA of Antwerp barely interfered in the hinterland. This was for the local, regional or national governments and the operators on the network. However, in recent years the PA has become increasingly involved, for two reasons:

1. The PA realizes that the competitiveness of the maritime port depends on the competitiveness of its hinterland. They recognize that the maritime port is part of a worldwide logistics chains and when improvement is achieved somewhere in those chains, the port will also become more attractive. This is certainly the case for the hinterland, because in this part of the chain the logistics costs are relatively high.
2. The local/regional/national governments are investing less in these networks.

At the moment, the PA invested in the platform Rail port in order to promote the use of rail transport in the hinterland. It is also increasingly involved in inland shipping operations. In this, the PA has created its own registration system in order to plan better and to reduce waiting times. In addition, the PA is the main shareholder of the national pipeline company in Belgium.

In the future, the PA could actively participate in the development of inland terminals. This is only a bit tricky in terms of governance. Another role is to facilitate: enabling data exchange between Stakeholders that is necessary for, among other things, intermodal / synchromodal transport. The PA should create win-win situations for the stakeholders. Especially, where the market stakeholders trust each other is too low. In addition, the PA could impose some conditions in the concessions with the terminal operators. However, it cannot go too far, as the powerful shipping companies can simply decide to go to another port. In addition, it is difficult to control behaviour with these conditions, because sometimes you require the terminal operators to do something that they have no direct control over. See the example of the modal shift targets in Rotterdam.

What about the container terminal operators in Antwerp at the moment, is there mutual exchange of goods and data? And how could the PA possibly promote this in the future?
In Antwerp you have four large container terminal operators (from large to small): 1. PSA 2. DP world 3. Euroports (has various cargo) 4. Zuidnatie (has various cargo). In terms of exchange of goods, it is very limited, only if the market requires it. Digital exchange of data is also minimal, because they compete with each other. The PA could play a role in improving this by setting up data platforms to, for example improve the planning, for its port operations and hinterland. The exchange of data would provide, in this example, insight in where capacities are available in real-time and how to respond to this. Moreover, in the future the PA could possibly free up space to promote the exchange of goods. In this, they investigated at a distribution centre for last-mile delivery to the city of Antwerp. However, the port of Antwerp and the city of Antwerp are two completely different worlds. The port serves much more than just the city of Antwerp and what is consumed in the city of Antwerp comes from many directions, even from the port of Rotterdam or the port of Hamburg.

What about the data platforms in Antwerp, are they linked to the Port Community System (hereafter: PCS)? And what possible next steps could the PA take?
As the port of Rotterdam has Portbase, has the port of Antwerp the PCS: C-point. This system has improved a lot in recent years. This now also includes modules that specifically deal with inland shipping. In addition, the PA is looking for modules that would improve the planning for road transport. Only C-point was a lot less advanced a few years ago, which led to the initiative from Alfaport and shipping line companies to set up NxtPort. NxtPort had the aim to improve the commercial transactions between stakeholders in the port. At first it was to counter C-point, but in recent years the PA has undergone good development and they are now also the sole shareholder of Nxtport.

They are still separate platforms, however they are increasingly being integrated. This further integration could also be the first next step. Besides, in terms of data exchange and data use, we are really still in the infancy stage. Many things are simply not yet digital. The PA is working on this port digitalisation and also tries to get stakeholders on the digital cart. They try to create awareness of the advantages of exchanging data and using it. This is partly done by creating win-win situations for the stakeholders, but sometimes also simply enforce something through legislation and regulations. An example of this is the customs declarations in Antwerp. The stakeholders involved are now required to submit the necessary documents via NxtPort. This is often done manually (via email and physically), but it is increasingly being digitized. In the further advancement of digitizing the documents the PA is only dependent on global players. In general, the role of the PA at this moment is more wait-and-see, see what the market is picking up and what is missing and then respond to that.

Is the PA working on applying SMART technologies and what are any next steps in this?
The PA is experimenting with the placement of sensors, the use of drones and autonomous inland vessels. But, leave the experimenting mainly to other stakeholders. The PA only provides access for all kinds of tests. Furthermore, they want to accelerate digitization, but it is still unclear what role they want to play in it. They probably don’t know their exact role either. If the market can do it, the PA does not want to duplicate it.

How could the PA advance the governance dimension?
The Incoterms and Rotterdam rules are important, but the most important thing is to agree who owns which data and who can use which data under which conditions. That’s breaking point. The big challenge does not seem to be the technology, it already exists: Blockchain, among others. The big bottleneck is trust. As a neutral party, the PA could play an important role in this by proposing rules and working together with stakeholders to determine these rules. In this, the PA could also cooperate with other ports in the region or on the other side of the world. However, there are two obstacles to this. Regionally, the ports are also competitors, which impedes cooperation and on a global scale, PAs mainly want to establish their own rules and not adopt rules from another countries or continents (Chauvinism). This can be observed by in the development of NxtPort, which was actually intended to become an international player, but now only is used in the port of Antwerp. In addition, the PA could be an important intermediary between stakeholders, for example by promoting data exchange by hosting a platform.

How could the PA deal with all the uncertainties in the future?
It is important that the PA is open to new innovation and looks at what is developing in the market. Take a good look at what the market demands. In this, the PA is currently a lot better than ten years ago, when the PA mainly imposed things on other stakeholders and they had to deal with it. However, this is no longer possible, the market power of the PA has changed. The role of the PA in the future is more in facilitating, mediating and performing consultancy to the stakeholders in the port community.

F.11. Interview 10

Interview with a teacher from the University of Groningen in system engineering. The interview was conducted via Zoom and lasted for about 70 minutes.

What are the main components of Physical Internet and what could the Port Authority (PA) do to enable this?

1. *Decentralisation:* The coordination in the Physical Internet (PI) network should be locally organised between different agents. This is the most important element.

2. *Modularity:* Each transshipment should have its own unit of transport (a container for example).

3. *Automation:* Less human intervention. In the Port of Rotterdam (PoR) this is already happening on a large scale. This makes the port more effective and safer.

4. *Openness:* For the PA it is important to allow new participants and enable new innovations. It would in this respect be wise to collaborate with other maritime ports around the world and give more power to the little parties. On the seaside you have the oligopoly and on the land side there is more competition. Give the carriers on the land side, for example more power.

In general, should the PA encourage new things and enable these elements.

As decentralisation is the most important component of PI, how could the PA stimulate this in the maritime port?
At this moment logistics is already quite decentral, however still a lot of decisions are made top-down. In the long future the PA could impose standards. However, it would be wise to collaborate with other large ports to set standards for the communication in the PI. The PA on its own has only limited power here. It will all take time.

What are other policy measures the PA could apply?
The PA could make land and infrastructure available for shared warehouses or for the development of the ‘hybrid PI’, in which there are two parallel streams: one in which the PI is applied and everyone can join and the stream, in which the way logistics are currently operates continues. A disadvantage of the ‘hybrid PI’ is that the old stream can apply the good new innovations of the PI stream.

A first step in developing these parallel streams could be a shared warehouse in which containers open at the top and the pallets are taken out (interfaces on top the pallet). In this way, less movement of pallets is required to take out the right pallet. However, first more research to this concept is required. Moreover, the PA could develop platforms to enable the exchange of goods in the shared warehouses. This platform could be auction based. This auction-based system works with two auctions, one auction for the matching of the π-containers with the right destination and one auction for the matching of the π-container with a mode of transport.

A lack of digital infrastructure could make the maritime port less attractive, what for digital infrastructure is required in the port, what could the PA do?
Containers should have sensors, like RFID. Vessels might require satellite connection for connection outside the port, but in the port, the PA should enable Wifi to connect all the different elements of PI. For enabling the digital connection between the terminals, the PA should set standards, like earlier discussed.

What are the implications of PI for the customs in the port?
In the end, the main performance indicator for customs is the friction. The more friction in the port the less attractive the port will become. There is a lot of uncertainty about how PI will affect the customs. Currently, there are planning to do a use case in the Seaport of Groningen in which there are cameras in the container. However, what about trust and about the reliability of the system. The camera footage could be easily corrupted.

Endnote
Take everything I said with a grain of Salt. It is very uncertain what is going to happen in the long-term. Furthermore, at this moment there is a problem with the long-term vision. The PA of the PoR has some clue, but a lot of stakeholders don't. It might be wise for the PA of the PoR, the PA of the Seaport Groningen, the universities of Groningen and Delft to increase awareness by making small understandable professional videos about the vision of PI. This is an absolute must. Furthermore, this will align their general vision. Also watch out with using the analogy with the digital internet as there are obvious differences.

F.12. Interview 11

Interview with the manager innovations at the Port of Amsterdam. The interview was conducted via Zoom and lasted for about 60 minutes.

General information about the Port Authority (hereafter: PA) of the Port of Amsterdam
We, as the PA, facilitate the stakeholders of the port community. The market is ultimately responsible for the transport, handling, transhipment and storage of the cargo.

In general, you can distinguish four flows in the port:

- *The physical flows in the port:* the movements of vessels, trucks and trains. In this, you know quite well when a vessel will arrive.
- *What's in the vessels:* With coal, this is easier to detect than with 2000 containers on a vessel, with many different owners of the cargo. As a PA you will not find out about what is exactly on the vessel. Stakeholders often do not want to share this information.
- *Documentation:* The incoterms, customs declarations and port duties.
- *Financial flows:* These are in contrast direction to your logistical flows.

As the PA we, in general, have three roles:

- *The traditional role of a PA in a landlord port:* We ensure that the vessels are safely transported from the lock in IJmuiden to the quay in Amsterdam and vice versa. Furthermore, we rent out land in concessions. In this, the stakeholders must comply with the regulations imposed by the government.
- *Matchmaker role:* In this we look at innovations. Are these applicable for our customers?
- *Co-creator role:* In this we look with the market to see what we can develop. As the PA, we could among other things help with research and investing in the initial phase.

Furthermore, our sources of income are in the short term: the seaport and inland port duties. These port duties are also used to encourage clean ships through a discount. In the long term the main source of income is the concession payment of land. Often these concession contracts also include the quay rent for the terminal operators. Furthermore, it is difficult to control behaviour with the concessions, as they last for about 50 years.

Personally, I am the innovation manager of the port of Amsterdam, part of the innovation and strategy department. The Port of Amsterdam has four main themes in the field of innovation:

- The energy transition

- Circular economy
- Logistics and transport
- Digitalization

What are you, as the PA, currently doing to improve the digitalisation of the port of Amsterdam?
We distinguish three dimensions on a Rubik's cube:

1. *The time:* Three time periods are distinguished: the short / medium / long term. In the short term we would like to have information to optimize the daily planning. In this, we work together with the terminal operators and other planners. In the medium term, we would like to run reliable simulations to determine whether, for example, a terminal should be built at a certain location: does this not cause congestion? In the long term, we would like to estimate what the development of the port could be. Can we expand? How are things going with regard to environmental guidelines, isn't it too congested? What about hazardous substances?

2. *The data itself:* How do you generate the data? By means of your own sensors or other sources, including among others the terminal operators. This data must then be stored and analysed with, for example, Artificial Intelligence and Machine learning in order to do something useful with it. However, the stakeholders are not very willing to share certain competition-sensitive data. It could possibly be made anonymous (this is already done in Portbase).

3. *The third axis:* This has partly to do with the energy transition, the logistics part and the physical part. In which the physical part is about the cables in the ground and the transmission towers that make 4G / 5G possible. In this we give freedom to the stakeholders and we are further dependent on companies such as KPN, Ziggo and the transmission tower companies. They must see sufficient profitability before they will construct this infrastructure. This has not been the case until now (often limited 4G coverage in the port). We could steer with the port regulation, which states, among other things, what the vessels must comply with, how to deal with dangerous goods, but also how you steer the vessels that enter and leave the port. This also applies to inland shipping (not for rail, this is carried out by Prorail). This is legally laid down in the IMO and other national regulations. Nevertheless, this is more limit applicable on the digitalisation.

What is the role of the PA in improving the hinterland operations?
As the PA, we could try to get different stakeholders on board to, for example use the rail connection to Doesburg. Nevertheless, this is hard to accomplish as what is being transported and the terminal operators involved all have different Incoterms. For example, with the containers, a party like MAERSK is the most important stakeholder, which often takes care of the before and after transport. However, you also have containers that are delivered to the quay and then are transported further inland by another party. Furthermore, this is completely different for oil / coal. We cannot influence this very much, as we are really only a regional player. If we demand too much, the carrier will simply move to another port.

Currently, we have the Port Community System (hereafter: PCS): Portbase, in which a fair amount of data is shared for port duties, customs declaration and to get the vessels safely through the port (on the seaside). It is just that this data is not allowed to use for the optimization of the hinterland transport. Sharing data remains a problem. Different stakeholders are afraid that they will lose their competitive advantage. We have tried to organize all the hinterland transport to a certain location via rail via one terminal. Nevertheless, it did not work, as the other terminal operators were afraid to lose their business. However, the PA could play a role by showing through serious gaming and pilots that sharing data has benefits for everyone. Or the PA could play the role of a co-creator: it is only important that some stakeholders are willing to participate (this is often not everyone). In general, it is important to look at what the port customers want. Otherwise, promoting and investing in innovations is useless.

How is the relation of the PA with the city of Amsterdam?
We have good consultation with the municipality of Amsterdam. The municipality draws up the zoning plans and other governments (the environmental service) issues environmental permits. It is important for the PA to safeguard the interests of the stakeholders in the port community as well as possible. Not that, for example, you have promised a terminal operator that they can start their business somewhere

and you have to disappoint them later on. The municipality owns 100% of the PA, which means that they receive annual dividends payments. Moreover, the PA also provides a lot of employment for people living in the city. Nevertheless, the city is also bothered by us, there is a lot of need for housing and the port takes up a lot of space. Furthermore, there is also noise pollution and the emission of Green House Gasses. This is closely monitored with sniffer poles and sound sensors.

Sharing assets is an important element of Physical Internet (hereafter PI), how do you see this in the hinterland and what could the PA do to encourage this?
There are many limitations to this, such as the previously discussed reluctance to share data. But also, for example, the uncertainty of transport via rail. In this we are very dependent on Prorail, as they decide how much freedom we get on the rail connections to the hinterland. Furthermore, we are also dependent on rail operators and other stakeholders in Germany, Austria, Switzerland and Italy as freight trains do not stop at the national borders. This causes problems, as the legislation between these countries is too different. This is currently being worked on.

In addition, the transport of dangerous goods must also be taken into account. More and more houses are being built next to the track. This limits this throughput. The same also applies somewhat for inland waterways and road transport, in which Rijkwaterstaat is the important stakeholder.

In general, it is important for the PA to outline where the port of Amsterdam is going regional / local / national governments. This not only concerns the physical flows, but also the 'environmental space' required for the port and its hinterland.

Furthermore, we don't have much legitimate power to improve the sharing of assets. This is more up to regional or national governments. We could make certain demands in the concessions for example, but if this is too much the carriers and terminal operators could also decide to go to another port. In addition, it is generally difficult to move the stakeholders to more rail or barge transport, because the trucks are more flexible and less complicated. Instead of dealing with three different companies, you are only dealing with one party.

Would there be an important future role of the PA to assemble the fragmented data as good as possible?
The PA cannot do this alone. It is important to consult with other ports in the region, but also ports worldwide to establish standards for customs declarations and so on. We could start pilots to see what works and what does not work.

A general problem is that each stakeholder almost has its own website with its own login details and so on. This makes it all very unclear and non-transparent. This could be solved with the iShare idea. In this idea, everyone has his or hers own ID and the data owners can give each ID certain access about whether you can see certain information or even adjust the information. This could, for example, work in a port, in which every involved stakeholder gets his or hers ID.

Many people think that PI requires a centrally managed control tower, but that is not true at all. It would be better if the control is decentral organized. That each stakeholder optimizes its own operations, also based on data from other stakeholders directly in its environment and thereafter shares this information so other stakeholders can optimize their operations, like a flock of birds.

It is also important to look at data patterns from, for example terminal operators. Perhaps a more limited PI application is good enough for an oil terminal, while for a container terminal this should be more extensive.

F.13. Interview 12

Interview with the Dean of industry relations from the university of Groningen. Furthermore, she is project leader of 'Towards virtual ports in a Physical Internet'. The interview was in the end conducted via Skype and lasted for about 40 minutes.

As you researched shared warehouses, could this be important concept for the Port Authority (PA) to enable in the port?
Exploring in that way and in other concept related to shared economy is highly important for the concept of Physical Internet (PI). However, the PA doesn't make the decisions about whether the warehouses become shared. They only can add constraints to the concessions of land. At this moment, there is, however, no research performed to shared warehouses in ports and what the role of the PA could be in this endeavour.

How do you see the development of Synchromodality and the role of the PA in this development?
Synchormodality in the PI is not only about the container, but also about the content in the π-container. There are two ways of thinking: the first way is to add up smaller π-containers until the (maritime sized) π-containers is full. Or the other way is to separate the (maritime sized) π-containers into smaller π-containers. This enables higher capacity for, for example barges as they can put up an extra half (maritime) π-containers on top, before reaching the maximum height to travel under a bridge. For Synchromodality, it is important that separating and recombining is made possible at the terminals. Furthermore, there should be real time decision making, so when there is a problem somewhere in the supply chain the routes and/or mode of transport can be easily adjusted. The system should therefore be flexible. The PA could have a role in creating this by enabling the sharing of information between the terminals and allowing to change booking in a digital platform. However, this is quite centrally organized. It would be better to have a decentral platform, in which agents (for example a representation of a π-containers) could communicate with each other. In this, could the PA play a role by bringing the digital and physical infrastructure up to the next level to enable this exchange of data and goods.

What policy measures could the PA implement to make the maritime port more sustainable?
Two ways the PA could improve the sustainability of the maritime port. Firstly, they can make their own operations more sustainable and secondly, they can facilitate the change of other operations in the maritime port. An example, of the second way is using the concessions to enforce in some way more sustainable operations. Furthermore, they can connect the heat produced by data centres with the operations of companies that require heat. In this way you create a closed system. This is, in general, important to think about. There could also be an interesting link with the PI here. Furthermore, it is important that these developments are a joint collaboration with the other stakeholders in the maritime port.

F.14. Interview 13

Interview with a Professor of the School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta was conducted at two moments. The first interview was conducted via Zoom and lasted for about 60 minutes. The second interview, also conducted via Zoom, lasted for about 30 minutes.

First interview
First note
You have, among others, a landlord type of port, in which the superstructure is owned and operated by private companies and is separated from the publicly owned Port Authority (hereafter: PA), who is, among other things, responsible for the infrastructure in the port. You also have more publicly owned ports, like the port of Georgia, in which the PA is also responsible for the port operations.

What is your current research about?
I mainly look to Physical Internet (hereafter: PI) from various perspectives:

- *The logistics side:* in which PI is the global interconnected system.
- *The supply chain side:* in which PI is researched from the perspective of the PI users, like the retailers, the manufacturers and so on.
- *Research within facilities:* including facilities at ports or other nodes of the network.
- *Dealing with urban areas and less dense territories*

- *And many other perspectives*

This research can be distinguished into four stages:

1. *Conceptual research:* PI is an artefact that needs to grow, be enriched and adopted to new and constantly changing technologies. An example of such a work is the collaboration with Patrick in developing the PI port framework.

2. *Assessments of all kinds of research:* like, simulation studies to assess the potential of various concepts within PI.

3. *Construction:* Designing facilities, containers, protocols and so on.

4. *Validation studies:* Running pilots about, for example the impact of using new technologies, like Artificial Intelligence and machine learning on decision making. But, it is basically about all disciplines that could help us exploit or leverage PI.

Maritime wise, I collaborate with Patrick for some years now. I work closely with the Port Authority (hereafter: PA) of Georgia and I also work with other ports in the USA. I did some linking between the evolution of ports, port cities and PI, so I know the port community.

What is your vision on the role of the maritime ports in the PI?
PI is in essence a multimodal/synchromodal/transmodal network (or how you want to call it), in which, the (large) maritime ports are the core of the worldwide trade and basically have to become nodes that are very well connected by both maritime links or hinterland links. Ports that interconnect nicely with, for example, the car industry or other large industries are the ones who will win. The PAs have to consider how they could make the port contribute to an efficient, fast or at least time adequate, seamless and reliable end to end pick-up and delivery and not only talking about the time from port to port.

Currently, people look at ports and see the number of containers stacked there and say: Oh that is great! However, from a PI perspective this is an old-fashioned way of looking at it. It only shows how inefficient you are in flowing containers through the port. Furthermore, the current system has many fixed routes and has a very rigid structure based on a long evolution, in which the container had a huge impact. However, this transformation to more standardisation has to continued further. Which has challenges, like the big vessels. These vessels have to be optimally used, which could lead to solution directions that are not really PI like.

In terms of logic it is similar to road/rail transformation. There is a huge potential for maritime ports in PI, however there are several players that don't think in ways that make this possible.

