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Risk Assessment Methodology for Vessel Traffic in Ports by Defining the Nautical Port Risk Index

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Abstract: Ports represent a key element in the maritime transportation chain. Larger vessels and higher traffic volumes in ports might result in higher risks at the navigational level. Thus, the dire need for a comprehensive and efficient risk assessment method for ports is felt. Many methodologies have been proposed so far, but their application to aggregated vessel traffic risks for the overall assessment of ports is not developed yet. Hence, the development of an approach for the appraisal of the vessel traffic risks is still a challenging issue. This research aims to develop an assessment methodology to appraise the potential risk of accident occurrence in port areas at an aggregated level by creating a 'Nautical Port Risk Index' (NPRI). After identifying the main nautical risks in ports, the Analytic Network Process (ANP) is used to derive the risk perception (RP) weights for each criterion from data collected through surveys to expert navigators. The consequences related to each nautical risk are identified in consultation with risk experts. By combining the RP values and the consequence of each criterion for a time period, the NPRI is calculated. The risks in the Port of Rotterdam are presented in a case study, and the method has been validated by checking the results with experts in assessing nautical port risks from the Port of Rotterdam Authority. This method can be used to assess any new port design, the performance of different vessel traffic management measures, changes in the fleet composition, or existent ports using the Automatic Identification System (AIS) data.

Keywords: risk assessment; risk analysis; vessel traffic; port; AIS data

1. Introduction

Navigation in ports has become more and more complex during the last decades. The increase of the maritime transportation of goods and the vessel sizes lead to higher vessel flows in ports. Consequently, the potential risks at the navigational level increase, due to the lower manoeuvrability of larger vessels in restricted areas, higher probabilities of close encounters or overtakings, and larger consequences of incidents. For this reason, risk analysis in maritime transportation has become a relevant topic in recent years, as shown by research on historical accident analysis in ports [1–3].

There are different types of risk assessment, such as qualitative or quantitative, with different purposes, such as collisions or terminal operations. This research focuses on the quantification of nautical risks in ports. A wide variety of quantitative maritime risk assessment methods exists [4–6]. Most of the existing methods calculate the risk in a data-driven or probabilistic way (an in-depth literature review on risk assessment methods is discussed in Section 2.3). However, since the amount of casualties in ports is limited, maritime traffic in ports cannot be assessed based on single casualties.

Moreover, the risk prediction for a non-existent situation could not be performed with a data-driven approach. The risks and uncertainty involved in the navigation process, and the human influence in the navigational vessel behaviour are a significant factor contributing to the overall risk. The aim of this research is to provide a methodology that provides a risk indicator for the different port areas that supports decision-makers to assess port navigational risks in different types of future situations, such as changes in traffic or infrastructure design. We have named this index as 'Nautical Port Risk Index' (NPRI).

The main contribution of this research is to develop a methodology that allows any port to build an indicator according to its features. The methodology depends on the overall vessel traffic information and not only on single casualties, and that it combines the relevant nautical risk criteria with expert judgement for the assessment of any port area. Since each port has specific issues that will impact more or less vessel navigation, this methodology can be extrapolated (step by step) and applied to any port after considering the factors that are meaningful to each specific area, infrastructure design, vessel characteristic, etc.

This paper is organized into four sections. The methodology for the new risk assessment methodology is presented in Section 2. The section includes the definition of NPRI, the choice of the risk criteria in port navigation, the content of the assessment method and the NPRI calculation. Section 3 presents the empirical analysis of the previously introduced methodology, the data collection from expert navigators and the results from the risk quantification in a case study, with a sensitivity analysis. Finally, Section 4 presents the conclusions of the present work as well as recommendations for future research.

