# Assessing policy focus of Port Authorities in the uncertain future of Physical Internet using the Bayesian Best Worst Method

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**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

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[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

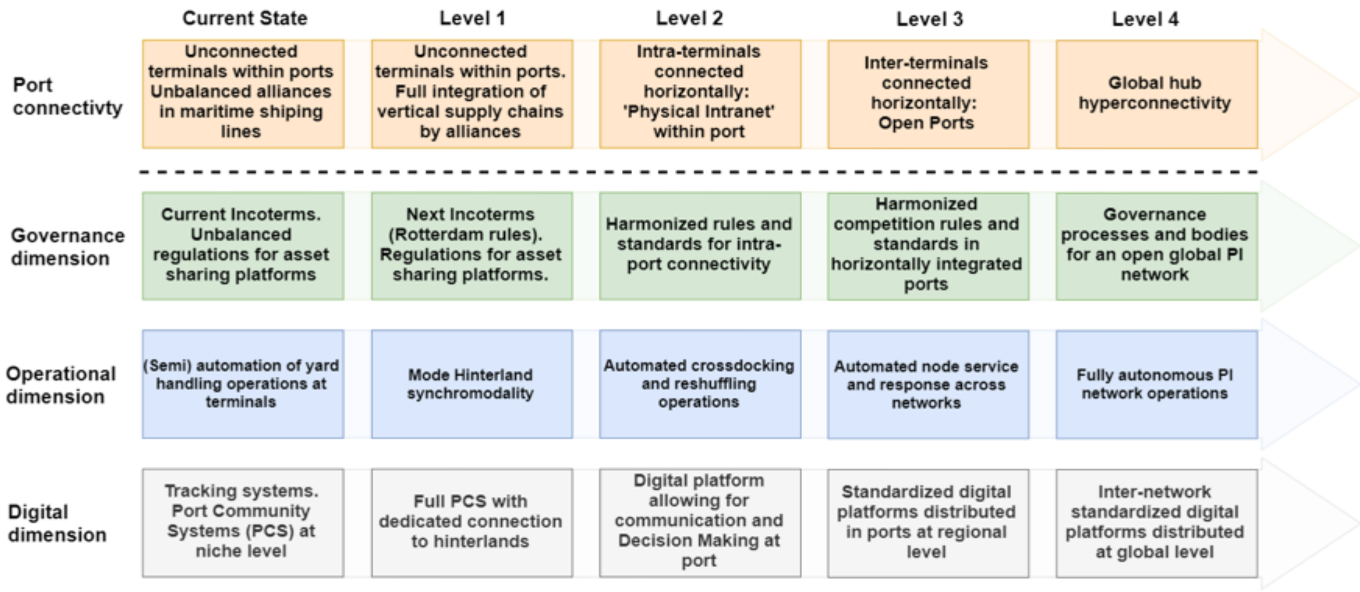


**Figure 1.** PI port framework (Martinez 2019; Voster 2019)

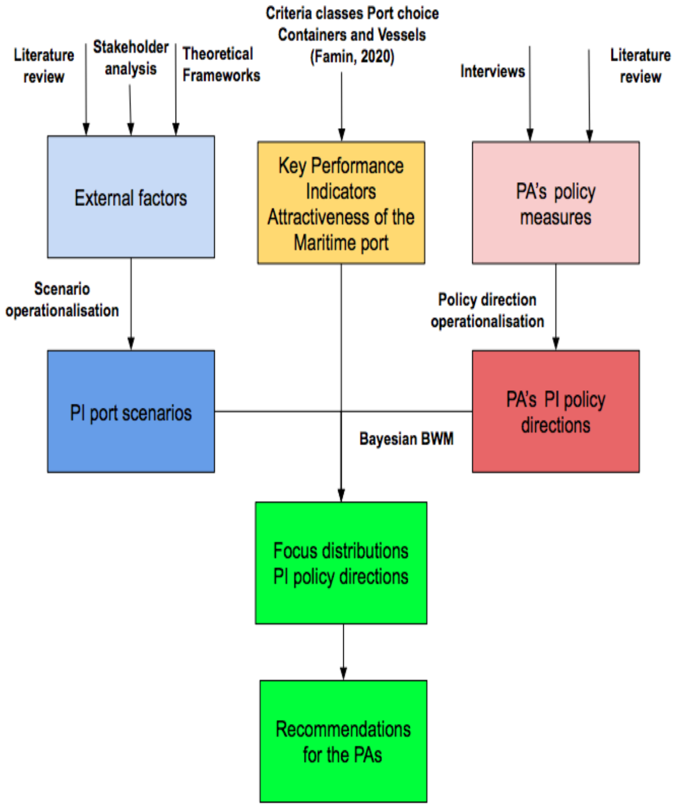


**Figure 2.** Research approach

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 $w^k$, $k = 1, \ldots, K$*
These weights are obtained based on the following probabilistic model:

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

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

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

$$gamma(0.1, 0.1)$$

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

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 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

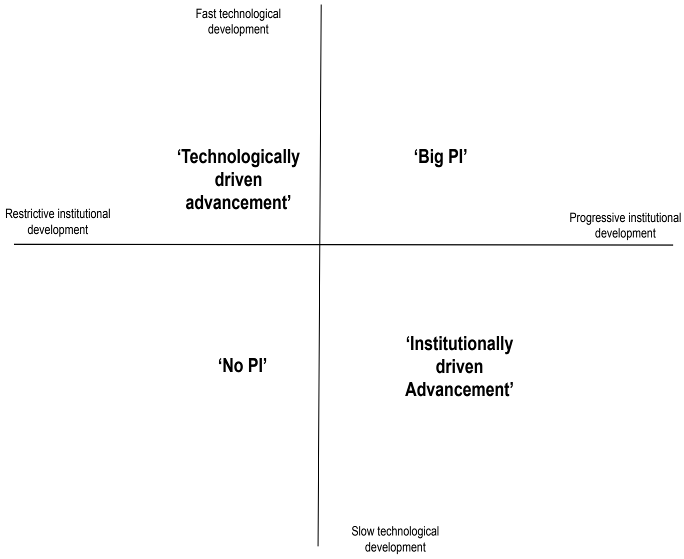


**Figure 3.** Scenario logic PI port scenarios

## 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<br>2. Migration flows Poulain (2008)<br>3. Urbanisation McGranahan & Satterthwaite (2014) |
| **C. Flow patterns** | **D. Global institutional integration** |
| 1. Nearshoring & Backshoring Dachs et al. (2019); Slepniov et al. (2013)<br>2. Safety stock<br>3. Increase in vessel size Notteboom (2016); Merk (2018)<br>4. New trade routes Liu & Kronbak (2010)<br>5. Digitalisation of society Brennen & Kreiss (2016); Degryse (2016); Yu et al. (2016); Liang & Turban (2011)<br>6. Mass individualism Ince (2017)<br>7. Hinterland infrastructure Rodrigue & Notteboom (2006) | 1. Trade agreements Eicher & Henn (2011)<br>2. Import tarrifs & quotas Eicher & Henn (2011)<br>3. Different tax environments |
| **E. Regulatory frameworks** | **F. Technological innovations** |
| 1. Cybersecurity Craigen et al. (2014)<br>2. Antitrust policies Ordover & Willig (1985); Posner (2009)<br>3. Labour protection Aaronson & Phelan (2019)<br>4. (PI) standardisation | 1. Internet of Things Wortmann & Flüchter (2015); I. Lee & Lee (2015); Montreuil, Meller, & Ballot (2012); Treiblmaier et al. (2016)<br>2. Big data Ward & Barker (2013); Zhong et al. (2017)<br>3. Artificial Intelligence Barr & Feigenbaum (2014); Korb & Nicholson (2010)<br>4. Blockchain Treiblmaier (2019)<br>5. Drones Frederiksen & Knudsen (2018); Floreano & Wood (2015)<br>6. Hyperloop Braun et al. (2017)<br>7. 3D printing Abeliansky et al. (2015)<br>8. Machine learning Mitchell (1997)<br>9. 5G network Ni et al. (2018)<br>10. Industry 4.0 Maslarić et al. (2016); Tjahjono et al. (2017)<br>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)<br>2. (Long-term) Terminal contracts Van der Lugt et al. (2014)<br>3. (New) Business models Geels (2004)<br>4. Network externalities Tavasszy (2018)<br>5. Willingness to share assets | 1. Environmental regulation Qc (1995)<br>3. Land-use planning Lindholm & Behrends (2012)<br>4. Traffic measures Lindholm & Behrends (2012)<br>5. Work condition regulation<br>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 |