In my thesis I focus on landlord ports, like the PoR, in which the terminal operators have contracts with certain shipping line companies and inland carriers. How is this in a more publicly owned port, like the port of Georgia?
In Georgia, it is much different. In this port, the PA is the one making contracts with the carriers and so on. In this, they are playing the same game, with large shipping line companies and so on. The difference is, however, that Georgia port is perceived as a common engine for Georgia and the PA has more degrees of freedom. In some ports, they have to implement rules and contracts to make stakeholders do something, while in Georgia port, if the PA wants to try something, they can just do it as long as it is legal.

However, the beauty of competition between terminal operators in one port is that it doesn't matter when some of these stakeholders operate poorly. In the port of Georgia, if the PA fails the entire port is becoming less attractive. A disadvantage of a landlord port, however, is that the terminal operators are working with only specific shipping line companies, carriers and so on, which leads to rigid structures and low flexibility. To conclude here in general, many current models have weaknesses and in some way are being challenged.

How could the PA enable the mode hinterland Synchromodality?
First of all, everything where I deal with, I see complexity. We have to be very cautious with a quick answer to this kind of questions. Let's say I put myself in the shoes of the PA, the first thing I would do is to get the overall picture of what is happening right now, what are really the demands and then show different stakeholders what they could do to be more efficient and sustainable. For example, there are many stakeholders involved in the port, with many dual assets. There is a lot of waste. If you find ways to make this easier, try to make the stakeholders think in the same way. For smaller ports, like the port of Quebec, they can develop this more from the ground up. Make smart connections between vessels and rail-, inland waterways- and road modes of transport. Also, the digital infrastructure to support the connections have to be developed. You have to put the decision-making infrastructure in place, to enable the use of the advantages of each mode of transport and/or other opportunities. Furthermore, the current regulation, protocols, contracts and so on have to change.

If you want to take it further: why not use π-containers, as a lot of stakeholders cannot fill an entire maritime container in even a few weeks. These smaller containers have to be modular, easily composed/decomposed, loaded and unloaded. Those who will succeed in using this kind of containers will be way ahead in the game.

Could the port be an important area to try new things, like shared warehouses? Could it be a role of the PA to make land available for this kind of activities?
There is potential here, but the notion of it is: that it depends. In some situations, it is better to make land available further inland as it is cheaper and closer to the market. Furthermore, the port has to live with the pressure from the city. This is a very important relation to maintain. The logic here is that PAs have to be smart enough to connect with the logistics clusters, which are not too far into the hinterland. Most PA have not invested enough in understanding that the goods have to get in and out the port as fast as possible and being connected to the hinterland network in a very smooth manner is very important. If you don't succeed in this, then you create numerous of negative side effects, like congestion.

Patrick: Innovative concept: to have offshore ports, which are for example connected to land by a Hyperloop
That is something I presented a few years ago. This idea considers the notion: why do we get all those vessels to the maritime ports, this leads to a lot of congestion. There are many different propositions to do this. One of the latest ones is to have something pop up from the water taking a few containers of the vessel and transport these via a pipeline (rail, hyperloop or so) to land. Nevertheless, I am careful with such propositions as it takes years to even become feasible and it is uncertain if it really becomes feasible at all. It is important to consider the degrees of freedom we are getting ourselves into: from small changes to large changes.

Patrick: We always talk about hinterland transport modes: rail, road and inland waterways, but never air?
Most people say when it is that urgent why don't you send it by plane directly? The answer is: in today's world there are two speeds: there is the speed of before you get an order and there is the speed of when you received the orders. So, this means, that I first estimate my demand for a product in an area, with some variety, so I ship this number of products there. Now, I know when the products will arrive at the port, for example in two days. Then, I can say to my customer that they can have their product in three days. Now air transport becomes important. However, often big maritime ports and airports are not in the same area (Georgia – Atlanta) (Rotterdam – Amsterdam). It might be convenient to have airports near maritime ports. This will make the network more agile.

As there is uncertainty in which degree the future will change, how should the PA deal with this uncertainty?
PA in this game could play several roles, dependent on the situation. We are not deciding for the companies where they have to put their products. We have to give them better options to be more efficient, reliable and sustainable. There are two levels here:

1. The PA's on its own has many analysts that look at possible changes in the future, which they are quite good at.

2. They have to be agile and resilient. Not locking in to one type of solution. Yes, they have to take some risk, use pilots experiment based on a general vision. Test the pieces of this vision and adapt where it is needed.

A PA is not alone in this. Many PAs around the world face the same struggle. Furthermore, if you implement some new system or innovation in different ports it will have a huge impact in comparison to just implementing it in one port (network externalities). This could be protocols for handling or an advanced Port Community Systems (hereafter: PCS).

Second interview
How could the PA improve the digital dimension, in the near/mid/long term?
At this moment, the PAs are improving their PCSs, which connects several stakeholders. This development is, however, in its infancy stage, as only basic information is shared about related activities in only a single port. These systems should in the future also be connected with stakeholders outside the maritime port. For example, currently most PAs run blind, regarding when a vessel arrives. This should be improved by tracking the vessels and share this information with different stakeholders. Furthermore, the PAs should know in advance what is inside the vessel. This provides the opportunity to align the hinterland transport with the moment when the vessel arrives (and vice versa). Furthermore, the PA should find ways to make it much easier to dynamically change from specific vessel/truck/train. Not being restrained by rigid processes of contracts between certain terminal operators, shipping line companies and other carriers. What would even make this much better, is considering smaller containers, the earlier mentioned π-containers.

To enable this, there should be digital platforms in place. In this the PA could play a role as neutral stakeholder. If only one terminal operator will adapt this, it will not make much of a difference.

During the last interview you briefly mentioned the relation between the port and the port-city, could you maybe elaborate?
Ports generate a huge outflow of goods to its hinterland, which in most cases have to go through cities. This negatively affects many people living there. For this reason, the idea discussed last Wednesday could be ideal, if the pipeline ends further inland. Other, more short-term solutions should aim to improve the seamlessness of the port. This includes three main type of solutions:

1. *Dedicated infrastructure:* for the goods, like tunnels
2. *Dynamic signalling:* adapting, for example, the roads when a specific load of containers comes inland.
3. *Improve the efficiency of the infrastructure:* using autonomous trucks/trains/barges for hinterland transport (easier when it is dedicated infrastructure or in combination with dynamic signalling) or in case of rail, reduce the waiting time before entering the port. At this moment, many kms of rail is just used for trains waiting before entering the port. This has a huge impact on land-use.

Furthermore, in general it is important that the PA understands that the port is part of a larger ecosystem. For this reason, they should actively have a dialog with the city. A potential solution in this direction is an Urban Distribution Centre in the port area. Nevertheless, this really depends on the function of the port and its hinterland connections. For example, the port of Savanna is located far away from the nearest urban area. In this case it is more important to have good (synchromodal) connections with inland ports near these urban areas or in other cases it is important to have good connections with an industrial area.

You also briefly mentioned that ports could collaborate with each other, could you maybe elaborate on this, also about collaboration between ports within the same geographical region?
Collaboration is a bit a big word. The most important thing is that ports understand that they are part of a larger ecosystem. First, the worldwide picture: At this moment global ports are developing, like the PoR, port of Singapore and so on, which in essence are a cross-docking area for transhipment from one (big) vessel to another (smaller) vessel and/or are important hubs for a large hinterland area. What if these ports are able to receive and send the π-containers and reshuffle this in an easy way. This will

be a game changer. For this, standard protocols and interfaces have to be in place. To enable this the different PAs should cooperate to put pieces of the puzzle together and gradually develop the required standard protocols and interfaces.

Now, within a geographical region: here the same thing is important: The PAs should understand that they are part of a larger ecosystem, with each port having another added value by, among other things, its location. Furthermore, every PA should invest in the waterside access to accommodate larger vessels? As the containers could also be reshuffled in a global hub into smaller vessels and then transported to the smaller ports? Or the containers could be taken out the vessels even outside the port, with the use of the innovation discussed last Wednesday. Nevertheless, at this moment most PAs are competing with their neighbouring PAs about a small piece of hinterland.

F.15. Interview 14

Interview with a strategist at the PA of the PoR was conducted at two moments. The interview was conducted via Teams and lasted for about 60 minutes. The second interview also conducted via Teams lasted for about 70 minutes.

Could you maybe explains something about your Port Community System (hereafter: PCS): Portbase?
Portbase is a PCS developed by, both the PAs of the Port of Amsterdam (25%) and the Port of Rotterdam (75%). In this system, mainly information flows from Business-to-Government (hereinafter: B2G) take place. For example, the customs declarations are submitted via this system. Gradually people started to realize that money could be made with the information submitted into Portbase. This for example by offering products at a commercial rate. This is, however, very sensitive since the parties have given the data to Portbase in confidence. It is therefore important to find methods in which we can use the commercial value of the whole without offending the data suppliers.

You, as the PA of the PoR have already developed PortXchange, in which data is exchanged Business-2-Business (hereafter: B2B), what does this platform entail?
This is a product that enables an accommodated planning for the operations required for the arrival and departure of vessels. In this, data is exchanged B2B which a sensitive issue. For this reason, it has been decided to make this platform part of the PA activities. Furthermore, no money is made with this platform. This could, when this platform is sold to other ports be organized in a different way.

What could the future role of the port authority in enabling the exchange of data between different parties?
A current issue is that many different parties in the port (including Portbase and Port Call Optimization) request the same data from, for example, a terminal operator. This creates resistance, especially if the parties requesting the data want to earn money with it. Moreover, it leads to a lot of fragmentation in terms of data and data flows. This could, in the future, be solved by developing a single point of contact where the parties submit and request all the data. Further, there should be a kick-back payment from the data user to the data owner, when the data is used for commercial purposes.

The port authority could play an important role in this. Namely, when a private party develops such a platform, it will strive for profit maximization, which could possibly lead to a suppliers lock-in and the payment of high commissions to this party. As a neutral stakeholder, the port authority can prevent this. Nevertheless, the port authority must gain trust and suppress all commercial tendencies. It is therefore important to be 100% transparent and, in all cases, show the private parties what is being done with their data through tight governance. This platform could possibly be developed by Portbase, but trust is very important. If this is not the case, the parties can also choose to submit their customs declaration via other means. Furthermore, the port authority must leave the applications, which are used to analyse the data up to the market (the PA can also develop things themselves, such as PortXchange, but always in competition with the market).

In addition, the port authority can provide expertise to market parties that have too little knowledge of data sharing and data use.

To enable data sharing via such a platform, there should be kind of standardisation. What could be the role of the PA in this?
In many areas of the maritime industry are widespread standards not yet in place. Therefore, ports can hardly talk to each other. In order to arrive at a working platform and to further develop Physical Internet (hereafter: PI), these must be set. The port authority must make a case for this. The PA of the PoR is already working on this in Port Call Optimization. Nevertheless, the standards developed in this project don't have to become the global standards.

Setting standards is probably much easier in a smaller port, because there are far fewer stakeholders involved and one large party can simply impose standards. Moreover, their information management is already a lot clearer.

How important is the hinterland for your competitiveness and could the platform discussed earlier be connected to the hinterland?
Mainly the focus is on the seaside, as the vessels pay the bills. Nevertheless, when the hinterland is badly organized the vessels will not come. So, the hinterland is quite important. To connect such a data platform to its hinterland is a possibility. However, the PA should not want to control the entire chain. It should stay by its origin, a local node.

What would be a suited way to cluster the policy measure of the PA?
It is important that you define the terms used in your questionnaire in a clear way, so there will not be discussion about it. Furthermore, you should, despite, the broad spectrum of policy measures be concrete in your formulation and prevent overlap. This is also applicable on the scenarios. In this it is furthermore important to describe your axis on the 'same level' and prevent the suggestion that the PA could influence these factors.

F.16. Conclusions from the interviews

In this sections the main conclusions regarding the two goals of the interviews are presented.

Gain insight in policy measures for the PA to make the maritime port more attractive (in the context of PI).
In this the interviews were very successful, as a lot of experts with a different background were interviewed and the open structure of the interviews provides a wide scale of different policy measures. The experts were encouraged discuss policy measures related to their field of expertise. A clear distinction between experts with more a researcher background or a practitioner was observed. The practitioners, in general had a more short-term focus in identifying policy measures for the PA and researches had a more long-term vision about what the PA could do in context of PI. For this reason, the interviews with the practitioners and researchers were complementary to each other.

The interviews strengthen the literature review to identify policy measures, as certain interviews gave new ideas to explore new literature directions. Besides, not all the policy measures identified with interviews could be contrived from literature, as the research combination between PI and maritime ports is limited.

In short, the interviews gave a lot of new insight in policy measures, which even went outside the current existing literature. The policy measures identified with the interviews are, further, used in section 5.2.

Gain insight in how to group the identified policy measures into approximately 4-5 policy measure clusters for further analysis.
Due to the many different backgrounds of the interviewees and the open structure of the interviews no clear line can be drawn from the interviews in clustering the policy measures. Some experts had, for example more knowledge from the background of PI and less knowledge about a maritime port, which gave a much different resulting interview than an interview with an expert with work experience in developing policy for the PA. Still, some general remarks can be made from their opinions on which the PI policy directions can be developed:

The PA especially has power in the port territory, as they are responsible for the land development (see interview F.2). With their concession power, access regulation and pricing strategies they can also influence behaviour in the hinterland and foreland (see interview F.2 and F.3).

The PA could collaborate with stakeholders from the port community (see interviews F.3 and F.12), the local/regional/ national governments (see interviews F.3, F.4, F.5, F.7 and F.8) or even other maritime ports with the same hinterland (see interviews F.6, F.5 and F.9) to develop the appropriate hinterland connections and improving the accessibility of the port. In the long term, this could include Hyperloop connections (see interview F.14).

The PA should consider the land development required for the PI like activities and enable hinterland Synchromodality (see interviews F.2, F.5 F.9, F.11, F.13 and F.14). This could include the development of shared warehouses and/or PI-hub facilities (see section 2.2.4). These facilities, they can build on their own or stimulate/enforce building by other stakeholders by using their concession power (see interviews F.5, F.7 and F.13). The PA could consider the development of transport system in the port connecting the different terminals and enable shuffling of goods to take place (see interviews F.3 and F.13). They can integrate in their concession automation requirements for the terminals and shared warehouses (see interview F.7).

The PA could play an important role in using pilots and best use cases to raise awareness and show what works and what not (see interviews F.2 F.3, F.5, F.6, F.7, F.8, F.9 and F.12). This could include pilots and best use cases for PI standardisation (see interviews F.2, F.5 and F.6), standardisation required for the digitalisation (see interviews F.2, F.12 and F.6), standardisation for nautical standards and standards required for intermodal transport (see interview F.3). The PA could also start best use cases and pilots to experiment with new land development strategies (see interviews F.10 and F.14), sensors in the port (see interview F.10), new ISs (see interview F.6), Synchromodality (see interview F.7) and show with pilots and best use cases what (data) sharing could bring to the community (see interviews F.6 and F.12).

The PA could invest in inland terminals (see interviews F.3 and F.7), in inland infrastructure (see interviews F.6 and F.7), in innovative start-ups to developing IS or certain standards (see interviews F.3, F.4 and F.6), in Hyperloop terminals (see interview F.14), in Offshore ports (see interview F.14) and in vessel traffic safety systems to enable autonomous vessels in the port (see interview F.8).

The PA could collaborate with stakeholders from the port community (see interviews F.3, F.4, F.8, F.10 and F.15), other maritime ports (see interviews F.3, F.7, F.4, F.5 F.10 and F.14) or lobby by institutions, like the EU to set standards (see interviews F.3 and F.15). The PA could set their own standards (see interviews F.3, F.5, F.9 and F.11). This is, however, not really useful as the other stakeholders in the port community are not always willing to comply with these standards and could potentially move to another port in the region (see interviews F.3 and F.11). The PA could stimulate the use of the appropriate standards in the port community with the use of their concession power, by access regulation and pricing strategies (see interviews F.2 and F.5).

The PA could themselves develop or enable other stakeholders to develop IoT like applications which provide all kinds of value-added services which improve the predictions, planning and the performance of the port operations (see interviews F.6, F.7 and F.10). The PA could enable this by installing or enable other stakeholders to install all kind of sensors (see interviews F.7, F.8, F.10, F.11 and F.12) and wireless communication technologies, like 5G in the port (see interviews F.8, F.11 and F.12). In the end, it is important to have the digital infrastructure ready for future steps of among other new innovations PI (see interviews F.8, F.9, F.13 and F.14). The PA should consider tools to evaluate the consequences of policy measures (see interview F.12).

The PA has an important role in synchronizing the information streams between stakeholders in the port community (see interview F.2, F.3, F.5, F.10, F.12, F.13 and F.15). This is already partly happening with the PCS (see interviews F.2, F.6, F.7 and F.10). The PA in some way only has an intermediate role, as they do not actually own the data (see interviews F.2 and F.3). The PA should, therefore come up with ways to use the data, without offending the data suppliers (see interview F.15). In the long-term, the PA could as a public stakeholder potentially play a more active role in developing digital platforms/ISs required for the reshuffling activities to take place and optimizing the flow of goods through the port (see interviews F.4, F.5, F.6, F.7, F.8, F.9, F.11, F.14 and F.15). In general the trust in a public stakeholder developing such platforms/ISs is higher in comparison to a private stakeholder (see interviews F.6 and F.15). Besides, these digital platforms/ISs could also be connected to the hinterland to enable e.g. hinterland Synchromodality (in combination with shared warehouses or PI like facilities in the port) (see interviews F.2, F.4, F.6, F.7, F.10 and F.15) or with other maritime ports (see interviews F.5 and F.6).

The PA could play an important role in advancing the sustainability of the port operations and port related activities. In context of PI, this means stimulating and enforcing the better utilization of the assets in the port (see interviews F.2 and F.5). It could also incorporate using their concession power, using access regulation and pricing strategies to stimulate sustainable behaviour (see interviews F.2, F.4, F.5 and F.8). The PA could implement systems to monitor and evaluate the impact of the port related activities and port related activities on the environment and safety (see interview F.6). Also, the PA could take policy measures to reduce the negative externalities of their own operations (see interviews F.6 and F.13). Collaborate with local/regional/national governments (see interviews F.7 and F.12) and stakeholders in the port community (see interview F.13) to define a plan to be sustainable.

In general, the PA should consider the facilitator role and bring the different stakeholders in the port community together (see interviews F.2, F.3, F.6, F.8, F.9, F.10 and F.12). This includes listening to their demands, providing the stakeholders of advice and sometimes stimulate or enforce certain desirable behaviour (see interviews F.2, F.3, F.10 and F.12). The PA could not go too far in stimulating and/or enforcing certain behaviour, as port users ultimately have the option to make use of another port in the region (see interviews F.3, F.7, F.10 and F.12). The PA should broaden its perspective and look at their role in the entire logistics system (see interviews F.5, F.6, F.9 and F.14). Not only considering their local optimum, but also the overall system optimum (see interview F.5). This could mean, not investing in extra terminal capacity (see interviews F.5, F.6 and F.9). This new way of thinking they should also promote among the other stakeholders in the port community (see interviews F.5 and F.6).

G

Respondents of the questionnaire

In this appendix is an overview provided of the respondents of the questionnaire. For each PI port scenario the following respondents filled in the questionnaire:

PI port scenarios: 'Big PI' and 'No PI'

- Chief Information Officer (hereafter: CIO) and manager digital innovation Groningen Seaports
- Full Professor, Freight & Logistics, Delft University of Technology.
- Teacher Systems Engineering, University Groningen.
- Director of Innovation and Port Cluster Development at Fundación Valencia port.
- Strategist at the PA of the PoR.
- Professor Multi-Machine Operations & Logistics
- Associate Professor in Maritime Logistics
- CEO and Partner of consultancy company specialised within container shipping industry
- Professor Quantitative Logistics
- Senior project manager of a logistics and transportation company
- Researcher Physical Internet in maritime port
- Professor Faculty of Civil Engineering and Geo Sciences Transportation Planning and Traffic Engineering

PI port scenarios: 'Technologically driven advancement' and 'Institutionally driven advancement'

- Full Professor, Freight & Logistics, Delft University of Technology.
- Research Professor Transport, Logistics and Ports, University of Antwerp
- Professor of Global Supply Chains and Ports, Erasmus University.
- CIO of a Port Authority in Europe
- Technical Director of the technical Innovation Office of the Bahía de Algeciras and Port innovation manager by port of Algeciras.
- Dean of Industry Relations from Universitity Groningen.