2. Assessment Methodology for Nautical Port Risk

The methodology proposed in this research for the nautical port risk assessment consists of several steps, which are described in Figure 1. After identifying the problem to be assessed, the methodology starts with the definition of the Nautical Port Risk Index (NPRI) based on existing risk definitions in Section 2.1. This definition determines the selection of the risk criteria to be used in this research by a group of experts in port navigation in Section 2.2. Once the criteria have been chosen, the risk assessment method has been developed following several steps, which combines expert judgement from navigators and experts in port risks, and it is described in Section 2.3. A literature review supporting the choice for the definition, risk criteria, and assessment method for this research is included in each subsection. Finally, the theoretical quantification of risks with the NPRI is presented in Section 2.4. When the results of the quantification might appear not realistic or abstract to the corresponding decision makers, a reconsideration of some of the selected risk criteria must be done to avoid inconsistencies for the specific case study according to the interests of the corresponding decision makers. The methodology can be applied to case studies by using real or simulation data, followed by a final analysis of the results and assessment of the port. A case study using real data with its application is presented in Section 3.

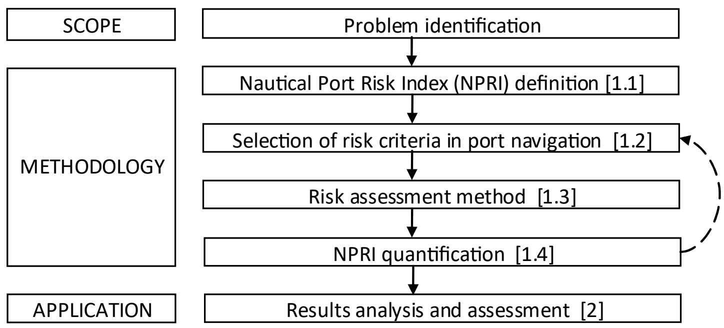


Figure 1. General structure for the development of the Nautical Port Risk Index (NPRI) methodology (corresponding sections are indicated between brackets).

2.1. Nautical Port Risk Index Definition

In the field of risk assessment, there is no unique definition of the risk concept, and different ways of defining and understanding risk exist. This concept has evolved with different definitions depending on the field of application or on the risk perspective chosen [7]. Recently, a comprehensive classification of risk definitions and an overview of risk analysis approaches for maritime transportation has been presented [8]. The most common definition of the risk concept is using frequencies and consequences [9]. The International Maritime Organization (IMO) [10] defined *risk* as "the combination of frequency and severity of the consequence" (p. 4). We consider this definition as an adequate formulation of the risk concept because it allows a quantification of the potential risk of accident in ports. However, this quantification is subject to how these frequencies and consequences are defined, and it should be developed for each port according to the decision makers who perform the assessment.

The frequencies have been traditionally defined by means of probability [2,11]. All these different approaches are mostly based on accidents that can be quantified from historical data, or a probability derived from accident data. However, these approaches do not include a way to quantify the risks caused by near misses, high densities or the effects of external conditions in navigation. Merrick and Van Dorp [12] presented a methodology to assess uncertainty in maritime risk assessments. Its application is dependent on the availability of data or expert judgement, but the definition of these probabilities implies the comparison of detailed scenarios. To define the probabilities using this approach at a port level would require a lot of time from experts.

The NPRI consists of a combination of the risk perception and consequences, where the terms are introduced more in detail below. In this research, we define risk perception (RP) as the frequency of accidents (similar as done in [12]), which can be quantified by defining a weighting system with the contribution to the nautical risk of a predefined set of relevant criteria related to risks in navigation. Hence, RP will be derived from expert judgement when comparing different navigational risk criteria according to their experience and background in a given location. Because of the complexity and dependencies between all the factors involved in navigation, the RP cannot be determined in a general way, and it should be related to specific areas of interest.

The RP factor provides a value of the risk level perceived in each situation of a potential accident or near-miss occurrence. The higher the risk criteria are rated by experts, the higher risk perception, thus the higher their contribution to the overall risk. RP measures the risk without any dependency on historical data, although the expertise of each expert will condition the results. Hence, this is generally applicable to any future port expansion or port under development. Moreover, since the RP value is based on expert judgement, if the experts have deep knowledge in navigation, the uncertainty in navigation and the possible non-reported accidents or near misses are implicitly included in this value.

The consequences, that provide an expectation of the impacts of each factor to risk, can be defined by the corresponding decision maker, such as harbour stakeholders or port authorities, who want to assess the specific situation, according to the knowledge and the importance of each factor for their risk evaluation. The scale of consequences is a subjective factor that should be defined, as previously done in other risk assessment [13,14].