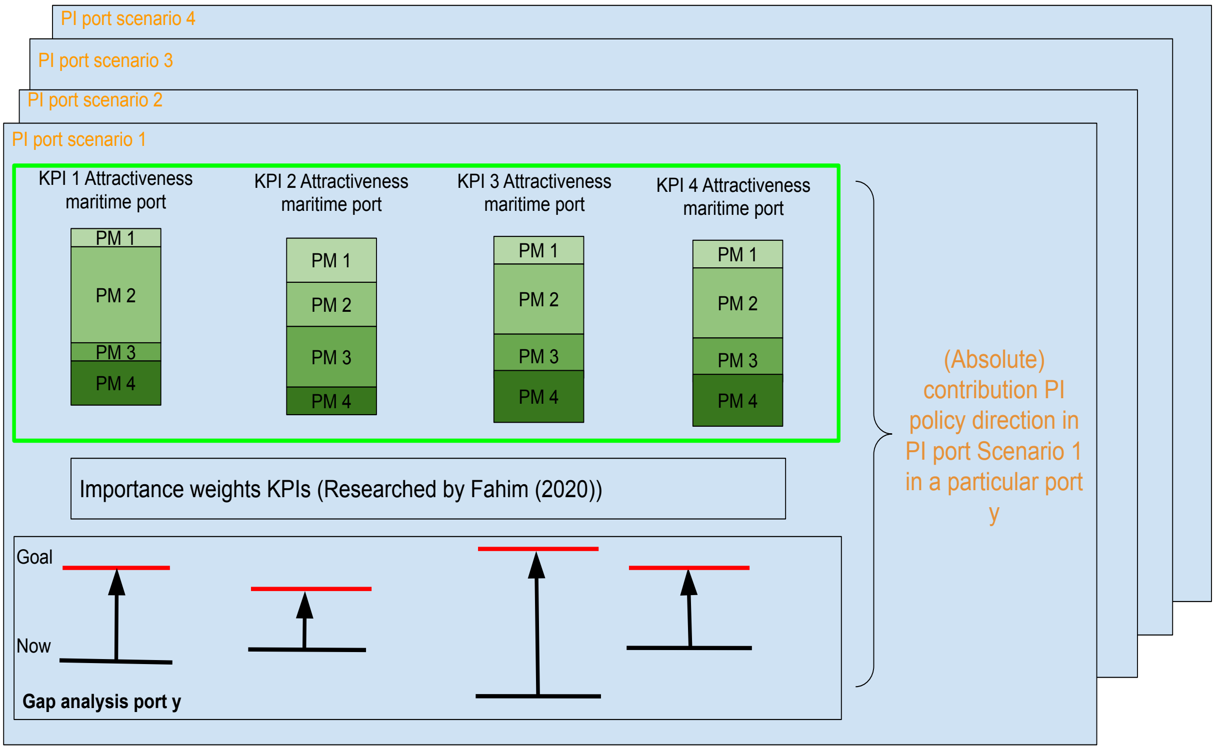


**Figure E1.** Perspective research contribution

**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 |