- Adjunct Professor of Logistics and Academic Director of Executive Education at Kühne Logistics University
- Researcher Physical Internet in maritime port
- Head strategy and analytic at a Port Authority in Europe
- Professor Urban, Ports and Transport Economics
- Researcher Physical Internet in maritime port

H

Documentation attached to questionnaire

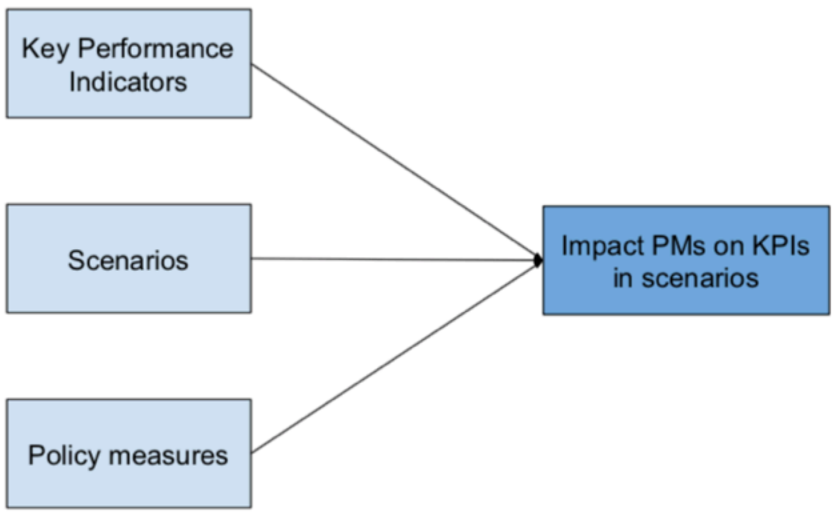
In this appendix is the documentation used for the questionnaire given:

PI policy Questionnaire

Function:
Univerisity/Company:
Sector:

General Introduction

In previous research criteria/KPIs and scenarios have been determined. In this current research policy measures the PA could apply to make the maritime port more attractive have been established. Now, by means of this questionnaire we would like to analyse the impact of these policy measures on the KPIs in the different scenarios (see figure below).



PI Policy Measures

Table H.1: PI policy measures

PI policy Measure	Description
Transport Infrastucture (TI)	This PI policy measure includes **investments in the port infrastructure**, like increasing the rail shunting capacity and **investments in the waterside access**. This PI policy measure, furthermore, includes **investments and collaborations** with stakeholders from the port community and authorities, in improving the **accessibility of the port and in capacity enlarging projects**, like the Maasvlakte II in Rotterdam.
(PI) standardisation ((PI) stand.)	**Advance the** administrative, nautical, legal and functional **standardisation** required for PI (like for the modular containers) and digitalisation (e.g. for the digitalisation of the Bill-of-Lading) by either developing their own standards, lobby at large institutions and/or collaborate with other stakeholders in the port community and other Port Authorities. The PA could, in the long term, **stimulate or enforce the usage of certain standards** by incentives or rules in the concession, by access regulation or by pricing strategies.
Advanced Terminal Areas	Develop land to enable flow orchestration in the port. This by either develop and operate its **own shared warehouses**, in which reshuffling operations of (PI) containers take place. Alternatively, the function can be **outsourced**, but keep it within the port area. Furthermore, the PA could use their concession power, access regulation or pricing strategies to **enforce/stimulate reshuffling operations** taking place in the port area.
ICT Hardware (ICT-H)	**Advance the installation of sensors and wireless communication technologies** in the port required for e.g. IoT applications. Stimulate the installation by the port community. This could be, by among other means be done with best use cases and pilots, showing the potential benefits that these applications could bring to the port community.
Information systems and information exchange platforms (IS and IEP)	**Advance the alignment of the Information Systems (IS). Improve the SMART functionalities** of the Port Management System and contribute to the Port Community System by applying AI, IoT and Big data applications. Advance the **digital platform required for flow orchestration**. Connect these platforms and ISs with the hinterland and maritime side to **digitally integrate the complete supply chains**.
Sustainability Management (SM)	**Develop monitoring systems**, controlling the safety, air and water quality and nuisance. Comply with, among others, environmental regulation, work condition regulation and traffic measures. Policy to **reduce the negative externalities of their operations and encourage/stimulate the stakeholders** in the port community to implement sustainable policy by incentives and rules in the concessions, by access regulation and by pricing strategies.

Key Performance Indicators (KPIs) Attractiveness Maritime port

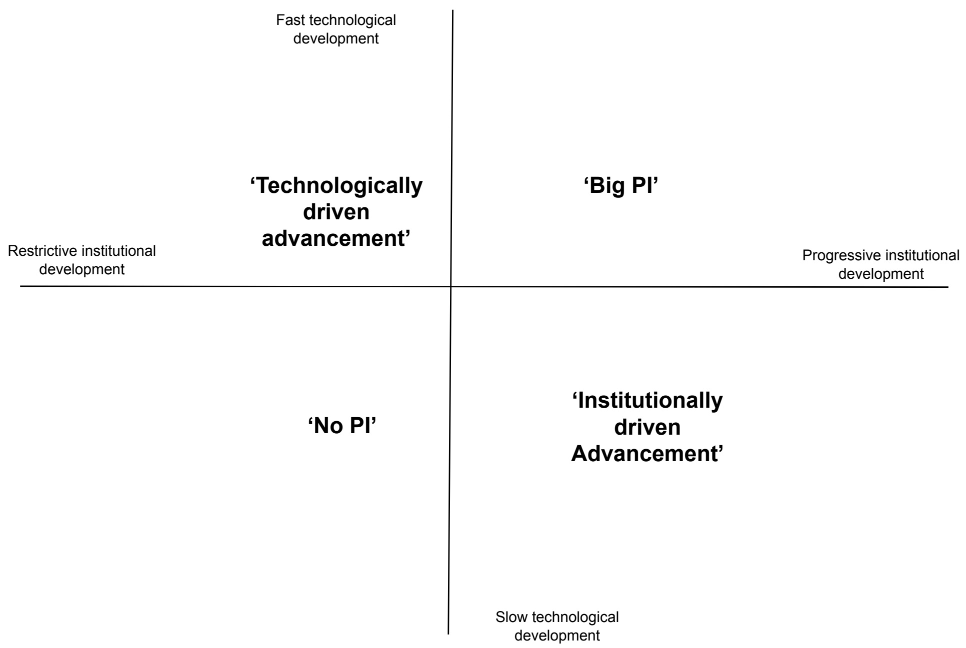
KPIs Attractiveness Maritime Port	Description
Transport Chain Quality (TCQ)	Refers to **the effectiveness of the port operations**, including the speed, reliability and quality of operations, and the agility to respond to changes/disruptions in the port operations
Costs	Refers to the **cost for the port users**
Digital Connectivity (DC)	Refers to the **digital connectivity in the port** and the **seamless digital integration** of the port in the supply chains
Physical Network Connectivity (PNC)	Refers to the **physical connectivity** of the port, the **reliability of the maritime side and hinterland** and the **agility** to respond to changes/disruptions in **the maritime side and hinterland**

The Questionnaire

In the questionnaire the impact of the different PI policy measures on the KPIs in two PI port scenario is assessed with the use of the Best Worst Method. According to this methodology we kindly ask you, firstly, to determine the MOST IMPACTFUL and the LEAST IMPACTFUL PI policy measure. Secondly, we kindly ask you to perform pairwise comparisons based on the following scale:

Scale number	*Linguistic Variable*
1	Equal impactful
3	Moderate more impactful
5	Strongly more impactful
7	Very strongly more impactful
9	Extremely more impactful
2,4,6,8	Intermediate values between the two judgments

PI Port Scenario



Introduction of the two PI port scenarios analysed in the questionnaire

KPI A: Transport Chain Quality

Considering **KPI A: Transport Chain Quality (TCQ)**, select the MOST IMPACTFUL PI policy measure from the six PI policy measures and insert it in the most left-hand side cell of the second row.

Now use a number between 1 and 9 to show the relative performance of your MOST IMPACTFUL PI policy measure over the other policy measures.

PI port scenario X

MOST IMPACTFUL on TCQ:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

PI port scenario X

MOST IMPACTFUL on TCQ:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

Considering the **KPI A: Transport Chain Quality**, select the LEAST IMPACTFUL PI policy measure from the six PI policy measures and insert it in the top cell of the second column.

Now use a number between 1 and 9 to show the relative performance of the PI policy measures (first column) over the LEAST IMPACTFUL PI policy measure.

PI port scenario X

LEAST IMPACTFUL on Transport Chain Quality:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

PI port scenario X

LEAST IMPACTFUL on Transport Chain Quality:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

KPI B: Cost

Considering **KPI B: Cost**, select the PI policy measure which is the MOST IMPACTFUL the port user (lowest cost) from the six PI policy measures and insert it in the most left-hand side cell of the second row.

Now use a number between 1 and 9 to show the relative performance of your MOST IMPACTFUL PI policy measure over the other policy measures.

PI port scenario X

MOST IMPACTFUL on Costs:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

PI port scenario X

MOST IMPACTFUL on Costs:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

Considering **KPI B: Cost**, select the PI policy measure which is the LEAST IMPACTFUL (highest cost) for the port user from the six PI policy measures and insert it in the top cell of the second column.

Now use a number between 1 and 9 to show the relative performance of the PI policy measures (first column) over the LEAST IMPACTFUL PI policy measure.

PI port scenario X

LEAST IMPACTFUL on Costs:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

PI port scenario X

LEAST IMPACTFUL on Costs:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

KPI C: Digital Connectivity

Considering **KPI C: Digital Connectivity (DC)**, select the MOST IMPACTFUL PI policy measure from the six PI policy measures and insert it in the most left-hand side cell of the second row.

Now use a number between 1 and 9 to show the relative performance of your MOST IMPACTFUL PI policy measure over the other policy measures.

PI port scenario X

MOST IMPACTFUL on DC:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

PI port scenario X

MOST IMPACTFUL on DC:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

Considering the **KPI C: Digital Connectivity**, select the LEAST IMPACTFUL PI policy measure from the six PI policy measures and insert it in the top cell of the second column.

Now use a number between 1 and 9 to show the relative performance of the PI policy measures (first column) over the LEAST IMPACTFUL PI policy measure.

PI port scenario X

LEAST IMPACTFUL on Digital Connectivity:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

PI port scenario X

LEAST IMPACTFUL on Digital Connectivity:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

KPI D: Transport Chain Quality

Considering **KPI D: Physical Network Connectivity (PNC)**, select the MOST IMPACTFUL PI policy measure from the six PI policy measures and insert it in the most left-hand side cell of the second row.

Now use a number between 1 and 9 to show the relative performance of your MOST IMPACTFUL PI policy measure over the other policy measures.

PI port scenario X

MOST IMPACTFUL on PNC:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

PI port scenario X

MOST IMPACTFUL on PNC:	TI	(PI) stand.	ATA	ICT-H	IS and IEP	SM

Considering the **KPI D: Physical Network Connectivity**, select the LEAST IMPACTFUL PI policy measure from the six PI policy measures and insert it in the top cell of the second column.

Now use a number between 1 and 9 to show the relative performance of the PI policy measures (first column) over the LEAST IMPACTFUL PI policy measure.

PI port scenario X

LEAST IMPACTFUL on Physical Network Connectivity:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

PI port scenario X

LEAST IMPACTFUL on Physical Network Connectivity:	
Transport Infrastructure	
(PI) standardisation	
Advanced Terminal Areas	
ICT Hardware	
Information systems and information exchange platforms	
Sustainability Management	

Credal Ranking

In this appendix the credal rankings of the PI policy directions (relative) impact are presented.

I.1. PI port scenario 'Big PI'

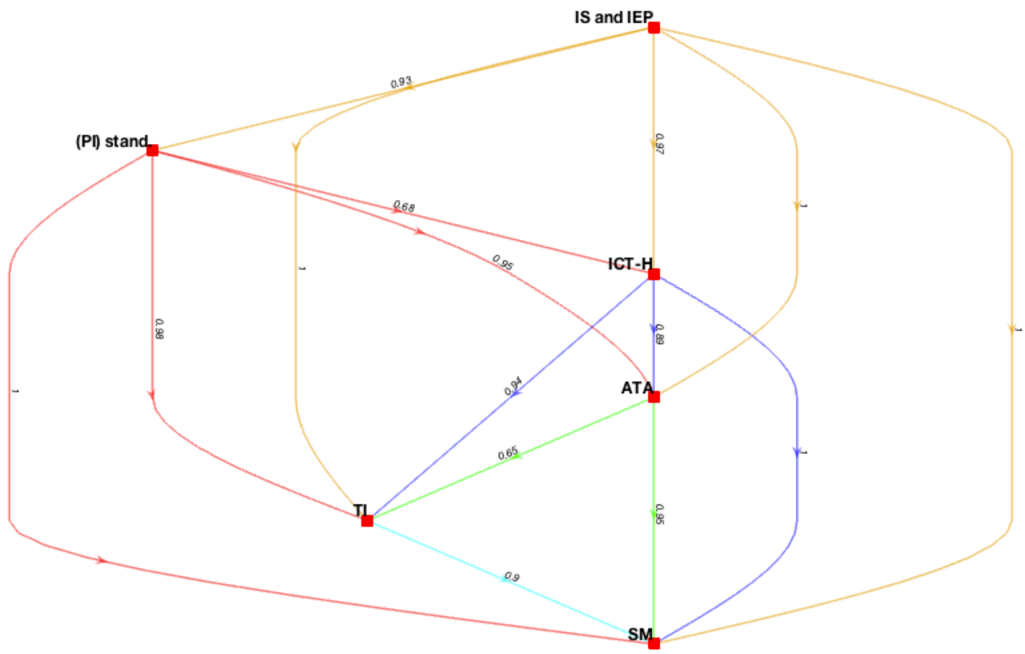


Figure I.1: Visualisation of the credal ranking Transport Chain Quality in PI port scenario 'Big PI'

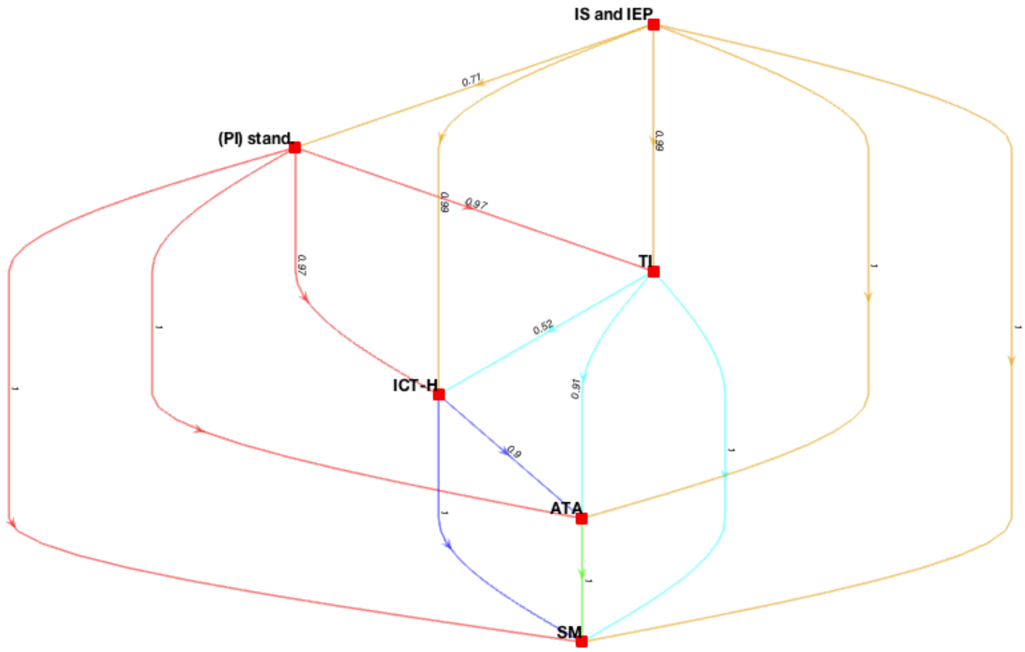


Figure I.2: Visualisation of the credal ranking KPI Cost in PI port scenario 'Big PI'

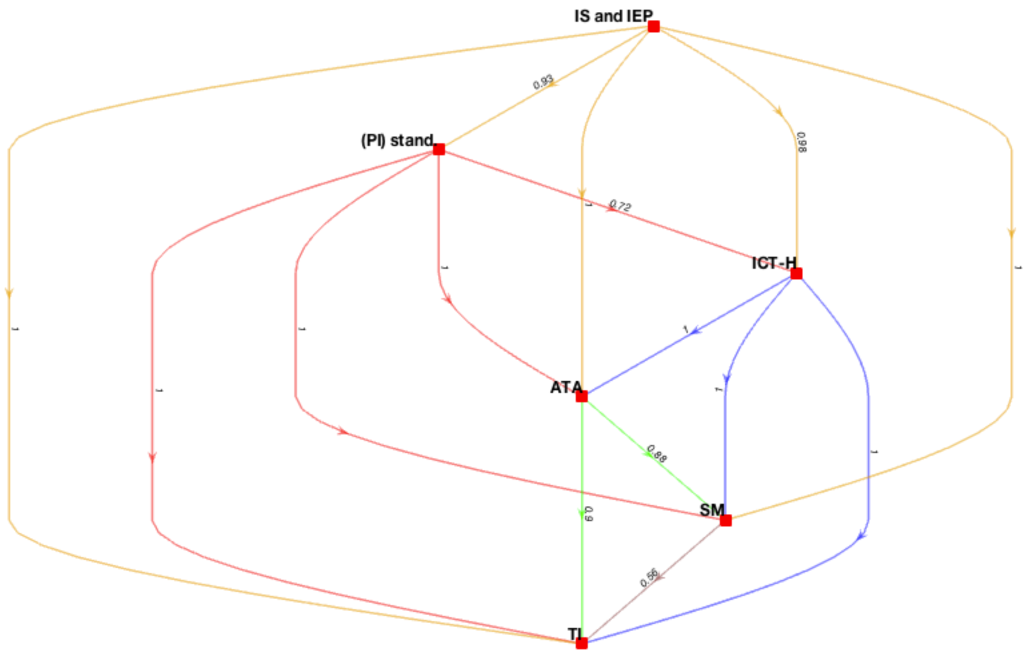


Figure I.3: Visualisation of the credal ranking KPI Digital Connectivity in PI port scenario 'Big PI'

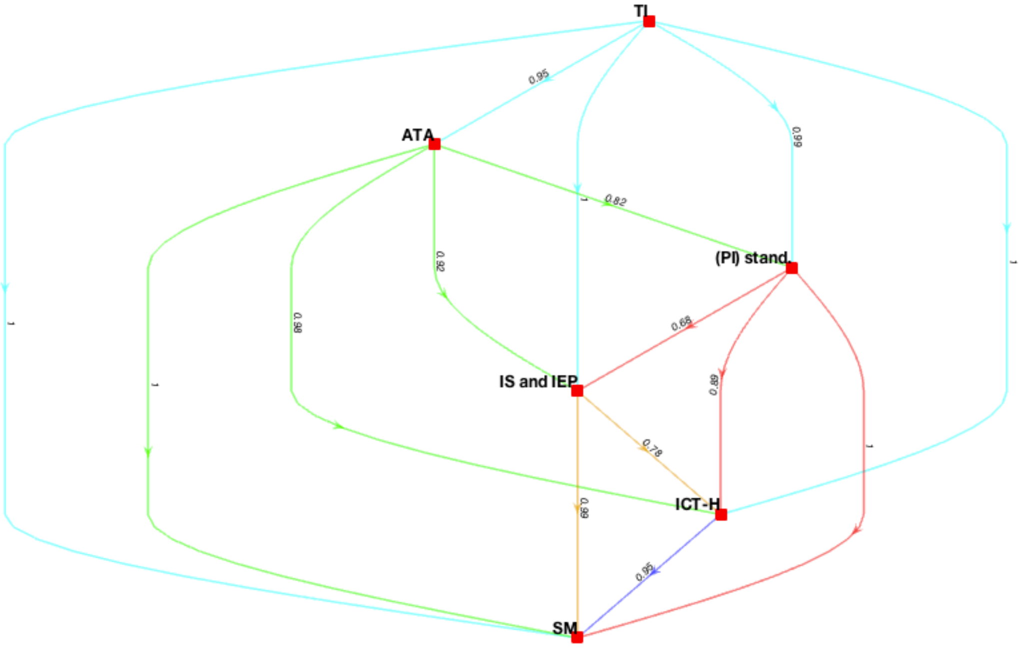


Figure I.4: Visualisation of the credal ranking KPI Physical Network Quality in PI port scenario 'Big PI'

I.2. PI port scenario 'Institutionally driven advancement'