The NPRI results from multiplying the RP value by the consequences in each area, based on the chosen scale for the characteristics of the port, which provides the total risk value of potential accident occurrence for each area within the port.

2.2. Risk Criteria in Port Navigation (Background and Scope)

The navigational risks are diverse and have many different features inside a port. In order to calculate the NPRI, all risk factors related to navigation should be assessed in a structured way, and a selection of the most relevant factors should be made according to expert judgement. An overview of factors previously used in navigational risk assessment related studies is presented in Table 1, where the application of each study is explained.

Table 1. Previous research using nautical risk factors.

Reference		Application
(a)	[13]	Risk based methodology to improve safety in ports
(b)	[15]	Definition of an individual ship risk factor
(c)	[2]	Identification of risks in Hong Kong port from historical data
(d)	[16]	Definition of a traffic safety index using AHP
(e)	[17]	Evaluate ship-handling risks for navigation in congested waterways
(f)	[18]	Identification of navigational risks and safety evaluation between ports
(g)	[19]	Analysis of marine casualties at the Strait of Istanbul

Table 2 shows a detailed overview list of all the factors considered in these studies. The table describes the wide variety of criteria that have been considered and the lack of overlap in many cases. For this research, expert opinion is used to make a thorough assessment of the more influential navigational risks. The choice of the risk criteria used in this research was based on in-depth discussions with port experts and experienced pilots from the Port of Rotterdam. Factors such as year of construction, flag, or target factor of Paris MOU might not provide sufficiently representative information, according to experts [20]. For example, the year of construction does not provide any information about the maintenance or current state of the vessel. Hence, this information does not provide an accurate representation of the vessel conditions and its effects on their navigation, as well as the corresponding risk associated with them.

In this research, the selection of factors was based on their direct effect on navigation and their possible quantification, according to these experts. Table 2 includes a column, where the risk criteria considered in this research are included. A detailed explanation of these criteria is provided in the following paragraph.

The infrastructure design is described by the location, depending on if it is close to high or low buildings, which might affect sailing perception, the type of the infrastructure (bend, straight, crossing, etc.), the water depth and the width of the waterway or basin. The environmental conditions are considered to be decisive in navigation, thus a contribution to the risk. The criteria considered are wind speed and direction (relative to the direction of the vessels), current (relative to the infrastructure orientation), visibility, and time of the day. In previous research, Pak et al. (2015) considered these factors as one single environmental factor [18]. However, because of their different effect in navigation, pilots recommended to include them as individual factors. According to expert knowledge, some of these factors have a larger impact on vessel navigation and manoeuvrability within a port area. The factors these experts considered to be most relevant for this research are wind speed, wind direction, current, visibility, and time of the day (day or night). To describe the traffic conditions, the vessel types are chosen in a generic way, based on the difference in manoeuvering. Hence, we selected only three factors to represent all vessel types, which are length, draught, and average speed of the vessels. Other relevant factors influencing manoeuvrability, for example, propulsion types, are not considered because the information might not be available. The traffic conditions in each specific area depend on the traffic mix, when vessels are equal or different, and the traffic volume (vessels/time period), indicating how congested the area is. In previous research, these factors were considered as traffic conditions as a single factor, but due to their relevance and impact to nautical risk, they have been divided into traffic mix and volume. Finally, the last criterion corresponds to the Vessel Traffic Management (VTM) of the specific port, which includes traffic rules and port regulations, pilotage, and Vessel Traffic Service (VTS) assistance as factors that directly affect safe navigation. The contribution to the risk of the traffic rules is considered as how flexible they are to, for example, allow navigators take certain decisions to avoid dangerous encountering or overtaking situations. In case of strict rules, we would consider them as 'rule based', while if they are flexible and adaptive to different situations, we would consider them as 'goal based'. Human factors are left out as a criterion, because their contribution to risk is difficult to explicitly be addressed by experts, except when analyzing a specific situation after the fact.

Since navigational experts will consider the specificities and complexities in the navigation of the areas, the human factors are not included as an independent factor, but their contribution will be implicitly included in the other criteria.

Table 2. Review of nautical risk criteria used in previous research.

	Main Criteria	Sub-Criteria	References							
			[13]	[15]	[2]	[16]	[17]	[18]	[19]	Current Study
1	Waterway	Location	x							x
		Traffic separation	x							x
		Type			x				x	
		Complexity					x	x		
		Depth						x		x
		Width						x	x	x
2	Environmental conditions	Wind speed	x	x		x	x	x		x
		Wind direction	x						x	x
		Tide	x					x		
		Current	x			x	x		x	x
		Visibility	x	x				x	x	x
		Time of the day		x		x			x	x
		Wave height						x		
3	Vessel	Size	x			x		x	x	x
		Type	x	x	x	x		x	x	
		Age	x						x	
		Crew	x							
		Manoeuvrability	x						x	x
		Pilotage requirements	x							
		Escorting requirements	x							
		Gross Tonnage		x						
		Duration detentions		x						
		Year of construction		x						
		Flag		x						
		Target factor of Paris MOU		x						
		Port of registry			x					
		Load				x				
		Speed							x	x
4	Traffic conditions	Overall					x	x		x
		Local							x	
		Passing							x	
		Anchored							x	
5	Vessel reliability	Propulsion, steering, electrical power ...	x							
6	Port control	Traffic rules, navigational equipment, number of pilots/tugs	x							x
		Pilotage							x	x
		VTS							x	x
		Escort and salvage							x	
7	Organization	Management practices	x			x				
		Developing technologies							x	
		Pipelines							x	
		Regulations							x	
8	Human	Judgement/safety culture	x						x	
		Knowledge	x			x			x	
		Communication	x			x			x	
		Experience				x				
		Over worked				x				
		Fatigue				x			x	
		Resource shortage							x	
9	Machinery factors	Failures of engine, rudder, propulsion ...				x				

2.3. *Assessment Method*

There are different types of risk assessment [4]; this research focuses on the quantitative navigational risk assessment of ports. Previous researchers on quantitative risk analysis of vessel navigation have used different methods for risk assessment with different applications, such as event and fault trees [11], Bayesian networks (BN) [21,22], or the Analytic Hierarchy Process (AHP) [18,19,23]. Event and fault trees are useful for the causal-effect analysis of a specific risk, and they are easy to understand.

However, they depend on historical data and they become time consuming when the number of factors increases. BNs are a quantitative tool applied in modelling vessel traffic, and they are really extended in the maritime traffic safety field. They allow for the combination of data with expert knowledge, and even though they are suitable for complex systems and include uncertainty in the probabilities, their complexity and the probability determination from experts might be difficult [24]. In addition, data is necessary for their development.

The analytic hierarchy process (AHP) has been used in several studies for risk assessment in the maritime field, such as for the assessment of shipping routes at sea [25]. A qualitative hierarchical modelling of perceived collision risks in port fairways from experts was developed by Debnath and Chin [26] for the Singapore Strait. Balmat et al. (2009) [15] proposed a global risk factor for individual ships based on ships characteristics (dimensions, type of cargo, etc.), meteorological conditions, and instant speed. Merrick et al. (2007) [27] developed a model to compare safety levels at a port level for strategic decisions for funding new vessel traffic service centres. Recent research proposed a port safety evaluation from a captain's perspective based on fuzzy AHP [18]. These different researches show different approaches of expert judgement, but the questioners that define the risk weights with AHP assume a top to bottom structure with independency between all the factors.

Despite the extensive literature related to maritime risk assessment, there is an absence of research that quantifies the risk value due to the interaction between factors, such as infrastructure, vessel traffic, and environmental conditions, in a proactive way. In navigation, there are many dependencies between factors where a change in one can affect others. The analytic network process (ANP), which is an improved version of the AHP, allows for the inclusion of these dependencies [28]. The method has been extensively applied in other risk assessment or decision-making processes that prove its usefulness [29] and will be used in this research to derive the RP from experts for each risk criterion.

The assessment method, according to the NPRI definition, is developed in two blocks, the RP and the consequences. The next two sub-sections describe the background on the method chosen for the weighing of RP and the definition of the consequence scale.