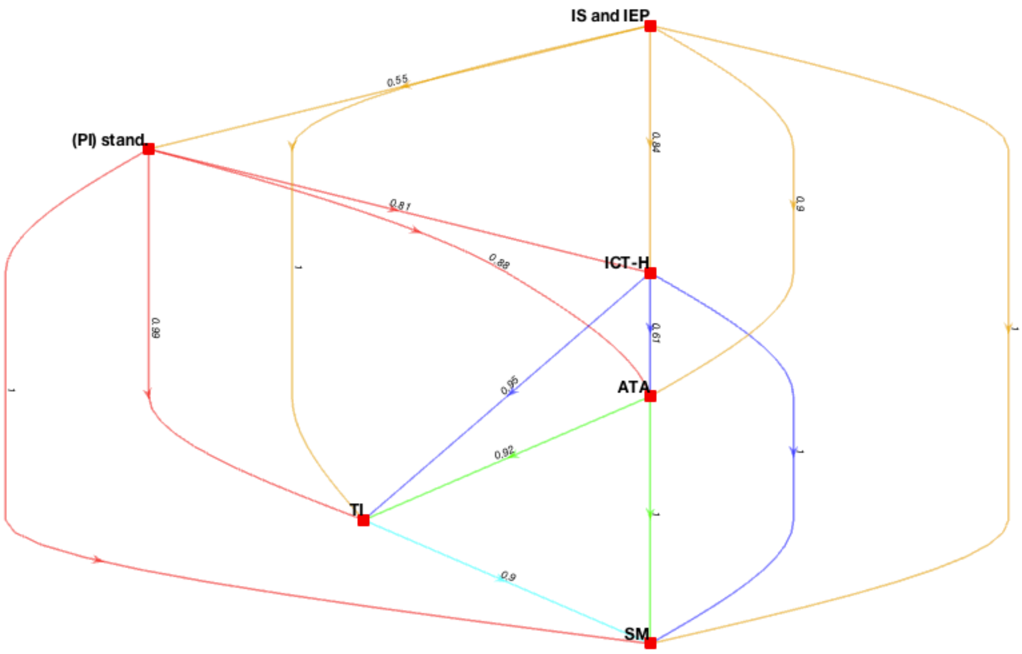


Figure I.5: Visualisation of the credal ranking KPI Transport Chain Quality in PI port scenario 'Institutionnally driven PI'

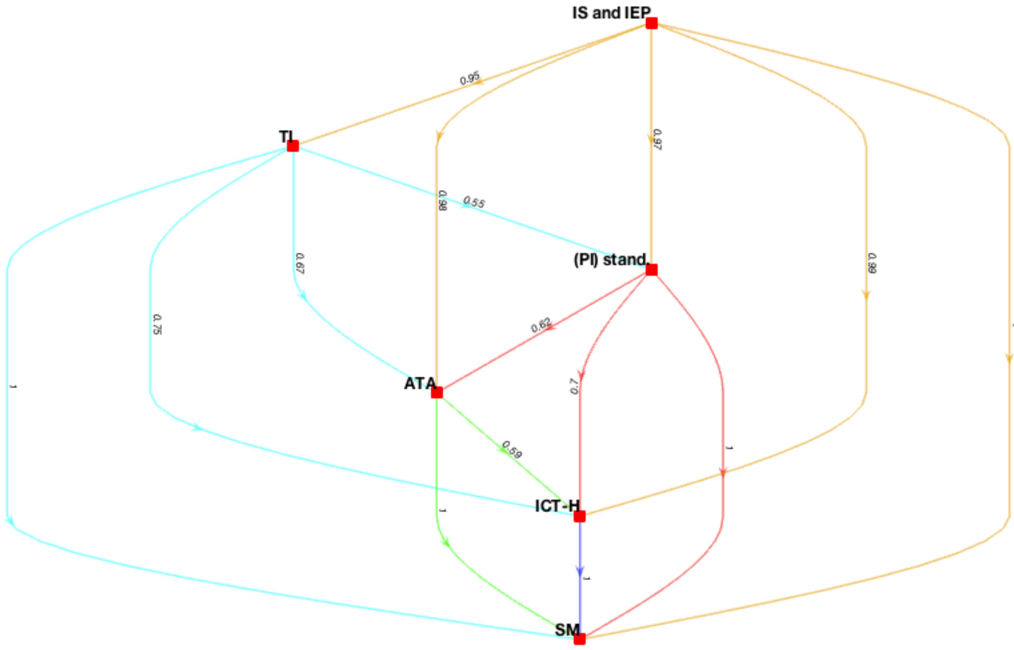


Figure I.6: Visualisation of the credal ranking KPI Cost in PI port scenario 'Institutionnally driven PI'

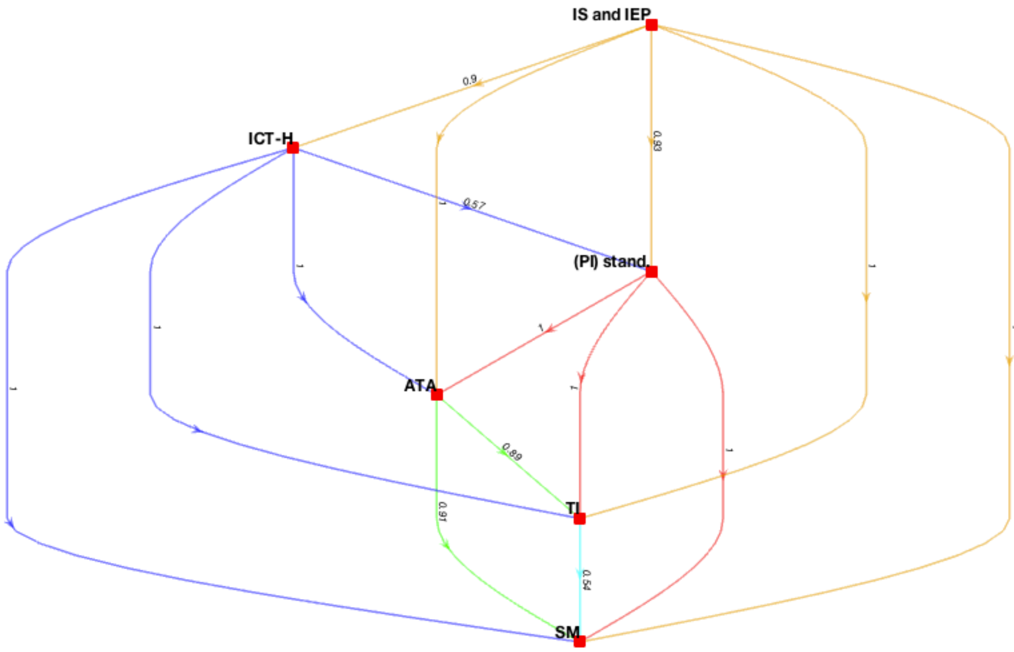


Figure I.7: Visualisation of the credal ranking KPI Digital Connectivity in PI port scenario 'Institutionnally driven PI'

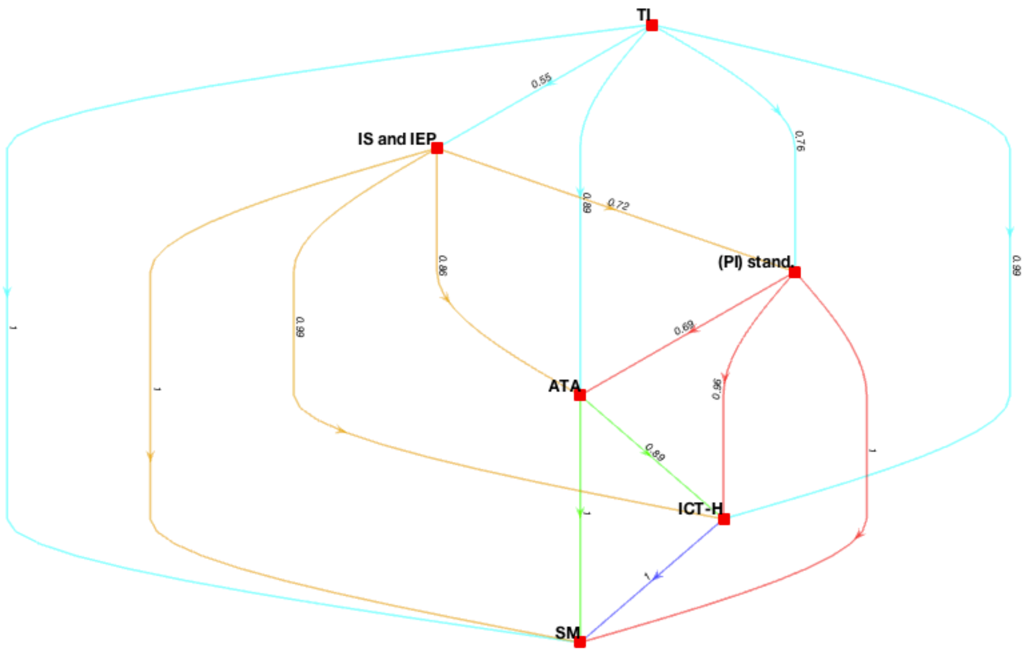


Figure I.8: Visualisation of the credal ranking KPI Physical Network Quality in PI port scenario 'Institutionnally driven PI'

I.3. PI port scenario 'Technologically driven advancement'

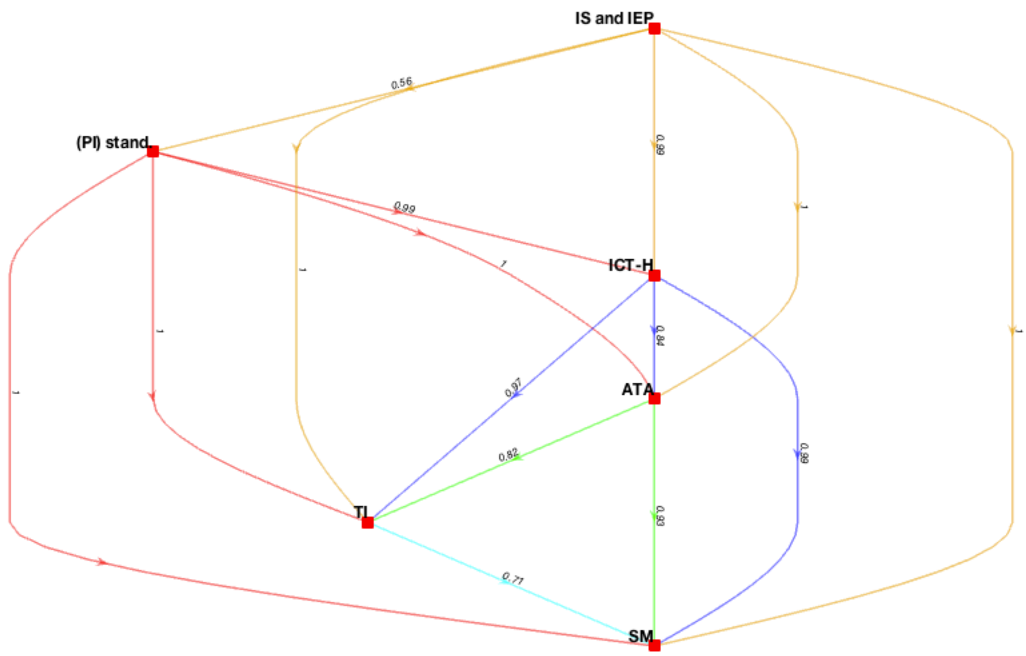


Figure I.9: Visualisation of the credal ranking KPI Transport Chain Quality in PI port scenario 'Technologically driven advancement'

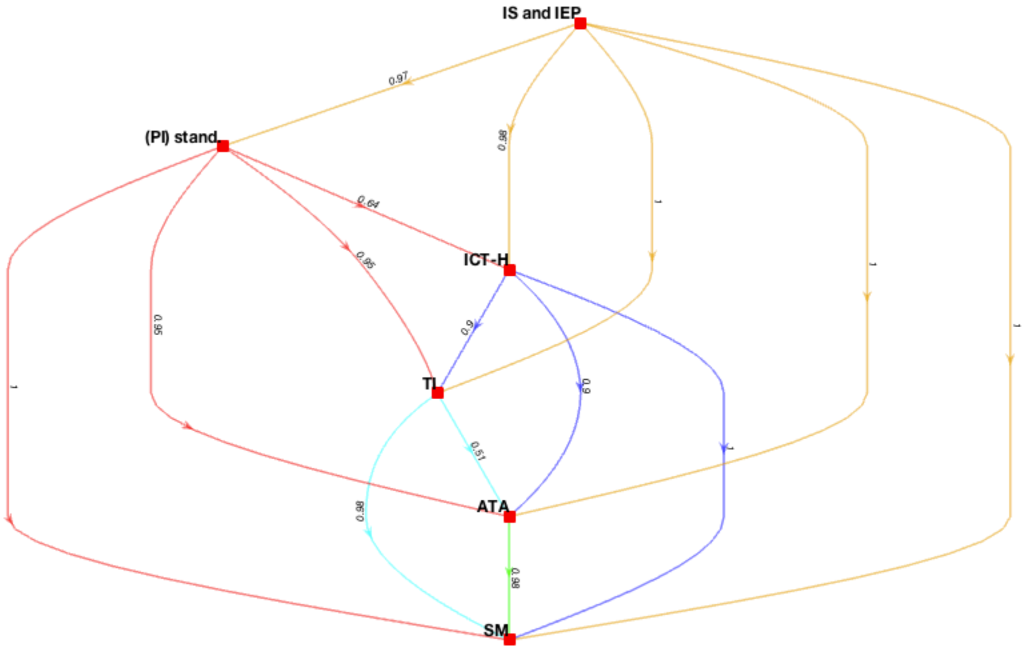


Figure I.10: Visualisation of the credal ranking KPI Cost in PI port scenario ’Technologically driven advancement’

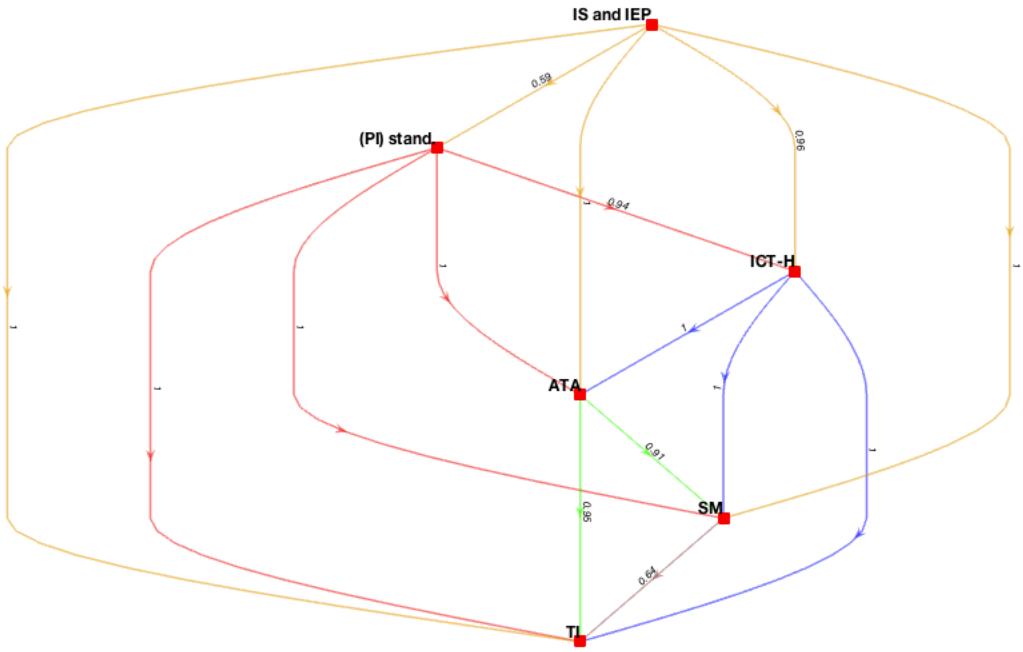


Figure I.11: Visualisation of the credal ranking KPI Digital Connectivity in PI port scenario ’Technologically driven advancement’

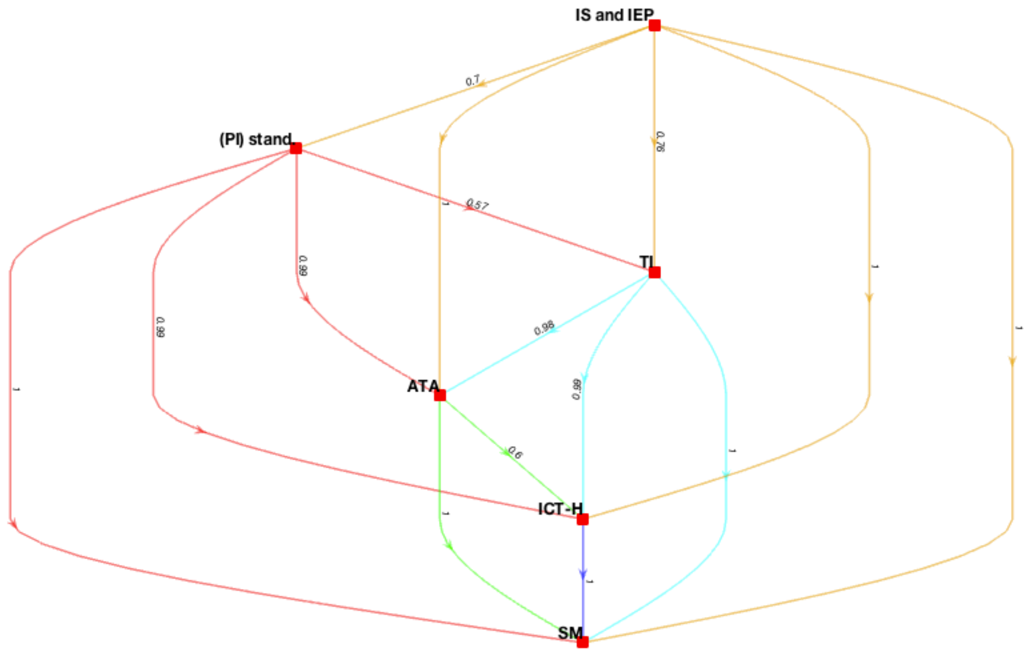


Figure I.12: Visualisation of the credal ranking KPI Physical Network Quality in PI port scenario 'Technologically driven advancement'

I.4. PI port scenario 'No PI'

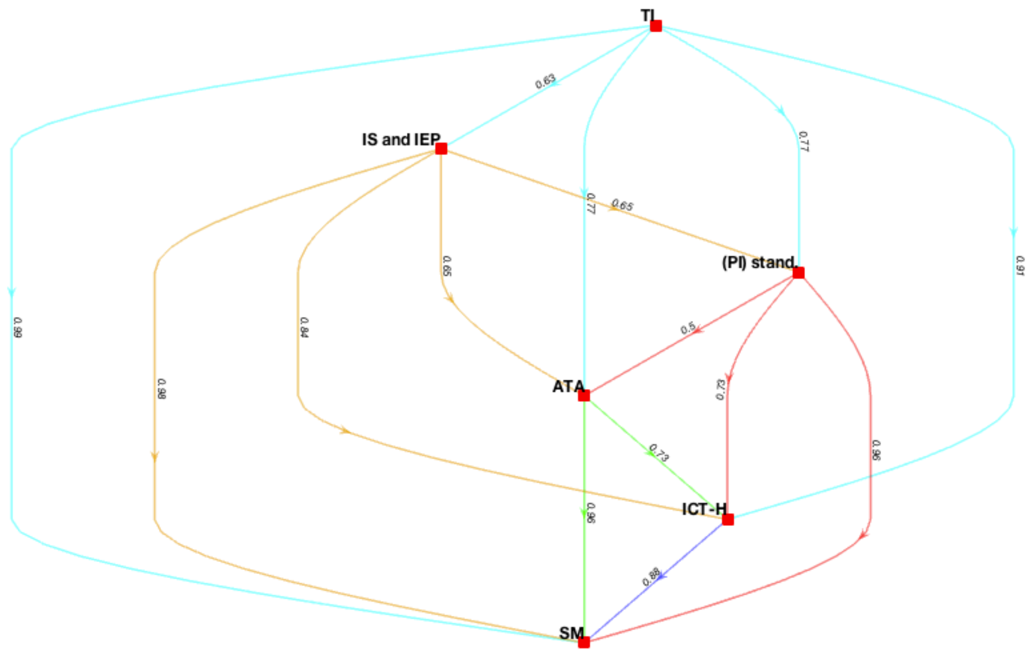


Figure I.13: Visualisation of the credal ranking KPI Transport Chain Quality in PI port scenario 'No PI'