2.3.1. Analytic Network Process (ANP) Methodology

ANP is a tool to help solve decision-making problems based on the analytical hierarchical process method (AHP) developed by Saaty [30]. The AHP method is structured in a hierarchical structure, and the problem is divided into different clusters, while the decision problem has a network structure in ANP. One limitation of AHP is that the method assumes independence between factors, and the complex dependencies between the criteria describing real problems cannot be included in this technique. A similar approach using AHP was developed by Merrick et al. (2007) [27], where the difficulties in answering the comparisons between factors were alleviated using eliciting weights. In this research, the difficulty is alleviated by setting the comparisons at an area level and not at a port level. Moreover, to overcome this disadvantage of the AHP models, the ANP method can be used [28,31]. ANP allows the modelling of more generalized and complicated structures where the factors are divided into clusters that have interdependencies between them or within the same cluster. These relationships are evaluated, and their influence over the overall decision-making process is calculated.

The ANP technique has several strengths, as both quantitative and qualitative factors, and individual and aggregated values can be included in the decision-making process. The technique is conceptually easy to apply and allows navigational experts to express their preference with pairwise comparisons between the decision criteria. Moreover, the main criteria and sub-criteria of the problem structure can be determined based on specific objectives from the interested working group. This provides significant flexibility to adapt the problem design to any situation. A main limitation of the ANP method is that it does not allow for any uncertainty among factors [32].

The application of ANP consists of several steps that, according to Saaty [33], can be structured and summarized in the following steps:

(1) Determine the relations between different clusters to relate the different criterion and define the whole network, as depicted in Figure 2. These relations are determined between the main criteria or sub-criteria previously introduced in Table 2, with respect to the research objective, according to in-depth discussions with experts. The individual relations between the different risk factors are shown with a 1 in Table 3, and 0 represents that there is no relation. When defining other risk criteria for a specific port that might have other characteristics, the ANP network should be accordingly adapted.

(2) Perform pairwise comparisons at each level, between clusters of main criteria and between sub-clusters with the sub-criteria elements, according to their contribution to navigational risk. These pairwise comparisons are scaled according to their relative importance (Table 4). Experts should be asked with questionnaires to rank each pair of elements according to the contribution to risk that each of them has. Their answers provide a pairwise score a_{ij} (eigenvector), which is the ratio between the row element (i) over the column element (j), and it represents the relative importance of each element with respect to the other.

A drawback of the method is the complexity to perform comparisons, which might seem abstract or difficult to understand by experts because of being unfamiliar with the method [34]. Another drawback is the difficulty to relate completely different or dependent factors for comparison. Hence, the questionnaire should be better carried out with the support of a facilitator.

(3) After composing the matrix of pairwise ratios (A), the w weight is calculated as a unique solution of Equation (2). In this equation, the largest eigenvalue of A is represented by λ_{max} and w is its corresponding eigenvector. A consistency index of a matrix of comparisons is defined by CI = $(\lambda_{max} - n) \cdot (n - 1)$. Then, a consistency ratio (CR) is obtained by comparing the CI and the random consistency index (RI) defined by Saaty and Vargas [34]. CR is calculated for each cluster of judgements, and when CR is lower than 0.10, which implies that the adjustment is small compared to the actual values of the eigenvector entries, the comparison is considered to be consistent.

$$\begin{pmatrix} w_1/w_1 & \ldots & w_1/w_n \\ w_2/w_1 & \ldots & w_2/w_n \\ \ldots & & \ldots \\ w_n/w_1 & \ldots & w_n/w_n \end{pmatrix} \cdot \begin{pmatrix} w_1 \\ w_2 \\ \ldots \\ w_n \end{pmatrix} = \begin{pmatrix} 1 & \ldots & a_{1n} \\ a_{21} & \ldots & a_{2n} \\ \ldots & & \ldots \\ a_{n1} & \ldots & 1 \end{pmatrix} \cdot \begin{pmatrix} w_1 \\ w_2 \\ \ldots \\ w_n \end{pmatrix} = A \cdot w \tag{1}$$

$$A \cdot w = \lambda_{max} \cdot w \tag{2}$$

(4) Build a supermatrix, a matrix that includes all the w obtained from the paired comparisons for each cluster.

(5) Weigh the elements of each cluster with respect to the other clusters within the supermatrix (unweighted).

(6) Perform paired comparisons among the main criteria based on the influence between each element.

(7) Use the resulting value of each cluster (main criteria) to weigh each block of the unweighted supermatrix, resulting in a weighted supermatrix.

(8) By raising the weighted supermatrix to powers until the weights converge, a limit supermatrix is obtained, and the global priority weights are derived.

The resulting global priority weights can be used in this research as the risk perception (RP) values from experts, which indicates the contribution to the risk in the navigation of each individual element previously defined. The resulting weights include the influence of some criteria and sub-criteria with others through the network design, which provides more realistic results than assuming them completely independent.

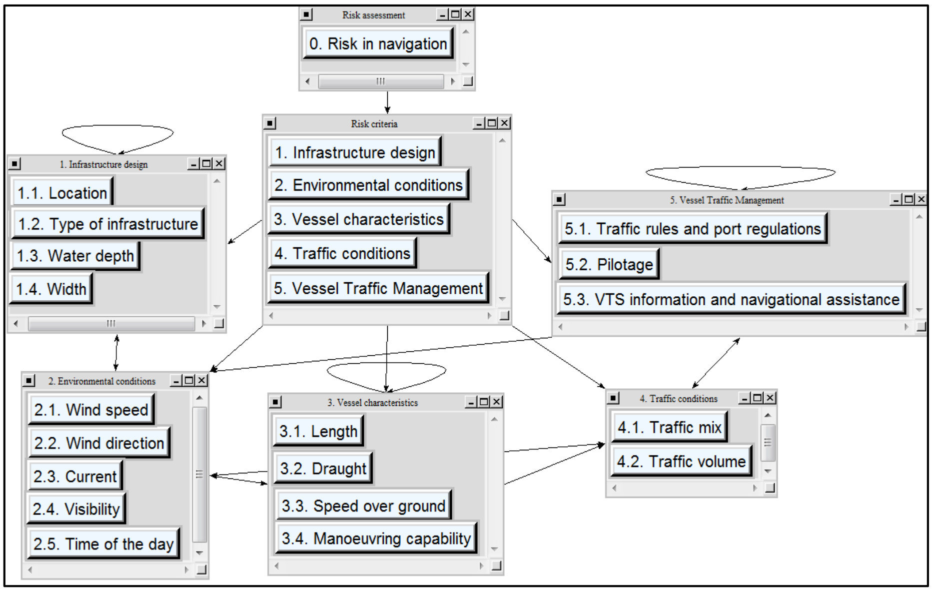


Figure 2. Structure of the links between criteria.

Table 3. Influence matrix.

.		**1**	**2**	**3**	**4**	**5**	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**5.1**	**5.2**	**5.3**
1	Infrastructure design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Environmental conditions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Vessels characteristics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Traffic conditions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Vessel Traffic Managment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.1	Location	1	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
1.2	Type of infrastructure	1	0	0	0	0	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
1.3	Water depth [m]	1	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1.4	Width [m]	1	0	0	0	0	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0
2.1	Wind speed [knots]	0	1	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	0	1	1
2.2	Wind direction	0	1	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	0	1	1
2.3	Current [knots]	0	1	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	0	1	1
2.4	Visibility [m]	0	1	0	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1	1	1	0	1	1
2.5	Time of the day	0	1	0	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1	1	1	0	1	1
3.1	Length [m]	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	0	0	0	0	0
3.2	Draught [m]	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	0	0	0	0	0
3.3	Speed [knots]	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0
3.4	Manoeuvring capability	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
4.1	Traffic mix	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1		0	0	1	1
4.2	Traffic volume [ves/3h]	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	1	1
5.1	Traffic rules and port regulations	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
5.2	Pilotage	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
5.3	VTS assistance	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0

Table 4. Fundamental scale to estimate dominance in pairwise comparisons (Saaty, 2008).