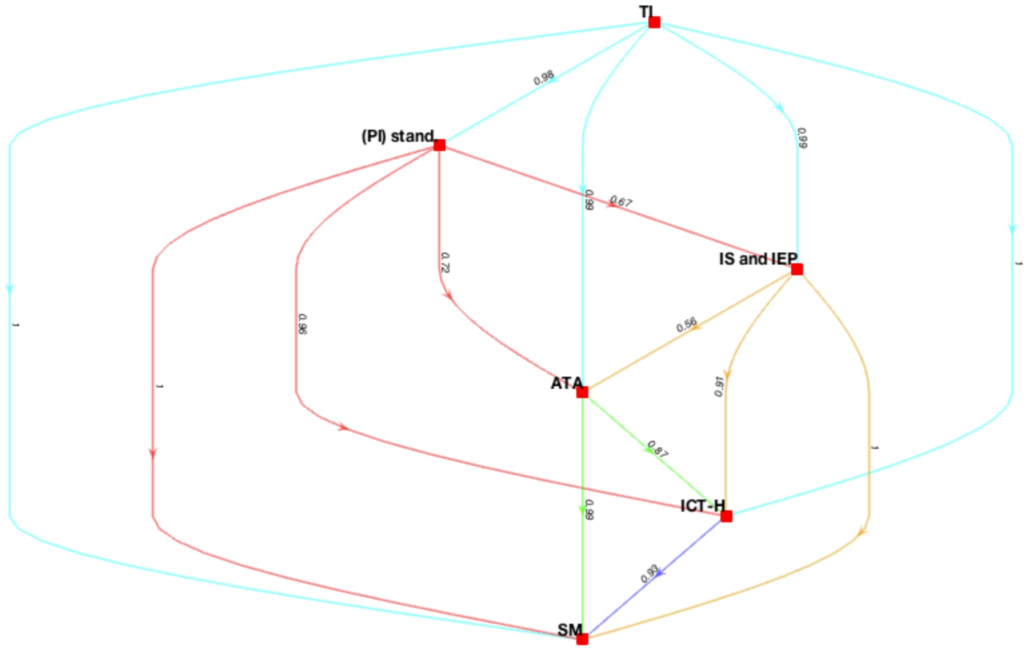


Figure I.14: Visualisation of the credal ranking KPI Cost in PI port scenario 'No PI'

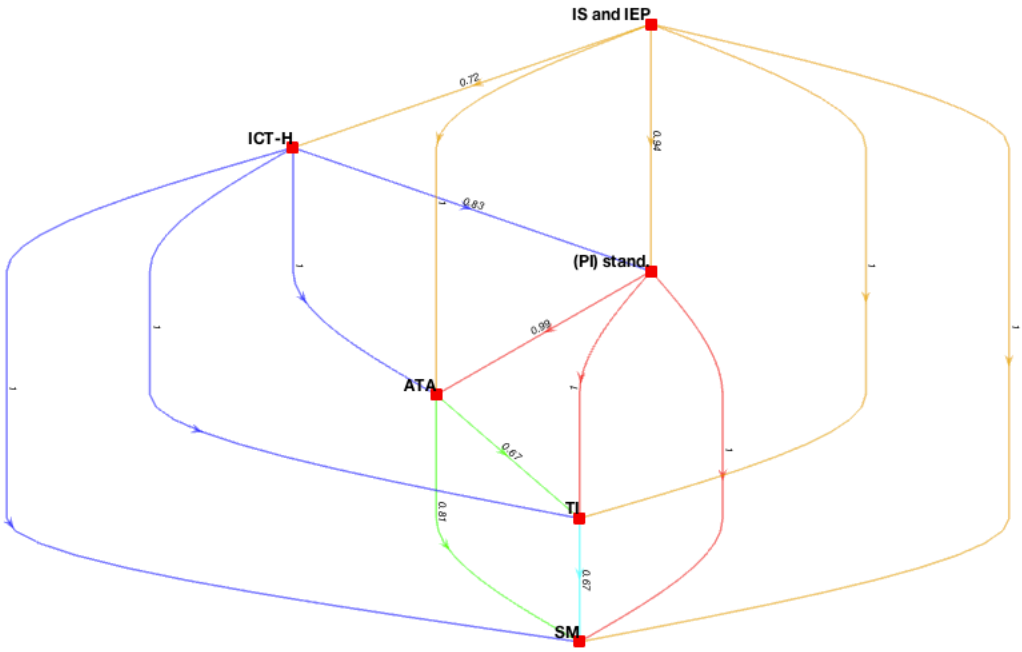


Figure I.15: Visualisation of the credal ranking KPI Digital Connectivity in PI port scenario 'No PI'

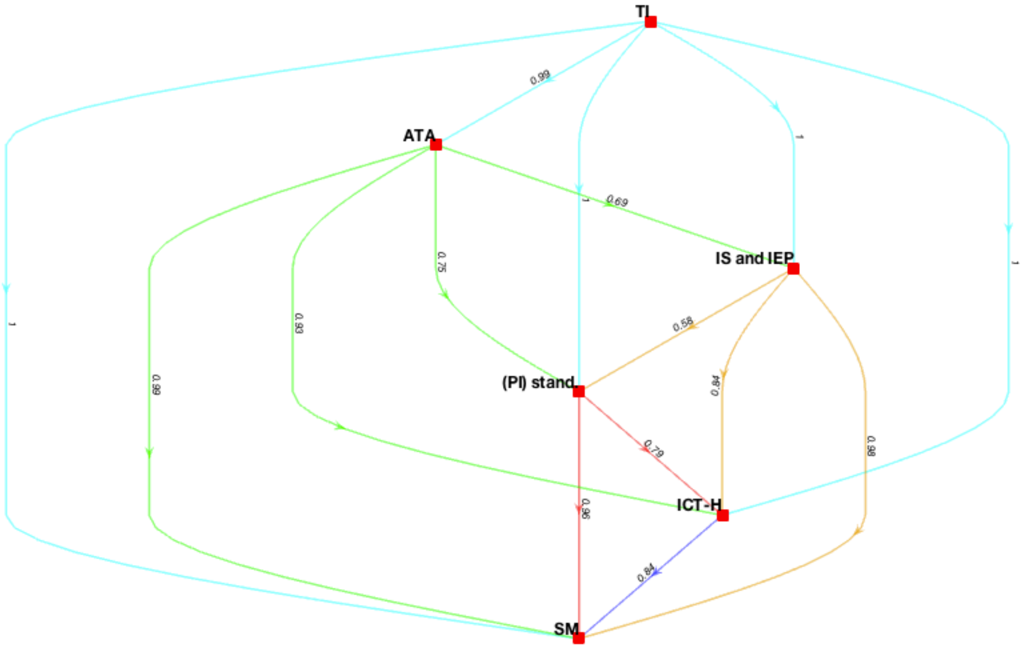


Figure I.16: Visualisation of the credal ranking KPI Physical Network Quality in PI port scenario 'No PI'

J
Contribution applied Bayesian BWM

In this appendix the contribution of the Bayesian BWM applied in this paper is discussed (see figure J.1).

The results of the Bayesian BWM provides insight in the 'best-fit' focus distribution of the different PI policy directions on the KPIs for the attractiveness of the maritime port in the different PI port scenarios (see green outlined part of the figure). However, to determine the 'absolute' contribution of the PI policy directions on the KPIs, also a **Gap analysis** should be performed to how much a particular KPI can be improved in a particular port y for the different PI port scenarios. This will, in combination with the 'best-fit' focus distributions provide insight in effective policy directions for the particular port y.

To determine the overall (absolute) contribution of the PI policy directions in a particular PI port scenario, the weights of the KPIs determined by Fahim (2020) can be used. These weights are only determined for the PI port scenario *'Big PI'* and *'No PI'* and the general applicability of these weights can be questioned.

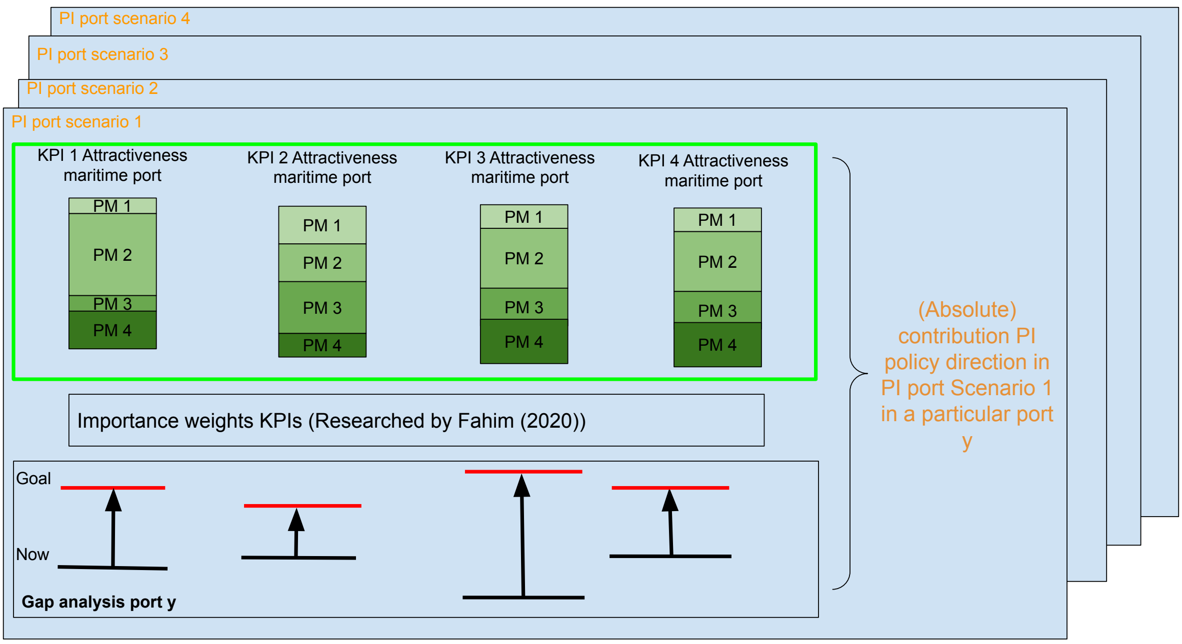


Figure J.1: Contribution applied Bayesian BWM in the bigger picture

K

General reflection on the thesis

In 2019, I went on the study tour with Dispuut Verkeer to Colombia and the United Stated. This was an awesome experience on its own. However, little did I know about Physical Internet, when I met Patrick in a bus from one company to another in Colombia. He enthusiastic started talking about his PhD and he got me interested.

After the Study Tour, Patrick reached out to me and asked me whether I was willing to do my master thesis about Physical Internet in maritime ports. This after some further research, I enthusiastically accepted. Before I could start my master thesis, it was at first, hard to find a well-suited scope of the thesis, which fitted in the PhD of Patrick and would built upon previous research of Manuel Martinez de Ubago Alvarez de Sotomayor and Jeff Voster. Two master students, who both did great research to the subject. Based on their research, conversations with Prof. Tavassazy, Prof. Rezeai, Prof. van Binsbergen and especially Patrick, I could scope my thesis to analysing potential policy measures the Port Authority could apply within Physical Internet and at the end of November 2019, after my Kick-off meeting, I could officially start with my master thesis.

However, after the first few weeks trying to combine my last course and my master thesis, I decided to fully focus in this last course and restart my master thesis in February. After the restart, it took me some time to really get into the right mindset to fully focus on the thesis. Nevertheless, this time, got me realizing, how awesome this subject actually is, how innovative, how this research combined all the knowledge I gathered during my Bacehlor Technische Bestuurskunde and my master, how this research triggered me to learn more about alot of things and the opportunity to work with such intelligent people, I was willing to go the extra mile to finish my master in style.

After this realisation, it was still highly uncertain how to adequately analyse the effects of policy the PA could apply in context of the PI. It took some brainstorm sessions, at that moment in time already taking place via Zoom with prof. Rezaei and Patrick to really get to a well-suited approach. I remember discussing the right method with prof. Rezaei and Patrick, when prof. Rezaei was sitting outside in his garden enjoying the spring weather of May. This was really an enriching experience for me, in which I was triggered to think outside the box.

After the methodology was set, I had my midterm meeting in the beginning of June and afterwards Patrick and I started interviewing experts about potential policy the PA could apply in the context of PI at the end of that same month. This was another really enlightening experience. I had the opportunity to talk with the most knowledgeable people in the field of Physical Internet and talk with a lot of very intelligent people from ports all over Europe. I am really grateful for this opportunity and it really added a lot of value to my thesis and the final defined PI policy directions.

Furthermore, I was really happy, when almost all of these interviewed experts were also willing to perform the questionnaire, which was used to analyse the impact of the PI policy directions in the different PI port scenarios.

Just before these questionnaires started, I think, was the most stressful period of my thesis, in which a lot of last minute changes led to a different scope of the questionnaire. Nevertheless, these changes improved the questionnaire and in the end the questionnaire was in general well-received by the experts and had at least a meaningful contribution to the results of my thesis and I also hope to Patrick's PhD.

In general, I would like to say that I'm really grateful for everyone who contributed to the end result of my thesis: from all the experts who participated in the interviews and the questionnaires, my friends, my family, the supervisors of my thesis and especially Patrick, who gave me the opportunity to do all this research and helped me through some though moments during the process.

Looking back at this experience, I am happy to finish my master in this way and start a new chapter of my live. Thereby, I hope my master thesis, in some way or another has a contribution to the adoption of Physical Internet in the maritime port. It really is an novel innovation, with a lot of benefits to the society. And, I especially hope my master thesis had a contribution to the PhD of Patrick.

L
Scientific paper

This part consist of the scientific paper based on the research conducted in this thesis

Assessing policy focus of Port Authorities in the uncertain future of Physical Internet using the Bayesian Best Worst Method

G.B. Mientjes,[1]★ P.B.M. Fahim,[2] Dr. J. Rezaei[2] Dr.ir. A. van Binsbergen[3] Prof.dr.ir. L.A. Tavasszy[2]
[1] *Master student Transport Infrastructure & Logistics at the Delft University of Technology*
[2]*Delft University of Technology, Faculty of Policy and Management, 2628 BX Delft, The Netherlands*
[3]*Delft University of Technology, Faculty of Civil Engineering & Geosciences, 2628 CN Delft, The Netherlands*

ABSTRACT
Physical Internet (PI) is an innovation, which is introduced to cope with the unsustainable effects of logistics on society, environment and economy. Research to the implications of this innovation on important components/stakeholders in logistics, like maritime ports and Port Authorities (PA) lack. To fill in this gap, this study uses the Bayesian Best Worst Method to analyse different policy directions the PA of a landlord ports could apply to make the maritime port attractive in the uncertain future of PI. From this study can be concluded that dependent on how this innovation will develop, different policy focus for the PA is recommended. Still, in general the PA should focus on developing and providing information systems and information platforms, and the PA should focus on developing and stimulating the usage of (PI) standards.

Key words: Physical Internet (PI), Bayesian BWM, (Adaptive) Policy Making, Maritime port, Port Authority, Landlord port

1 INTRODUCTION

To facilitate the ever increasingly important international trade a global logistics system is in place (UNCTAD 2019). This system is under constant pressure, due to its social, economic and environmental unsustainable effect (Montreuil 2011; European Commission 2015). For this reason, innovations, like Synchromodality and Physical Internet (PI) are suggested (Montreuil 2011). The innovation Synchromodality is about creating the most efficient and most sustainable transportation plan for all orders in an entire network of different modes and routes, using its available flexibility (Van Riessen et al. 2015). This requires asset sharing, which is also one of the key principles of PI. PI, however, focuses on the entire global logistics system (Montreuil 2016). Synchromodality can, therefore be seen as a part of PI (ALICE 2019).

The underlying idea of PI is to move goods through the global logistics system, similarly to how data is transferred through the Digital Internet (DI). This implies that the goods[1] are not handled, stored or transported, but rather the package in which the goods are encapsulated is handled, stored and transported. Thereby, the PI network is constantly updating, to establish the most efficient and sustainable way to handle, store and transport all of the physical objects through the entire logistics system (Crainic & Montreuil 2016).

Research to the implications of this innovation on important components and/or stakeholders in logistics lack. One of these important components is the maritime port[2]. This component main function is to provide the transshipment between vessels and the land modes, such as trucks and trains (Ligteringen 1999). This is a crucial role in the logistics system, as maritime trade volumes are responsible for 80% of the total world merchandise trade (UNCTADa 2019).

To fill in the gap, this paper's objective is *to support the maritime port in designing policy to be attractive in the future, given the uncertain development of Physical Internet.* The research, especially, focuses on assessing policy, the Port Authorities (PA) of a landlord port could implement to improve the attractiveness of the maritime port. This stakeholder is responsible for the economic exploitation, long-term development of the land in the port, takes care of the (basic) port infrastructure and positions itself, as the coordinator that facilitates the ever evolving port users' needs (Brooks 2004; Vis et al. 2015; Van der Lugt et al. 2013).

In fulfilling the paper's objective, first theoretical backed PI port scenarios are developed, based on external factors determined by the application of two theoretical frameworks: the *Political-economy Model* of Feitelson & Salomon (2004) and the *Dynamic multi-level perspective for technological transition* of Geels (2004) on the adoption of PI in the maritime port and a stakeholder analysis from the perspective of the PA. Secondly, based on an in-depth literature review and 14 expert interviews, policy measures for the PA to make the maritime port attractive are identified and aggregated into six PI policy directions. Thirdly, the 'best-fit' focus distributions of these six PI policy directions for different Key

★ E-mail: g.b.mientjes@tudelft.nl

[1] For practical reasons the usage of the terms physical objects and goods are mixed

[2] For practical reasons the usage of the term maritime port and port is mixed

Performance Indicators (KPI) for the attractiveness of the maritime port in the different PI port scenarios are assessed with the use of the Bayesian Best worst Method (hereafter: BWM) (Mohammadi & Rezaei 2019). Based on patterns in and between these 'best-fit' focus distributions are recommendations provided to the PA to make the maritime port attractive in the uncertain future of PI.

The rest of the paper is structured as follows: in section 2, the relevant literature for the paper regarding the two main concepts: PI and maritime ports is presented. In section 3, the methodological approach used in this paper is treated. Section 4 discusses the operationalised PI port scenarios. Hereafter, in section 5 the KPIs for the attractiveness of the maritime port are outlined. Section 6 describes the operationalised PI policy directions. In section 7, the results of the Bayesian BWM are presented. Section 8 provides recommendations for the PA to make the maritime port attractive. Afterwards, in section 9, the results of the paper are reflected on and recommendations for future research are discussed and in section 10, the conclusion of the paper are given.

2 RESEARCH FOUNDATIONS

2.1 Physical Internet

The PI concept was firstly mentioned on the cover of The Economist in June 2006 and inspired Professor Benoit Montreuil, who started openly publishing about PI from 2009 (Markillie 2006). These publications led to the first scientific publication in 2011: *Towards a Physical Internet: meeting the global logistics sustainability grand challenge*. In this paper, Montreuil mentioned that PI is a response to the Global Logistics Sustainability grand challenge.

In 2012, six years after the first time the term PI was used, is based on the metaphor with the DI, the first definition of PI introduced by Montreuil, Meller, & Ballot (2012):

'An open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols'.

Using the DI metaphor in defining PI is a powerful tool. However, there are some key differences between physical object and data. Data can be transported at a much faster pace. The transportation of data is much cheaper and re-sending data is far easier and without significant delays (Crainic & Montreuil 2016). This is important to consider, for the real-world applications of this innovation.

PI, lately, has received more attention from researchers and policy makers (Ambra et al. 2019; Modulushca 2019; Rijksuniversiteit Groningen 2016; IPIC 2019; European Commission n.d.; CELDi 2015). Nevertheless, the state of literature is still in its infancy stage (Pan et al. 2017). There is a lack of theoretical foundations and shared understanding of the main components of PI is lacking. This is one of the main concerns for the future adoption of PI (Montreuil, Ballot, & Fontane 2012). One organisation, which tries to stimulate a comprehensive implementation of PI is ALICE. This organisation is an initiative from the EU, which among other things developed a roadmap for the implementing PI in Europa to achieve zero emissions in 2050 (ALICE 2019).

That the research of PI is still in its early stage can also be seen in the redefinition of PI by Montreuil (2016) to:

'A global hyperconnected logistics system enabling massively open asset sharing and flow consolidation across numerous parties and modes through standardized encapsulation, modularization, protocols and interfaces'

The four main components retrieved from these definition are the: *modularity, encapsulation, protocols and interfaces*. There is a lot of inconsistency in literature about these components.

2.2 Maritime port

Maritime ports have a key role in the overall logistics system, as it is the link between vessels and the land modes (Ligteringen 1999). Besides, the maritime ports have increasingly a hub function in the supply chain, as it is the place where imported goods are supplied from and the place were the goods shipped out are collected (Zondag et al. 2010). And, new developments change the role of the maritime port. Flynn et al. (2011) describes the future maritime port, as *Dynamic customer-centric community port*, in which information is distributed via an 'single window system' and logistics activities are seen as part of the maritime logistics chain (P. T. W. Lee & Cullinane 2016). This is in line with the PI development, which consider the entire logistics system.

The changing role of the maritime port, also affects the PA's function (P. T. W. Lee & Cullinane 2016). Currently, the function of the PA can already be better described as facilitator within the logistics chains (Centin 2012).

Another development, in line with the broader perspective of the maritime port development and PI, is the port regionalization (Notteboom & Rodrigue 2005). This development is the result of the change in shipper's focus to the total logistics costs and the relatively high costs of inland operations. Two types of port regionalization are distinguished (Rodrigue & Notteboom 2010):

- *Foreland regionalization:* includes the development of ports into intermediate hubs, in which the goods are transferred from larger to smaller vessels to be further transported to smaller more regional ports and vice versa.
- *Hinterland regionalization:* includes the inland freight distribution and the inland terminals.