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A logical assumption

2.3.2. Consequence Scale

The consequences related to each of the risk factors previously chosen should be qualified on a scale based on their possible impacts that allow the risk calculation. Previous research has qualified consequences using different approaches. As an example, Trbojevic and Carr introduced a qualitative scale of consequences related to the likelihood with four levels for each of the variables (people, assets, environment, and reputation) [13]. A similar approach was used by Ulusçu et al. (2009) [14], where the consequences depend on the vessel and shore attributes, and their consequence is related to the impacts on property, human casualty, environment, and traffic.

Since this is a subjective qualification, we consider that experts in navigation should not quantify or qualify the impact of the consequences themselves, since every individual might not have a proper sense of the consequences implied by some criteria. The scale directly depends on the criteria and thresholds of the stakeholders who want to assess the risks. Hence, consultation with port risk experts should provide the definition of this scale. Each sub-criteria can be qualified on a scale from very low (1) to very high impact (5) in a normalized scale.

2.4. NPRI Quantification

Once the RP values have been calculated and the consequence values have been defined, the NPRI for each sub-area can be obtained. This step consists of the calculation of the NPRI in the desired area for the specific time period required, which depends on the assessment period desired by the decision makers. This allows risk qualification at the specified level, on a scale from 1 (very low) to 5 (very high). This level might depend on the requirements for a determined purpose from the decision makers, as explained in the previous sub-section, and the risk calculation can be done using either real or simulated data as follows:

$$NPRI^{i}(t) = \sum_{w} w_k \cdot c_k^{i}(t) \tag{3}$$

where $NPRI^i(t)$ is calculated for each sub-area i, w_k is the weight of each criterion, $c_k^i(t)$ is the consequence value associated with the criterion k at the interval of time t for the sub-area i. The results provide the NPRI value for each area in each time step.

From all the NPRI values obtained, the maximum could be chosen as a reference value. Since there might be specific situations where the maximum NPRI is extreme due to a certain specific situation, this might lead to an overestimation of the risk in the area. Hence, in this research, we define the final NPRI value by ordering the results from each area from low to high and choosing the 95 percentile higher NPRI value. These results can be mapped for each port area to provide decision makers with a clear picture of the areas with higher risks, as done in previous research by Wang et al. (2014) [25], and to support their assessment.

3. Case Study in the Port of Rotterdam

This risk assessment methodology for ports should be built for each port where it is applied. In this research, two areas from the Port of Rotterdam were chosen, and, because of their differences, the methodology will be adapted consequently for each of them. These areas are the Maasvlakte (A1), with large container terminals and big vessels, and the Petroleumhaven (A2), which resembles an inland or river port, and they are shown in Figure 3.

By considering the input from navigational experts (VTS operators and pilots from the Port of Rotterdam), the weights related to the RP are obtained. The consequence scale is defined by experts from the Port of Rotterdam Authority. Finally, data from 2014 that includes weather, current, and traffic, as well as the infrastructure design details required by the criteria considered in the assessment methodology, were provided by the Port of Rotterdam Authority for this research.

This section includes all the steps required for the complete application of the risk assessment method previously introduced to quantify the NPRI in two different port areas.