In PI literature, design studies to other types of hubs in the PI network are performed (Ballot et al. 2013; Walha et al. 2016). And, the main characteristics of a PI hub are developed by Montreuil et al. (2018). Nevertheless, no particular research is performed to the role of maritime ports in the uncertain future of PI, until Martinez de Ubago (2019). Martinez de Ubago (2019) described a large maritime port, like the PoR, as a global hub in the proposed interconnected multi-plane meshed network of PI (Montreuil 2019). In this network, the global hubs are the PI-nodes, which connect the different international regions with each other. Each of these international regions consists of local and regional networks, with each local and regional PI-nodes.

Martinez de Ubago (2019) also developed in collaboration with Voster (2019), the PI port framework. This framework is a bottom-up model, which shows how their three main PI characteristics develop and guide the evolution of a port towards a globally hyperconnected PI-hub (see figure 1).

After the research of Martinez de Ubago (2019), Fahim (2020) researched the port choice of the smart containers and smart vessels in PI. In this research, thirteen criteria for the port choice of containers and vessels are distinguished and grouped into the following for criteria classes (see appendix A for the importance weights of the criteria classes from the container- and vessel perspective):

A Transport Chain Quality: In this class the criteria *level of service, physical port infrastructure, reliability, safety & security* and *sustainability* are grouped. *The level of service* refers to the transit time, the availability of vessels, the port throughput time and the route congestion. *The physical port infrastructure* refers to the available handling capacity and the overall efficiency of port operations. *Reliability* refers to the risk of disruption. *Safety & security* concerns issues with theft, injuries and casualties. *Sustainability* refers to the total emissions, the nuisances and the social responsibility.

B Cost: In this class the criteria *transport cost* and *transshipment cost/seaport duties* are grouped. *The transport cost* depends on the cost of a particular vessel with a particular route. *The transshipment cost/seaport duties* relate to the handling and the operational cost of the terminal and cost related to retain the port services.

C Technology: In this class the criteria *automation of operations, Information System (hereafter: IS)* and *SMART* are grouped. *The automation of operations* refers to the level at which operation are taken place in an automated way. *IS* refers to the level at which the stakeholders are connected via the PCS. *SMART* refers to the usage of machine learning, optimisation and simulation.

D Network Quality of Port: In this class the criteria *geographical location, logistics/maintenance facilities* and *network interconnectivity* are grouped. *Geographical location* refers to the location of the maritime port. *Logistics/maintenance facilities* refer to the facilities for value-added services, warehousing and repair. *Network interconnectivity* refers to the connectivity of the maritime port with the hinterland and foreland.

3 METHODOLOGY

Policy making for the PA is highly complex, as they make decisions about large scale projects, which often take years to implement, with often an irreversible character and in the meantime changing environments, including other stakeholders' opinions, changes in the economy and unpredictable events, like the outbreak of COVID-19 (Notteboom & Winkelmans 2001; Rodrigue 2010). And, as in this research, policies in the highly uncertain future of PI are analysed, insights from Adaptive policy making approaches, such as the Dynamic Adaptive Policy Pathways (DAPP) approach are used to develop the overall research approach (Haasnoot et al. 2013) (see figure 2 for an overview of the research approach)

3.1 Scenario operationalisation

Based on literature review, stakeholder analysis and the applications of the theoretical frameworks *Political- Economy model* of Feitelson & Salomon (2004) and *Dynamic multi-level perspective of Technological Transition* of Geels (2004) on the adoption of PI in the maritime port external factors for the PA to make the maritime port attractive are determined.

These external factors are, with insights from Martinez de Ubago (2019) and the *Dynamic multi-level perspective of Technological Transition* of Geels (2004) aggregated into two driving forces, which describe the uncertain development of PI from the perspective of the PA. These two driving forces are with the use of the scenario logic developed into four different PI port scenarios (Enserink et al. 2010). The resulted PI port scenarios are presented in section 4.

3.2 PI direction operationalisation

The methods literature review and 14 expert interviews are applied to identify policy measures the PA could apply to improve the attractiveness of the maritime port and to determine particular roles the PA could play to improve the attractiveness of the maritime port in the uncertain future of PI. Based on these roles, the identified policy measures are aggregated into six different PI policy directions used for further analysis. The resulted PI policy directions are presented in section 6.

To identify the right candidates for the interviews the expert knowledge is assessed by:

- Looking at the publications of the expert. These should be related to the subject PI and/or policy making in maritime ports.
- Looking at the work experience of the expert. This should be related to policy making in maritime ports.

A researcher or a practitioner is perceived as an expert when he or she is part of a small community of people currently working, studying or are dedicated to the subject. Besides, whether the expert is open-minded to explore the boundaries of his/her research area is assessed (Enserink et al. 2010). (see appendix B for an overview of the interviewees).

3.3 Bayesian BWM

To determine the 'best-fit' focus distributions of the identified PI policy directions on the different KPIs in the different PI port scenarios the Bayesian BWM is used.

The original BWM is an Multi Criteria Decision Making (MCDM) method that finds optimal weights based on preferences Rezaei (2015). This methodology is an alternative to the generally used MCDM method Analytic Hierarchy Process (AHP) (Saaty 1977). The BWM in comparison to the AHP reduces the inconstancy, as the respondents, before actually performing the pairwise comparisons determine the best and the worst factors. In this way the respondents have a better understanding of the range of evaluation. Also, the BWM reduces the number of comparisons for the respondents and is less sensitive for anchoring bias (Rezaei 2015, 2020).

Other pairwise comparison methods, like Simple Multi-attribute Rating Technique and Swing only uses one vector of pairwise comparisons (Edwards & Barron 1994). This reduces the workload for the respondents even more. Nevertheless, the consistency of the results in these methods cannot be checked. Therefore, BWM

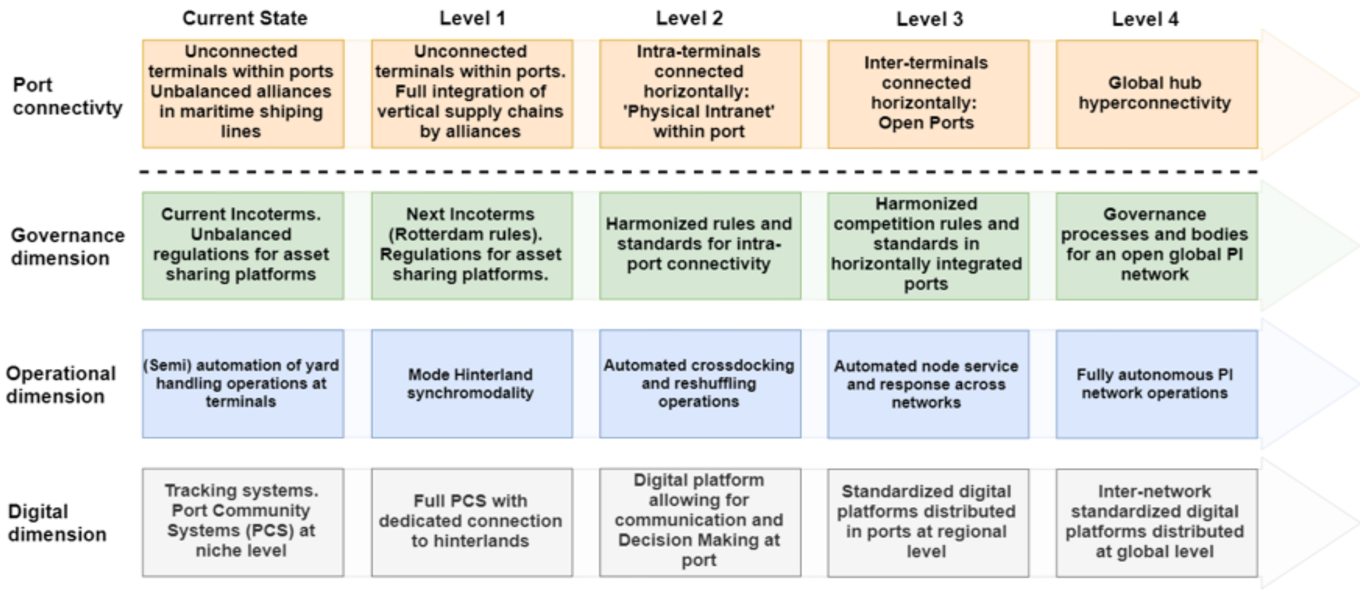


Figure 1. PI port framework (Martinez 2019; Voster 2019)

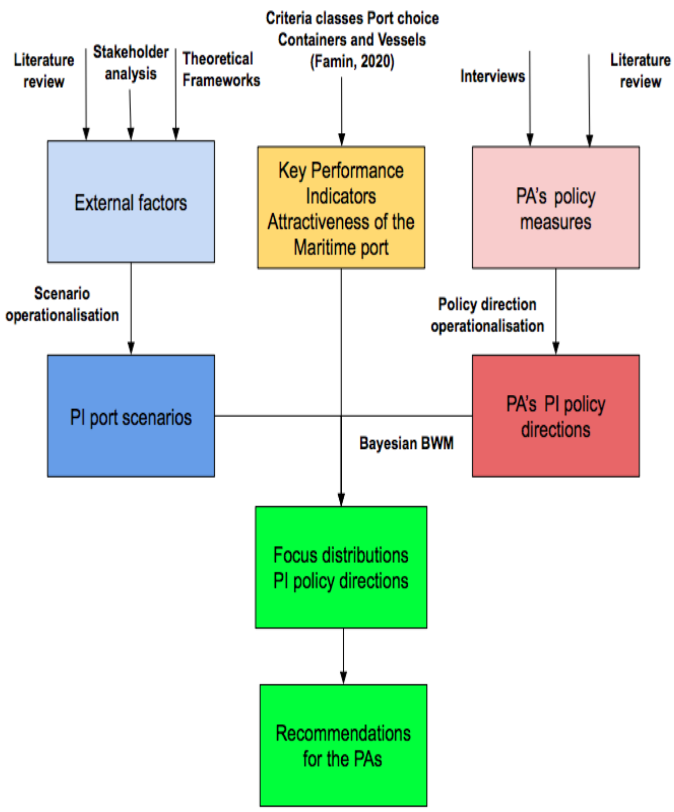


Figure 2. Research approach

seems to be the most data and time efficient method, which for pairwise comparisons also provides insight in the consistency of the results (Rezaei 2020).

The BWM is already used in analysing the importance of port performance criteria for port choice of different logistics stakeholders (Rezaei et al. 2019), is often used in suppliers' selection studies (Cheraghalipour & Farsad 2018; Rezaei et al. 2016, 2015), is used in assessing the performance of the supply chains (Ahmadi et al. 2017) and is used in assessing contributing factors in supply chain competitiveness (Sadeghi et al. 2016). Mi et al. (2019) provides a more elaborate overview of the applications of the BWM.

An disadvantage of the original BWM, however, is when the preferences of more than one expert is used in a group decision-making problem, this method is sensitive for outliers and provides limited information about the overall preference. For this reason, Mohammadi & Rezaei (2019) developed the Bayesian BWM method. In this method the same input is used as in the original BWM. The first four steps of both the methods are the same (see procedure below). However, in the fifth step, when the optimal weights are calculated, the Bayesian BWM uses probability distributions and a hierarchical model instead of averages and a linear programming problem. This makes the results less sensitive to outliers. The Bayesian BWM is, therefore preferred over the original BWM.

The following procedure of the Bayesian BWM, adopted from Rezaei (2015); Mohammadi & Rezaei (2019); Fahim (2020) is applied:

1. Determine a set of decision criteria c_1, c_2,..., c_n
This step is performed by using literature review and experts interviews to identify the policy measures the PA could apply to improve the attractiveness of the maritime port. These policy measures are clustered into PI policy directions (e.g. the decision criteria) to reduce the complexity for the respondents (see section 6).

The following steps 2, 3 and 4 are performed with the use of a questionnaire with experts and are repeated for all the different KPIs in all the PI port scenarios.

2. Determine the best (e.g. most impactful) and the worst (e.g. least impactful) PI policy directions
In this step, the respondents identify the most impactful and least impactful PI policy direction. No comparison made yet.

3. Determine the preference of the best PI policy direction over all the other PI policy directions using a number between 1 and 9
In this step, the respondents compare the most impactful PI policy direction with the other PI policy directions on a scale between 1 and 9. This leads to the following Best-to-Others vector:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$$

In which, a_{Bj} indicates the preference of the most impactful PI policy direction B over the PI policy direction j. $a_{Bj} = 1$, if the PI policy direction j is as impactful as the most impactful PI policy direction B and $a_{Bj} = 9$, if the PI policy direction j is much less impactful than the most impactful PI policy direction B. This means a_{BB} has to be equal to one.

4. Determine the preference of all the PI policy directions over the worst PI policy direction using a number between 1 and 9
In this step, the respondents compare the other PI policy direction with the least impactful PI policy direction with a number between 1 and 9. This leads to the following Other-to-worse vector:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$$

In which, a_{jW} indicates the impact of PI policy direction j over the least impactful PI policy direction W. $a_{jW} = 1$, if PI policy direction j is as impactful as the least impactful PI policy direction W and $a_{jW} = 9$, if the PI policy direction is much more impactful than the least impactful PI policy direction W. This also means a_{WW} has to be equal to one.

5. Obtaining the aggregated weights $w^* = (w_1^*, w_2^*), \ldots, w_n^*$ and the weight for each expert w^k, k = 1, ..., K
These weights are obtained based on the following probabilistic model:

$$A_B^k | w^k \; multinomial(1/w^k), k = 1, \ldots, K$$

$$A_W^k | w^k \; multinomial(w^k), k = 1, \ldots, K$$

$$w^k | w^* \; Dir(x w^*), k = 1, \ldots, K$$

$$gamma(0.1, 0.1)$$

$$w^* \; Dir(1)$$

In which, *multinomial* stands for the multinomial distribution, *Dir* stands for the Dirichlet distribution and *gamma(0.1, 0.1)* stands for the gamma distribution with the shape parameters of 0.1. Nevertheless, this model does not have an closed form. For this reason Markov-chain Monte Carlo (MCMC) methods, like *"Just Another Gibbs Sampler"* is used. The useful outcome of the model is the posterior distribution of weights for every single expert and the w^*. Nevertheless, this does not provide insight in the confidence of the superiority between the PI policy directions in the different PI port scenarios. Therefore, the Bayesian BWM also calibrates the degree of superiority by means of credal ranking. For credal ranking is credal ordering used:

Definition 1 Credal Ordering: For a pair of PI policy directions pd_i and pd_j the credal ordering O is defined as:

$$O = (pd_i, pd_j, R, d)$$

In which, R is the relation between PI policy direction pd_i and pd_j: > or <. and $d \in$ [0,1] represents the confidence of the relation.

Definition 2 Credal ranking: For a set of PI policy directions PD = (pd_1, pd_2, ..., pd_n), the credal ranking is a set of credal orderings, which includes all pairs of (pd_i, pd_j) for all $pd_i, pd_j \in$ PD

The confidence provides more insight in the certainty of the relation. To find the confidence of each credal ordering a new Bayesian BWM test is performed. The test is predicated on the posterior distribution of w^*. The confidence that pd_i being superior to pd_j is computed by:

$$P(pd_i > pd_j) = I_{(w_i^* > w_j^*)} P(w^*)$$

In which, I is equal to one when the condition in the subscript holds and 0 otherwise and $P(w^*)$ is the posterior distribution of w^*. This integration can be approximated by the samples via the MCMC. Having Q samples from the posterior distribution, the confidence can be computed as:

$$P(pd_i > pd_j) = \frac{1}{Q} \sum_{q=1}^{Q} I(w_i^{q*} > w_j^{q*})$$

$$P(pd_j > pd_i) = \frac{1}{Q} \sum_{q=1}^{Q} I(w_i^{q*} > w_j^{q*})$$

In which, w^{q*} is the q^{th} sample of w^* from the MCMC samples. Based on this information is for each pair of PI policy direction, the confidence superiority determined. The credal ranking could be changed into a traditional ranking. In which, $P(pd_i > pd_j) + P(pd_j > pd_i) = 1$. Hence, pd_i is more important than pd_j, if and only if $P(pd_i > pd_j) > 0.50$. As a result, can the traditional ranking be obtained by applying a threshold of 0.50 in the credal ranking. The credal ranking for the different KPIs in the different PI port scenarios is presented in appendix F and the resulted 'best-fit' focus distribution is presented in section 7.2.

The second until the fourth step of the Bayesian BWM is conducted with the use of a questionnaire. For the applicability of the results, it is important to consider who to approach for the questionnaire. There are, for instance, fundamental differences between researchers and practitioners. Both, these groups have very different assumptions on how knowledge is created. Researchers make assumptions about the real-world, which play a crucial role in dealing with, among other things, future uncertainties (Shrivastava & Mitroff 1984). To bridge this gap in this research, both researchers from the field of PI and maritime ports are asked to fill in the questionnaire, and practitioners with work experience related to policy making in maritime ports are asked to fill in the questionnaire. The expertise of the experts is in the same way judged as with the interviews (see section 3.2).

To prevent biasness and inconsistency in the results, all the questionnaires are conducted via interviews. Also, to reduce the workload for the respondents, each respondent only performed the questionnaire for the KPIs for two PI port scenario (see appendix D).

Still, due to the combination of the expert perceptions used in the (Bayesian) BWM and the highly hypothetical future situations described to the experts in the questionnaire, the resulted weights are not considered to be precise enough to exactly determine the focus distributions of PI policy directions on the different KPIs in the different PI port scenarios. Nevertheless, patterns in and the 'best-fit' focus distributions for the different KPIs and the different PI port scenarios can be used to formulate recommendations for future (adaptive) policy making by the PA to make the maritime port attractive in the uncertain future of PI.

To get insight in the 'absolute' contribution of the different PI policy directions, the potential absolute improvement of a KPI in a PI port scenario for a particular port has to be determined. This requires more research (see appendix E).

(Overall) policy focus distribution of PI port scenarios
When the following two assumptions are considered, the importance weights of the criteria classes estimated by Fahim (2020) (see appendix A) can be used to estimate the overall 'best-fit' focus distribution of the PI policy directions in the different PI port scenarios:

- The (potential) improvement of a KPI is relatively the same to the (potential) improvement of the other KPIs across the different PI port scenarios.
- The weights of Fahim (2020) for the criteria classes are representative for the KPIs and consistent across the different PI port scenarios.

With these assumptions the (relative) overall impact of the PI policy directions in the PI port scenarios is determined by the summed multiplication of the importance weight (w) for the criteria classes with the (relative) impact of PI policy direction (x) on KPI (z) in a PI port scenario (y).

$$P_{xy} = \sum_{z} w_z * P_{xyz}$$

3.4 Recommendations future (adaptive) policy making Port Authority

Based on the patterns in and between the 'best-fit' focus distributions of the PI policy directions for the different KPIs for the attractiveness of the maritime port in the different PI port scenarios, path-dependencies between the PI policy directions and different sell-by dates of the PI policy directions in the different PI port scenarios, recommendations to the PA to improve the attractiveness of the maritime port are provided. The KPIs for the attractiveness of the maritime port, considered are based on the criteria classes from Fahim (2020) and outlined in section 5.

Future outcome	Technological development	Institutional development
Positive	Fast	Progressive
Negative	Slow	Restrictive

Table 1. Positive and negative future outcome driving forces

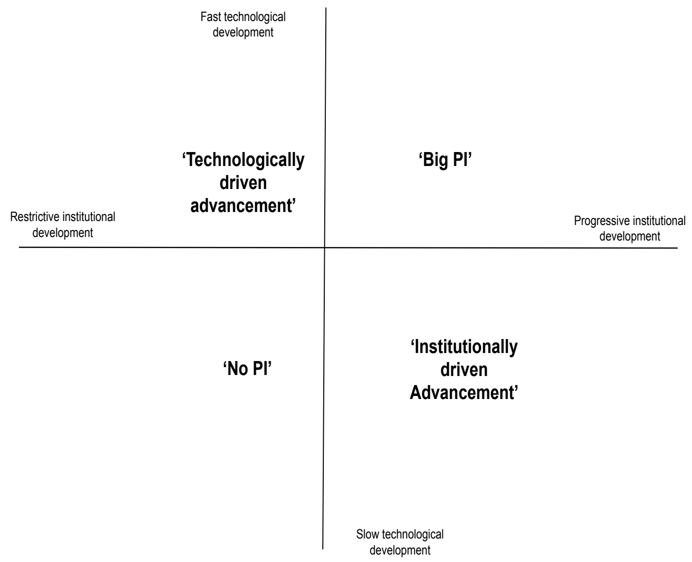


Figure 3. Scenario logic PI port scenarios

4 PI PORT SCENARIOS

In total 39 external factors are identified (see appendix table C1). These external factors are aggregated into the following two driving forces:

- **Technological development:** represents the development of technological innovations, such as IoT, Big data, AI and Blockchain.
- **Institutional development:** represents the restrictions and/or support from institutions[3] for implementing PI policy by the PA.

For both these driving forces the most positive and most negative future outcome is developed (See table 1 for an overview). These extreme positive and negative future outcomes are presented into the scenario logic of Enserink et al. (2010) (see figure 3). The quadrants in this figure represents the different PI port scenarios, as a combination of a positive and a negative future outcome of both the driving forces. The PI port scenarios are, subsequently, presented.

4.1 PI port scenario 1: 'Big Physical Internet'

In this PI port scenario, there are a lot of technological opportunities. The legal restrictions are limited and there are additional

[3] (Formal) institution refer to 'the humanly devised constraints that structure political, economic and social interactions' Williamson (1998)

sustainable incentives to implement PI like policy measures. The logistics stakeholders are willing to share data and physical resources, apply new innovations, apply new business models and cooperate with each other. In 2040, there will be full developed PI specific interfaces, protocols and modular containers.

4.2 PI port scenario 2: 'Institutionally driven Advancement'

In this PI port scenario, the legal restrictions are limited and there are additional sustainable incentives to implement PI like policy measures. The logistics stakeholders are willing to share data and physical resources, apply new innovations, apply new business models and cooperate with each other. There will be full developed PI standardisation for the protocols, the interfaces and modular containers in 2040. However, due to technological limitations in computing power of distributed systems and entities, limited development of IoT, Big Data, AI and Blockchain applications, the autonomous real time decision making capacity and connectivity between stakeholders, between stakeholders and physical objects and between physical objects is limited.

4.3 PI port scenario 3: 'Technologically driven advancement'

In this PI port scenario, the technological development is fast and provides opportunities to implement worldwide PI. Nevertheless, due to legal restrictions, limited sustainable incentives, limited developed PI standards and the logistics stakeholders not willing to share data, apply new innovations, apply new business models or cooperate with each other, only limited number of PI applications are applied around the world. These applications are, furthermore, taking place in a rather unstructured way and often have limited scope of one company or one (vertical) alliance.

4.4 PI port scenario 4: 'No PI'

In this PI port scenario, due to technological limitations in computing power of distributed systems and entities, limited development of IoT, Big Data, AI and Blockchain applications, the autonomous real time decision making capacity and connectivity between stakeholders, between stakeholders and physical objects and between physical objects is limited. Furthermore, legal restrictions, limited sustainable incentives, limited developed (PI) standards and the logistics stakeholders not willing to share data, apply new innovations, apply new business models or cooperate with each other, limits the number of PI applications. In this PI port scenario, PI stays in its infancy stage and only occasionally pilots are started.

5 KEY PERFORMANCE INDICATORS

The KPIs for the attractiveness of the maritime port are based on the port choice criteria classes for containers and vessels in the context of PI, determined by Fahim (2020). These criteria classes are considered relevant for the attractiveness of the maritime port, based on the following reasoning: In this research, the focus is on handling/transporting/storing containers rather than on bulk, which ensures vessels and containers are always playing a role in the transshipment between vessels and land modes. And, as can be stated that all activities and stakeholders in the maritime port are related to the transshipment of goods between vessels and land modes, can be stated that vessels and containers are the only two entities relevant for the attractiveness of the maritime port Ibrahimi (2017). Furthermore, a certain stakeholder perspective is less relevant, as it is uncertain which stakeholders will play a role in the uncertain future of PI and in what form.

To prevent confusion by the respondents between the KPIs and the PI port scenarios, which include the technological development, the criteria classes C *'Technology'* and D *'Network Quality of Port'* are redefined. Also, to reduce the workload for the experts, the descriptions of the KPIs are shortened to the following:

A Transport Chain Quality (TCQ): Refers to the effectiveness of the port operations, including the speed, reliability and quality of operations, and the agility to respond to changes/disruptions in the port operations.
B Costs: Refers to the costs for the port users.
C Digital Connectivity (DC): Refers to the digital connectivity in the port and the seamless digital integration of the port in the supply chains.
D Physical Network Connectivity (PNQ): Refers to the physical connectivity of the port, the reliability of the maritime operations and the hinterland operations, and the agility to respond to changes/disruptions in the maritime operations and the hinterland operations.

6 PI POLICY DIRECTIONS

The PA could play several roles to improve the attractiveness of the maritime port in the uncertain future of PI. The most important roles, determined by literature review and 14 expert interviews are used to develop six PI policy directions the PA could apply. For each of these six PI policy directions, the considered role is treated below:

- **Transport Infrastructure:** From both literature, and the interviews can be concluded that the PA should play a role in improving the accessibility of the port, both by land and by sea (Notteboom & Rodrigue 2005; De Langen 2009; CEMT 2001).
- **(PI) standardisation:** In literature, there are only a few references to the advancement of standardisation by the PA (Landschützer et al. 2015; ALICE 2019). However, from the performed interviews can be concluded that advancing (PI) standardisation could potentially be an important role for the PA.
- **Advanced Terminal Areas:** An important element of PI is to enable open asset sharing and flow consolidation. For this to happen reshuffling activities in the maritime port are required (see PI port framework operational level 2: *Automated crossdocking and reshuffling operations*). In this, the PA could play a crucial role, as it is responsible for the land development of the port (Baltazar & Brooks 2001; Brooks 2004). This potential role of the PA was also mentioned during the interviews.
- **ICT Hardware:** From literature and interviews can be concluded that the PA could play a role in advancing the installation of sensors and wireless communication technologies. This enables fast and fact based exchange of information required to improve the efficiency and sustainability of the port operations and the port related activities (Douaioui et al. 2018; Fernández et al. 2016; Molavi et al. 2020; Botti et al. 2017).
- **Information systems and information exchange platforms:** To enable the reshuffling activities in the maritime port Information Systems (IS) and information platforms should be in place. In both literature and interviews, it was often discussed that the PA could have a particular role in this (Douaioui et al. 2018;

Fernández et al. 2016; Molavi et al. 2020; Botti et al. 2017). Furthermore, the PA has an important role in providing information systems in the port, such as the Port Community System (PCS) and the Port Management System (PMS).

- **Sustainability Management:** As, the PA is responsible for the environmental policy and protecting the public interest, the PA should consider taking policy measures to reduce the negative externalities of port operations and thereby improving the attractiveness of the maritime port (Baltazar & Brooks 2001; Brooks 2004). This is both discussed in literature and in the interviews. This PI policy direction might be to a lesser degree related to PI, however as PI has to goal to improve the efficiency and sustainability of global logistics system, this PI policy direction is still considered relevant.

Based on these considered roles, policy measures the PA could apply, are used to develop the definitions of the PI policy directions. The definitions of the six PI policy direction are presented below.

Transport infrastructure (TI)
This PI policy direction includes investments in the port infrastructure, such as to increase the rail shunting capacity and to improve the waterside access, by deepening the river to relax draft restrictions (Notteboom 2016; Brooks & Cullinane 2006; Arduino et al. 2013; Brooks 2004; Voster 2019). In the long-term, this could also include investments in offshore ports or Hyperloop terminals. Also, this PI policy direction, includes investments, by among other means joint ventures and collaborations with stakeholders from the port community and governments, in developing hinterland infrastructure, inland terminals, dedicated transport services, air freight connections and potentially in the long-term Hyperloop connections (Rodrigue & Notteboom 2006; Voster 2019; Notteboom & Rodrigue 2005; De Langen 2009; Van der Lugt et al. 2014).

(PI) standardisation ((PI) Stand.)
This PI policy direction includes the development of standards required for e.g. the digitalization of the Bill-of-Lading and customs declarations, the development of nautical standards and the development of standardisation of PI specific interfaces, protocols and modular containers. In this, the PA could set their own standards, lobby at organisations like the EU, WTO, IMO, ISO, GS1 and/or collaborate with stakeholders from the port community and other PAs in setting (PI) standards (Voster 2019; ALICE 2019; Benmoshe 2020). Furthermore, the PA could show with best use cases and pilots, which standards might work and which standards be less useful (Thijsen 2020; ALICE 2019). In the long-term, the PA could stimulate or enforce the usage of certain standards by incentives or rules in the concession, by access regulation or by pricing strategies (Mocerino & Rizzuto 2019; Lam & Notteboom 2014; Bergqvist & Egels-Zandén 2012; Aregall et al. 2018; Wiegmans & Louw 2011; ALICE 2019; Notteboom & Lam 2018; P. T. W. Lee & Cullinane 2016; De Langen 2009).

Advanced Terminal Areas (ATA)
This PI policy direction, in the short term, includes showing with best use cases and pilots what sharing of assets and goods could bring to the port community (Thijsen 2020; ALICE 2019; M. Van der Horst et al. 2019; Daamen & Vries 2013). In the long-term, the PA could develop and operate its own shared warehouses, in which reshuffling operations of PI containers take place (Van den Berghe et al. 2018; Brooks 2004; Franklin & Spinler 2011). Alternatively, it could outsource this function (to a 3PL), but keep it within the port area (Voster 2019; Van den Berghe et al. 2018; Franklin & Spinler 2011). Besides, the PA could use their concession power, access regulation or pricing strategies to enforce/stimulate reshuffling operations taking place in the port area (Mocerino & Rizzuto 2019; Lam & Notteboom 2014; Bergqvist & Egels-Zandén 2012; Aregall et al. 2018; Wiegmans & Louw 2011; Notteboom & Lam 2018; P. T. W. Lee & Cullinane 2016; De Langen 2009).

ICT Hardware (ICT-H)
This PI policy direction includes, the installation of sensors, e.g. RFID tags and wireless communication technologies, such as 5G. This enables swift exchange of large data volumes, required for (e.g. IoT) applications, such as predictive maintenance, or applications required for the digital visibility of shipment and port operations (Yang et al. 2018). In this, the PA could play the role of facilitator, stimulating the implementation of physical (digital) infrastructure by the port community (Notteboom & Rodrigue 2005; Groothedde et al. 2005). This could be done by e.g. using their concession power (Mocerino & Rizzuto 2019; Lam & Notteboom 2014; Bergqvist & Egels-Zandén 2012; Aregall et al. 2018; Wiegmans & Louw 2011; Notteboom & Lam 2018; P. T. W. Lee & Cullinane 2016; De Langen 2009).

Information systems and information exchange platforms (IS and IEP)
This PI policy direction includes the PA showing with best use cases and pilots what data and data sharing could bring to the port community (Thijsen 2020; ALICE 2019; M. Van der Horst et al. 2019; Daamen & Vries 2013).. It includes, the PA integrates its different ISs and stimulate the alignment of ISs used by the port community, ensuring interoperability (P. T. W. Lee & Cullinane 2016). The PA could improve the Smart functionalities of the PMS and contribute to the PCS by applying AI, IoT and Big data applications (Barr & Feigenbaum 2014; Fernández et al. 2016; Belfkih et al. 2017; Douaioui et al. 2018; Yang et al. 2018). As a neutral stakeholder, the PA could, furthermore, play the role of logistics coordinator and develop a digital platform offering informational services required for reshuffling activities, the interoperability, the coordination of shipments and the corresponding money streams, complementing the Business-to-Government PCS (Sallez et al. 2016; Voster 2019; Martinez de Ubago 2019; Franklin & Spinler 2011; ALICE 2019). And, the PA could, in the long-term, connect their ISs and platforms with the hinterland and maritime side to digitally integrate the port within the complete supply chains Srour et al. (2008); Voster (2019); Benmoshe (2020).

Sustainability Management (SM)
In this PI policy direction, the PA develops monitoring systems, controlling the safety, the air quality, the water quality and nuisance (Puig et al. 2014; Pavlic et al. 2014; Molavi et al. 2020; Lam & Notteboom 2014; Di Vaio & Varriale 2018). The PA takes specific measures to comply with, among others environmental regulation, work condition regulation and traffic measures (Di Vaio & Varriale 2018). The PA implements policy measures to reduce the negative externalities of their operations and encourage/stimulate the stakeholders in the port community to implement sustainable policy by incentives and rules in the concessions, by access regulation and by pricing strategies (Mocerino & Rizzuto 2019; Lam & Notteboom 2014; Bergqvist & Egels-Zandén 2012; Aregall et al. 2018; Wiegmans & Louw 2011; Notteboom & Lam 2018; P. T. W. Lee & Cullinane 2016; De Langen 2009).

Table 2. 'best-fit' focus distributions PI policy directions on KPI Transport Chain Quality in the different PI port scenarios

	'Big PI'	'Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.130	0.126	0.110	0.202
(PI) Standardisation	0.195	0.214	0.247	0.173
Advanced Terminal Areas	0.141	0.169	0.132	0.172
ICT Hardware	0.179	0.179	0.160	0.151
Information systems and Information exchange platforms	0.255	0.219	0.253	0.188
Sustainability Management	0.100	0.094	0.098	0.115
Total	1	1	1	1

Table 3. 'best-fit' focus distributions PI policy directions on KPI Costs in the different PI port scenarios

	'Big PI'	'Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.167	0.179	0.139	0.260
(PI) Standardisation	0.222	0.175	0.190	0.182
Advanced Terminal Areas	0.134	0.165	0.139	0.163
ICT Hardware	0.165	0.158	0.178	0.131
Information systems and Information exchange platforms	0.241	0.242	0.263	0.168
Sustainability Management	0.073	0.082	0.092	0.096
Total	1	1	1	1

7 (BAYESIAN) BEST WORST METHOD

In this section, the Bayesian Best Worst Method (hereafter: BWM) is used to prevent the 'best-fit' focus distributions of the PI policy directions on the different KPIs in the PI port scenarios.

7.1 Data collection

To collect the data a questionnaire is presented to respondents with a background in PI and/or a background in policy making for maritime ports (see appendix D). In total 21 experts conducted the questionnaire via an interview. All these experts conducted the Bayesian BWM for at least two PI port scenarios. This led to in total twelve respondents for the PI port scenarios 'Big PI' and 'No PI' and in total eleven respondents for the PI port scenarios 'Institutionally driven PI' and 'Technologically driven PI'.

7.2 Focus distributions PI policy directions

In this subsection, the 'best-fit' focus distributions of the PI policy directions on the different KPIs for the different PI port scenarios are presented (see table 2 until table 5). Also, to estimate the overall 'best-fit' focus distributions of the different PI policy directions in the different PI port scenarios, the importance weights of Fahim (2020) (see appendix A) are used. This provides the following results for the container perspective and the vessel perspective (see table 6).

Table 4. 'best-fit' focus distributions PI policy directions on KPI Digital Connectivity in the different PI port scenarios

	Big PI'	Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.085	0.080	0.082	0.107
(PI) Standardisation	0.228	0.226	0.257	0.194
Advanced Terminal Areas	0.108	0.099	0.112	0.117
ICT Hardware	0.207	0.232	0.197	0.230
Information systems and Information exchange platforms	0.286	0.285	0.266	0.255
Sustainability Management	0.087	0.078	0.087	0.097
Total	1	1	1	1

Table 5. 'best-fit' focus distributions PI policy directions on KPI Port Network Quality in the different PI port scenarios

	'Big PI'	'Institutionally driven advancement'	Technologically driven advancement'	No PI'
Transport Infrastructure	0.260	0.214	0.204	0.271
(PI) Standardisation	0.166	0.190	0.211	0.154
Advanced Terminal Areas	0.196	0.175	0.141	0.176
ICT Hardware	0.132	0.141	0.135	0.131
Information systems and Information exchange platforms	0.152	0.210	0.231	0.160
Sustainability Management	0.095	0.072	0.079	0.107
Total	1	1	1	1

Table 6. Estimated 'best-fit' focus distributions PI policy directions in the different PI port scenarios for the Container- and Vessel perspective

	'Big PI		'Institutionally driven advancement		'Technologically driven advancement'		'No PI'	
	CP	VP	CP	VP	CP	VP	CP	VP
TI	0.165	0.163	0.156	0.156	0.137	0.136	0.222	0.222
(PI) Stand.	0.202	0.204	0.197	0.196	0.221	0.225	0.175	0.176
ATA	0.146	0.144	0.159	0.158	0.133	0.134	0.162	0.161
ICT-H	0.168	0.168	0.171	0.172	0.165	0.160	0.151	0.152
IS and IEP	0.234	0.236	0.234	0.236	0.253	0.250	0.185	0.186
SM	0.088	0.087	0.083	0.082	0.090	0.090	0.104	0.104
Total	1	1	1	1	1	1	1	1

8 RECOMMENDATIONS FUTURE (ADAPTIVE) PI POLICY MAKING

Based on patterns in and between the 'best-fit' focus distributions, the sell-by dates of the different PI policy directions and the path-dependencies between the different PI policy directions the following recommendations to the PA are provided to make the maritime port attractive in the uncertain future of PI.

Main focus points for the PA

The PA should mainly focus on the PI policy direction *Information systems and Information exchange platforms*, especially to improve the KPI Digital Connectivity. Nevertheless, in the PI port scenario 'No PI', it is advised, the PA should focus less on this PI policy direction, as it is less effective. This also applies for the *(PI) Standardisation*, which, however should generally be less focused in the different PI port scenarios. Still, it is advised to the PA to play an active role in developing (PI) standards in an early stage and dependent on the PI port scenario enforce/stimulate the usage of certain (PI) standards by the port community in a later stage. It is especially advised to focus on this PI policy direction in the PI port scenario 'Technologically driven advancement', as the

PA in this case could have an extra important role in developing and stimulating/enforcing standards, as other stakeholders are less willing to do so and the effective use of e.g. the *Information systems and Information exchange platforms*, technologically far developed in that particular PI port scenario, depends on it.

The PA should in the different PI port scenarios apply the PI policy direction *Transport Infrastructure*, especially to improve the KPI Physical Network Connectivity. In the PI port scenario 'No PI', the PA should focus a lot on this PI policy direction, as other PI policy directions become less effective.

Different policy focus of the PA outside the port territory
To improve the KPI Physical Network Connectivity, the PA should to a lesser degree focus on the PI policy directions *Information systems and Information exchange platforms* and *(PI) Standardisation*. These PI policy directions are considered to be less impactful on maritime operations and hinterland operations, as these operations are outside the port territory and less in the influence sphere of the PA. The PI policy direction *Information systems and Information exchange platforms* is, still impactful on the KPI Physical Network Connectivity in the 'Institutionally driven advancement' and 'Technologically driven advancement'. In the PI port scenario 'Technologically driven advancement', it is advised to stimulate efficient maritime operations and hinterland operations by providing more information system services and information exchange platform services outside the scope of the port, compensating the lack of interest of other stakeholders providing (or using) these services. In the PI port scenario 'Institutionally driven advancement', it is advised to provide, as much services by information systems and information exchange platforms as possible, to improve the hinterland operations and the maritime operations, as other systems providing these services lack behind due to slow technological development.

General recommendations for the PA
The PA could regardless of which scenario unfolds itself start pilots and best use cases to show what standardisation and sharing of assets, both physically and digitally (data) could bring to the port community. In general, for future (adaptive) policy making, it is always important to consider a broad perspective: what is the added value of the maritime port to the (global) logistics system and what could the PA influence with its policy, rather than the competitive approach: how can I attract the most companies to the port. This broader perspective will, regardless of which PI port scenario unfold itself make the maritime port attractive and make the implemented (PI) policy effective.

Other recommendations for the PA
It is advised to the PA to consider *Advanced Terminal Areas*, especially as the institutional development is progressive. Otherwise, logistics stakeholders will only make limited use or will not use these facilities. This PI policy direction is particularly effective in improving the KPI Physical Network Quality. Nevertheless, the focus of the PA should be less on this PI policy direction, as it is considered not entirely up to the PA to develop the terminal areas. This strongly depends on the terminal operators.

The PA should advance the installation of *ICT Hardware*, as the effective usage of the *Information systems and Information exchange platforms* depends on it. This PI policy direction is especially effective to improve the KPI Digital Connectivity and should be less focused on to improve the KPI Physical Network Connectivity.

On the PI policy direction *Sustainability Management* the PA should focus the least. A possible explanation for this is that this PI policy direction is considered a bit outside of the scope of PI. It does not mean the policy suggested is not sustainable. Other PI policy directions improve the sustainability by better asset utilization, including the PI policy directions *Information systems and Information exchange platforms* and *Advanced Terminal Areas*.

9 DISCUSSION

The paper offers room for discussion and room for future research:

This research only analyses four different PI port scenarios. This is relatively low to further develop (adaptive) policy making for the PA. For this reason, research based on more different scenarios is recommended. Also, in this research, only six aggregated PI policy directions are used. These PI policy directions include much more specific policy measures. It is, therefore, recommended to conduct more research to these specific policy measures and to how these policy measures can be translated into an actual policy plan.

In this research, the KPIs for the attractiveness of the maritime port are based on the criteria classes used for the port choice of containers and vessels. In future research, it might also be valuable to consider bulk transport and the industry in the maritime port. Furthermore, it is recommended to determine the cost-effectiveness of the PI policy directions by performing additional research to the investment cost of the different PI policy directions. Or, analyse the impact of the PI policy measures in a more quantitative way, e.g. what are the effects of the directions on the container throughput in the different PI port scenarios.

In this research, it is both assumed that the experts could make judgments from the perspective of the PA and the reference port of the experts does not influence the results of the (Bayesian) BWM. As, only experts from North-west Europa filled in the questionnaire, it can, therefore be argued that the results are particularly of use for PAs in this area. It would be valuable to perform a comparable (Bayesian) BWM with experts from other geographical areas. Also, as the (Bayesian) BWM only provides insight in the 'best-fit' focus distributions of the PI policy directions on the KPIs in the different PI port scenarios, it is recommended to perform a *Gap analysis* for a particular ports to determine to which extend, in this port the different KPIs can be improved in the different PI port scenario. In combination with the results of this paper the absolute contribution of PI policy directions in PI port scenarios can be determined. This provides valuable information for the PA to develop an actual policy plan. Alternatively, research can be recommended to determine the relative improvement of the KPIs in the PI port scenarios, by e.g. a (Bayesian) BWM. This can in combination with the results from this study and Fahim (2020) better estimate the overall 'best-fit' focus distributions of the PI policy directions in the different PI port scenarios.

This research is performed for the PA of a landlord port. For this reason, it can be recommended to perform a comparable research to the other types of maritime ports, to perform a comparable research from a different stakeholder's perspective and to perform a comparable research to other logistics system components, like airports.

10 CONCLUSIONS

The research objective *Supporting the maritime port in designing policy to be attractive in the future, given the uncertain development of Physical Internet.* is filled by, first of all, performing a literature review, a stakeholder analysis and perform applications of theoretical frameworks to define four different PI port scenarios. Secondly, literature review and 14 expert interviews are used to develop six PI policy directions the PA could apply to make the maritime port attractive in the uncertain future of PI. Thirdly, patterns in and between, the by Bayesian BWM, determined 'best-fit' distributions of the PI policy directions on the KPIs for the attractiveness of the maritime port in the different PI port scenarios are used to provide recommendations for the PA to make the maritime port attractive.

From these patterns can be concluded that dependent on how this innovation will develop, different policy focus for the PA is recommended. However in general the PA should focus on developing and providing information systems and information platforms, and the PA should focus on developing and stimulating the usage of (PI) standards. The overall scientific objective of improving the knowledge regarding the implications of PI on the future development of maritime ports is filled by providing the following scientific contributions:

Scientific contribution 1: Recommendations to the PAs to make the maritime port attractive in the uncertain future of PI
Based on patterns in and between 'best-fit' focus distributions of PI policy directions for different KPIs of the attractiveness of the maritime port in different PI port scenarios, sell-by dates and path-dependencies of PI port directions, for the first time recommendations are provided to the PA about making the maritime port attractive in the uncertain future of PI.

Scientific contribution 2: First set of theoretical backed PI policy directions
Until now, only Voster (2019) identified some policy measures the PA could apply in the context of PI. Nevertheless, these policy measures lack theoretical background and did not directly have to objective to improve the attractiveness of the maritime port. In this paper, with the use of in-depth literature review and 14 expert interviews, theoretical backed PI policy directions are formulated, which improve the attractiveness of the maritime port in context of PI.

Scientific contribution 3: A new case of the (Bayesian) BWM, specifically to determine 'best-fit' focus distribution for policy, in different (future) context
Currently, the Bayesian BWM is not widely applied. Only, Fahim (2020) applied this methodology in context of maritime ports and PI. This paper adds a new case in this context. However, more importantly, to the best of the writer's knowledge, it is the first (Bayesian) BWM application, which is used to provide recommendations for policy making, based on patterns in and between 'best-fit' focus distributions of policies, being in this paper PI policy directions, in/for different (future) contexts, being in this paper different KPIs and different PI port scenarios. There are studies, which uses the BWM in assessing different policies (Abadi et al. 2018; Mokhtarzadeh et al. 2018) or even assess the performance of different policies on different criteria (Safarzadeh et al. 2018). However, no comparable study is found, which uses the BWM to provide recommendations based on patterns in and between 'best-fit' focus distributions. From this research can be concluded that the (Bayesian) BWM is a useful methodology to find these patterns and provide recommendations based on these patterns. Thereby, it is important to note that, the (Bayesian) BWM uses experts perspectives and it is for this reason, especially recommended to use this methodology in highly hypothetical (future) contexts, when other methodologies are less applicable due to lack of (quantitative) information.

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Table A1. Criteria class weights from the container and vessel perspective (Fahim, 2020)

	Transport chain Quality	Cost	Technology	Network quality of port
Container perspective	0.305	0.325	0.145	0.225
Vessel perspective	0.264	0.369	0.160	0.207

APPENDIX A: IMPORTANCE WEIGHTS CRITERIA CLASSES

APPENDIX B: INTERVIEWEES

- Strategist at the PA of the PoR.
- Professor, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta.[4]
- Professor of Global Supply Chains and Ports, Erasmus University.
- Adjunct Professor of Logistics and Academic Director of Executive Education at Kühne Logistics University.
- Research Professor Transport, Logistics and Ports, University of Antwerp
- Chief Information Officer (hereafter: CIO) and manager digital innovation Groningen Seaports
- Full Professor, Freight & Logistics, Delft University of Technology.
- Technical Director of the technical Innovation Office of the Bahía de Algeciras and Port innovation manager by port of Algeciras.
- Dean of Industry Relations from Universitity Groningen.
- Teacher Systems Engineering, University Groningen.
- Professor at Mines ParisTech, PSL Research University, Director Centre de Gestion Scientifique.
- Senior Professor at Kedge Business School, Visiting Professor at the Shanghai Maritime University and at the World Maritime University.
- Director of Innovation and Port Cluster Development at Fundación Valencia port.
- Manager innovations at the Port of Amsterdam.

APPENDIX C: EXTERNAL FACTORS AND EXTERNAL FACTOR CLASSES

For the PI port scenarios, only the external factor classes E until H are used. The external factor classes A until D are about the demand side, not about the uncertain future of PI.

[4] This respondent, after repeated emails did not respond to whether they agree or disagree with the summary I use in this paper. Nevertheless, during the interviews I asked whether they were fine with using their functions in this way.

Table C1. External factors clustured

A. Economic growth	**B. Demographic changes**
1. (World) GDP Henderson et al. (2012)	1. Population growth 2. Migration flows Poulain (2008) 3. Urbanisation McGranahan & Satterthwaite (2014)
C. Flow patterns	**D. Global institutional integration**
1. Nearshoring & Backshoring Dachs et al. (2019); Slepniov et al. (2013) 2. Safety stock 3. Increase in vessel size Notteboom (2016); Merk (2018) 4. New trade routes Liu & Kronbak (2010) 5. Digitalisation of society Brennen & Kreiss (2016); Degryse (2016); Yu et al. (2016); Liang & Turban (2011) 6. Mass individualism Ince (2017) 7. Hinterland infrastructure Rodrigue & Notteboom (2006)	1. Trade agreements Eicher & Henn (2011) 2. Import tarrifs & quotas Eicher & Henn (2011) 3. Different tax environments
E. Regulatory frameworks	**F. Technological innovations**
1. Cybersecurity Craigen et al. (2014) 2. Antitrust policies Ordover & Willig (1985); Posner (2009) 3. Labour protection Aaronson & Phelan (2019) 4. (PI) standardisation	1. Internet of Things Wortmann & Flüchter (2015); I. Lee & Lee (2015); Montreuil, Meller, & Ballot (2012); Treiblmaier et al. (2016) 2. Big data Ward & Barker (2013); Zhong et al. (2017) 3. Artificial Intelligence Barr & Feigenbaum (2014); Korb & Nicholson (2010) 4. Blockchain Treiblmaier (2019) 5. Drones Frederiksen & Knudsen (2018); Floreano & Wood (2015) 6. Hyperloop Braun et al. (2017) 7. 3D printing Abeliansky et al. (2015) 8. Machine learning Mitchell (1997) 9. 5G network Ni et al. (2018) 10. Industry 4.0 Maslarić et al. (2016); Tjahjono et al. (2017) 11. Automated Guided Vehicles/equipment/vessels Kim & Bae (2004); Carlo et al. (2014)
G. Logistics market structure	**H. Sustainability**
1. (Vertical) Alliances Zhu et al. (2019); M. R. Van der Horst & De Langen (2008); De Langen (2009) 2. (Long-term) Terminal contracts Van der Lugt et al. (2014) 3. (New) Business models Geels (2004) 4. Network externalities Tavasszy (2018) 5. Willingness to share assets	1. Environmental regulation Qc (1995) 3. Land-use planning Lindholm & Behrends (2012) 4. Traffic measures Lindholm & Behrends (2012) 5. Work condition regulation 6. National subsidies

APPENDIX D: RESPONDENTS QUESTIONNAIRE

PI port scenarios: 'Big PI' and 'No PI'

- Chief Information Officer (hereafter: CIO) and manager digital innovation Groningen Seaports
- Full Professor, Freight & Logistics, Delft University of Technology.
- Teacher Systems Engineering, University Groningen.
- Director of Innovation and Port Cluster Development at Fundación Valencia port.
- Strategist at the PA of the PoR.
- Professor Multi-Machine Operations & Logistics
- Associate Professor in Maritime Logistics
- CEO and Partner of consultancy company specialised within container shipping industry
- Professor Quantitative Logistics
- Senior project manager of a logistics and transportation company
- Researcher Physical Internet in maritime port
- Professor Faculty of Civil Engineering and Geo Sciences Transportation Planning and Traffic Engineering

PI port scenarios: 'Technologically driven advancement' and 'Institutionally driven advancement'

- Full Professor, Freight & Logistics, Delft University of Technology.
- Research Professor Transport, Logistics and Ports, University of Antwerp
- Professor of Global Supply Chains and Ports, Erasmus University.
- CIO of a Port Authority in Europe
- Technical Director of the technical Innovation Office of the Bahía de Algeciras and Port innovation manager by port of Algeciras.
- Dean of Industry Relations from Universitity Groningen.
- Adjunct Professor of Logistics and Academic Director of Executive Education at Kühne Logistics University
- Researcher Physical Internet in maritime port
- Head strategy and analytic at a Port Authority in Europe
- Professor Urban, Ports and Transport Economics
- Researcher Physical Internet in maritime port

APPENDIX E: CONTRIBUTION BAYESIAN BWM

In this appendix the contribution of the Bayesian BWM applied in this paper is discussed (see figure E1).

The results of the Bayesian BWM provides insight in the 'best-fit' focus distribution of the different PI policy directions on the KPIs for the attractiveness of the maritime port in the different PI port scenarios (see green outlined part of the figure). However, to determine the 'absolute' contribution of the PI policy directions on the KPIs, also a **Gap analysis** should be performed to how much a particular KPI can be improved in a particular port y for the different PI port scenarios. This will, in combination with the 'best-fit' focus distributions provide insight in effective policy directions for the particular port y.

To determine the overall (absolute) contribution of the PI policy directions in a particular PI port scenario, the weights of the KPIs determined by Fahim (2020) can be used. These weights are only determined for the PI port scenario *'Big PI'* and *'No PI'* and the general applicability of these weights can be questioned.

APPENDIX F: CREDAL RANKING

Table F1. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Transport Chain Quality in PI port scenario 'Big PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.019	0.351	0.057	0.000	0.903
(PI) Stand.	0.980	0	0.953	0.675	0.069	0.999
ATA	0.649	0.047	0	0.111	0.001	0.951
ICT-H	0.943	0.325	0.889	0	0.027	0.998
IS and IEP	0.999	0.931	0.999	0.973	0	1
SM	0.097	0.001	0.050	0.003	0.000	0

Table F2. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Cost in PI port scenario 'Big PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.033	0.910	0.520	0.009	1
(PI) Stand.	0.968	0	0.999	0.971	0.289	1
ATA	0.090	0.001	0	0.097	0.000	1
ICT-H	0.480	0.029	0.903	0	0.007	1
IS and IEP	0.992	0.751	0.999	0.993	0	1
SM	0.000	0.000	0.000	0.000	0.000	0

Table F3. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Digital Connectivity in PI port scenario 'Big PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.000	0.097	0.000	0.001	0.444
(PI) Stand.	1	0	1	0.717	0.074	1
ATA	0.903	0.000	0	0.000	0.000	0.878
ICT-H	1	0.283	1	0	0.022	1
IS and IEP	1	0.926	1	0.978	0	1
SM	556	0.000	0.122	0.000	0.000	0

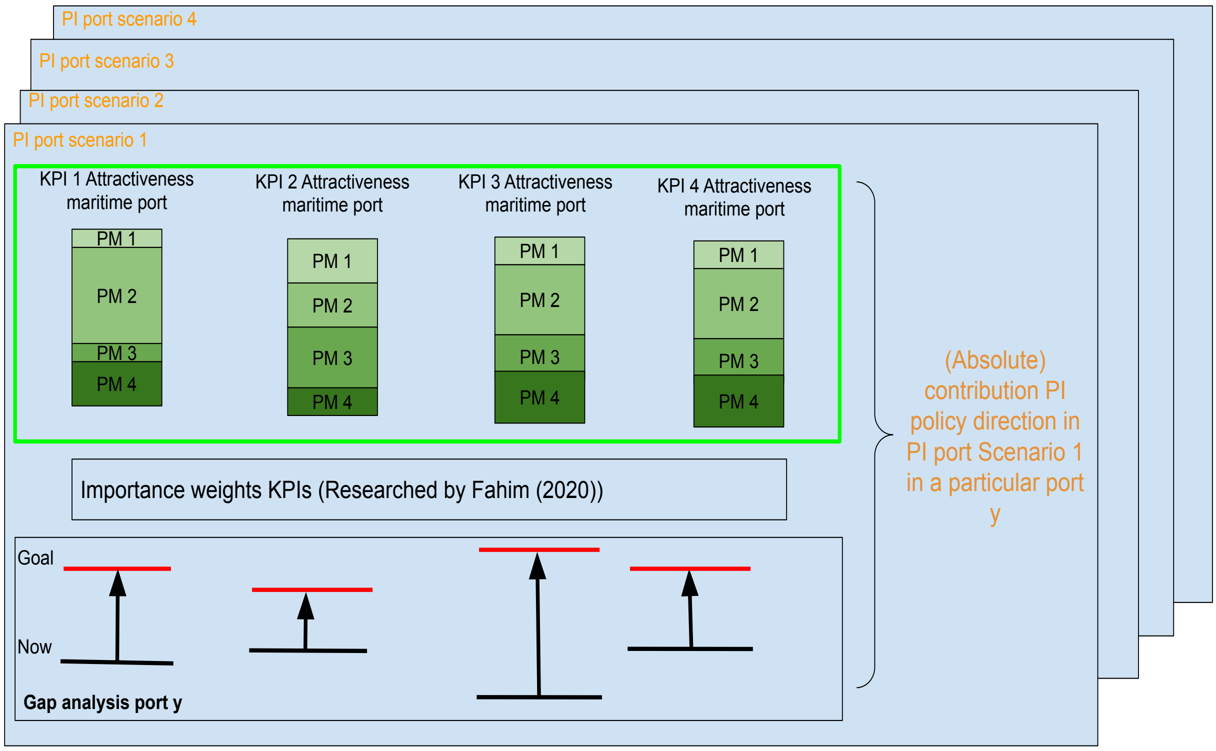

Figure E1. Perspective research contribution

Table F4. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Physical Network Connectivity in PI port scenario 'Big PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.994	0.952	1	0.999	1
(PI) Stand.	0.006	0	0.178	0.900	0.676	0.997
ATA	0.048	0.822	0	0.983	0.916	1
ICT-H	0.000	0.111	0.017	0	0.218	0.950
IS and IEP	0.002	0.324	0.084	0.783	0	0.991
SM	0.000	0.003	0.000	0.050	0.009	0

Table F5. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Transport Chain Quality in PI port scenario 'Institutionally driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.066	0.082	0.049	0.005	0.902
(PI) Stand.	0.993	0	0.880	0.814	0.450	1
ATA	0.918	0.120	0	0.390	0.099	0.995
ICT-H	0.951	0.186	0.610	0	0.156	0.998
IS and IEP	0.995	0.550	0.901	0.844	0	1
SM	0.098	0.000	0.005	0.002	0.000	0

Table F6. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Cost in PI port scenario 'Institutionally driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.554	0.672	0.746	0.046	1
(PI) Stand.	0.446	0	0.621	0.702	0.034	1
ATA	0.328	0.379	0	0.590	0.017	1
ICT-H	0.250	0.298	0.410	0	0.009	0.999
IS and IEP	0.954	0.966	0.984	0.991	0	1
SM	0.000	0.000	0.000	0.001	0.000	0

Table F7. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Digital Connectivity in PI port scenario 'Institutionally driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.000	0.109	0.000	0.000	0.535
(PI) Stand.	1	0	1	0.435	0.071	1
ATA	0.891	0.000	0	0.000	0.000	0.901
ICT-H	1	0.565	1	0	0.097	1
IS and IEP	1	0.929	1	0.904	0	1
SM	0.465	0.000	0.093	0.000	0.000	0

Table F8. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Physical Network Connectivity in PI port scenario 'Institutionally driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.762	0.887	0.993	0.548	1
(PI) Stand.	0.238	0	0.690	0.958	0.277	1
ATA	0.112	0.310	0	0.892	0.136	1
ICT-H	0.007	0.043	0.108	0	0.009	1
IS and IEP	0.452	0.723	0.865	0.990	0	1
SM	0.000	0.000	0.000	0.000	0.000	0

Table F9. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Transport Chain Quality in PI port scenario 'Technologically driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.000	0.180	0.029	0.000	0.712
(PI) Stand.	1	0	1	0.991	0.436	1
ATA	0.821	0.000	0	0.161	0.000	0.929
ICT-H	0.971	0.009	0.834	0	0.006	0.992
IS and IEP	1	0.564	1	0.994	0	1
SM	0.288	0.000	0.072	0.008	0.000	0

Table F10. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Cost in PI port scenario 'Technologically driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.055	0.509	0.102	0.001	0.978
(PI) Stand.	0.946	0	0.950	0.640	0.334	1
ATA	0.491	0.050	0	0.097	0.000	0.977
ICT-H	0.898	0.361	0.903	0	0.016	0.999
IS and IEP	1	0.967	1	0.984	0	1
SM	0.022	0.000	0.023	0.001	0.000	0

Table F11. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Digital Connectivity in PI port scenario 'Technologically driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.000	0.046	0.000	0.000	0.362
(PI) Stand.	1	0	1	0.942	0.412	1
ATA	0.954	0.000	0	0.001	0.000	0.910
ICT-H	1	0.058	0.999	0	0.036	1
IS and IEP	1	0.588	1	0.964	0	1
SM	0.638	0.000	0.090	0.000	0.000	0

Table F12. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Physical Network Connectivity in PI port scenario 'Technologically driven advancement'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.426	0.978	0.987	0.238	1
(PI) Stand.	0.574	0	0.986	0.993	0.299	1
ATA	0.022	0.014	0	0.599	0.004	0.998
ICT-H	0.013	0.008	0.401	0	0.002	0.996
IS and IEP	0.762	0.701	0.996	0.998	0	1
SM	0.000	0.000	0.002	0.004	0.000	0

Table F13. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Transport Chain Quality in PI port scenario 'No PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.766	0.767	0.905	0.630	0.993
(PI) Stand.	0.234	0	0.505	0.728	0.348	0.956
ATA	0.233	0.496	0	0.725	0.348	0.956
ICT-H	0.095	0.272	0.275	0	0.160	0.876
IS and IEP	0.370	0.652	0.652	0.840	0	0.983
SM	0.007	0.040	0.044	0.124	0.017	0

Table F14. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Cost in PI port scenario 'No PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.977	0.995	1	0.993	1
(PI) Stand.	0.023	0	0.725	0.959	0.668	0.999
ATA	0.005	0.275	0	0.874	0.435	0.995
ICT-H	0.000	0.041	0.126	0	0.094	0.934
IS and IEP	0.007	0.332	0.565	0.906	0	0.997
SM	0.00	0.001	0.005	0.066	0.030	0

Table F15. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Digital Connectivity in PI port scenario 'No PI"

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.002	0.328	0.000	0.000	0.672
(PI) Stand.	0.998	0	0.994	0.173	0.062	1
ATA	0.672	0.006	0	0.000	0.000	0.813
ICT-H	1	0.827	1	0	0.277	1
IS and IEP	1	0.938	1	0.723	0	1
SM	0.328	0.000	0.187	0.000	0.000	0

Table F16. The confidence PI policy measure (first column) is more impactful than PI policy measure (first row) for KPI Physical Network Connectivity in PI port scenario 'No PI'

	TI	(PI) Stand.	ATA	ICT-H	IS and IEP	SM
TI	0	0.999	0.990	1	0.998	1
(PI) Stand.	0.001	0	0.246	0.791	0.424	0.963
ATA	0.000	0.754	0	0.931	0.688	0.993
ICT-H	0.000	0.209	0.069	0	0.016	0.841
IS and IEP	0.002	0.576	0.312	0.843	0	0.975
SM	0.000	0.037	0.007	0.159	0.025	0