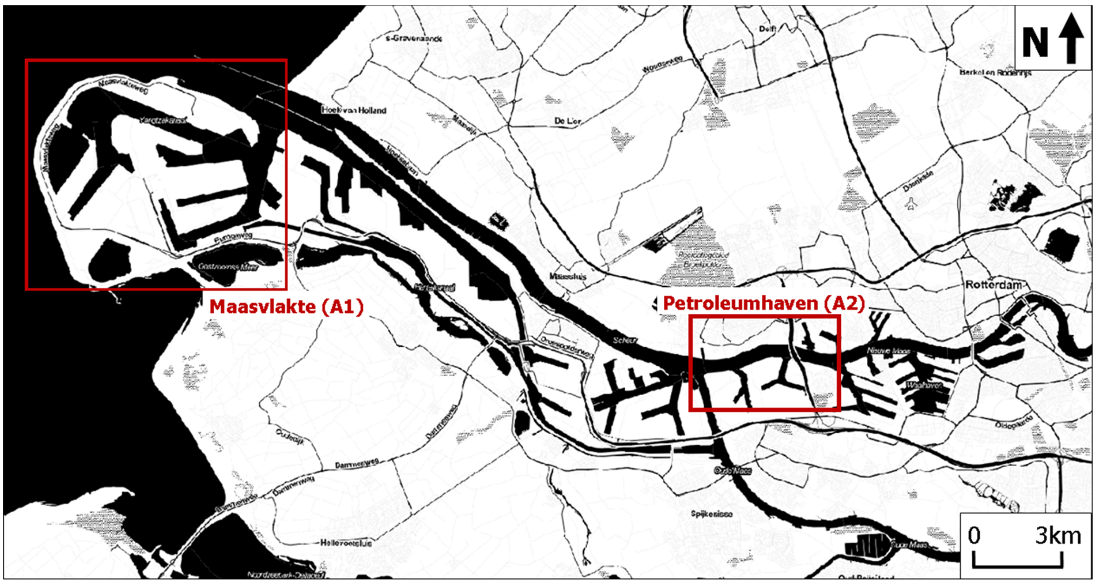


Figure 3. Port of Rotterdam (Maasvlakte left square and Petroleumhaven right square).

3.1. Risk Perception Using ANP

The risk assessment model has been developed using the risk criteria identified in Section 2.2. The criteria selected are set in a network structure (see Figure 2), and the relations between criteria are defined, as previously described in Table 3.

This section includes the data collection necessary for the ANP through a survey to derive the weights of the RP, the analysis of the collected answers and a sensitivity analysis.

3.1.1. ANP Survey

In order to collect the data necessary from navigation experts to apply the ANP, a questionnaire was designed, where the different criteria are ranged in a pairwise structure as shown with an example in Table 5, comparing assigning more importance (9) strongly to one factor compared to the other, to equally important (1). For this research, we used the expertise from VTS operators and pilots from the Port of Rotterdam, who have vast knowledge about navigation and the characteristics from the case study areas. The answers were collected either in person or with an online survey, including detailed explanations and clarifications to experts. A total of 23 VTS operators and 12 pilots filled in the survey for one of the port areas. Since each port has its own singularities, we asked them to answer based on the area where they had larger expertise. From the VTS operators, there were 14 respondents for the Maasvlakte area (A1) and 9 for the Petroleumhaven area (A2), and from the pilots, there were 10 and 2 respondents respectively, which leads to a total of 24 respondents for A1 and 11 for A2. Even though the experts provided their risk perception in a thorough way, the ANP method includes a consistency check. After calculating the consistency ratio (CR) for each of the questionnaires, some of them resulted higher than 0.10. Hence, a total of 11 respondents were excluded from the calculation for A1, 5 from the VTS operators and 6 from the pilots and, 3 respondents were excluded for A2, 2 from the VTS operators, and 1 from the pilots. This leads to a total amount of responses of 13 for A1 and 8 for A2. These consistent answers are used for the ANP calculation, but, before that, we performed a brief analysis of the answers provided to see how large the variations between respondents were.

Figures 4 and 5 show the results for the pairwise comparisons for the questions in each main criteria group for both port areas. For several questions, there is a clear preference for one of the criteria, while in others, the answers are close to 1, which means that the contribution to risk for both factors is considered to be equal. The answers also show that the perception changes a lot within each pairwise comparison between experts, so the larger the sample, the more normalized the results will be.

One interesting thing to point out is that when comparing the answers between the two areas, for some of the questions, the answers are similar, while for others, the perception is different for each area. For example, respondents have a clear preference in the comparison between visibility with respect to the time of the day in both areas. However, when looking at the question comparing layout of the infrastructure and water depth, their risk perception is different, as water depth is considered more important in A1, whereas respondents for A2 assign slightly more importance to layout of the infrastructure, probably due to the presence of narrow basins and more complex turnings to access these basins in A2. Another example when comparing between wind direction and current, the results for both areas are considerably different. As vessels visiting A1 are larger, the effect of wind has a larger influence in their manoeuvering. This shows how the characteristics and specificities of each port might affect the risk perception from experts, and how important it is to consider ports individually for this method.

Table 5. Sample question from the survey to experts.

With respect to the RISKS IN NAVIGATION please indicate the relative importance of the following factors, according to your expertise and perception.																		
Location	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental conditions

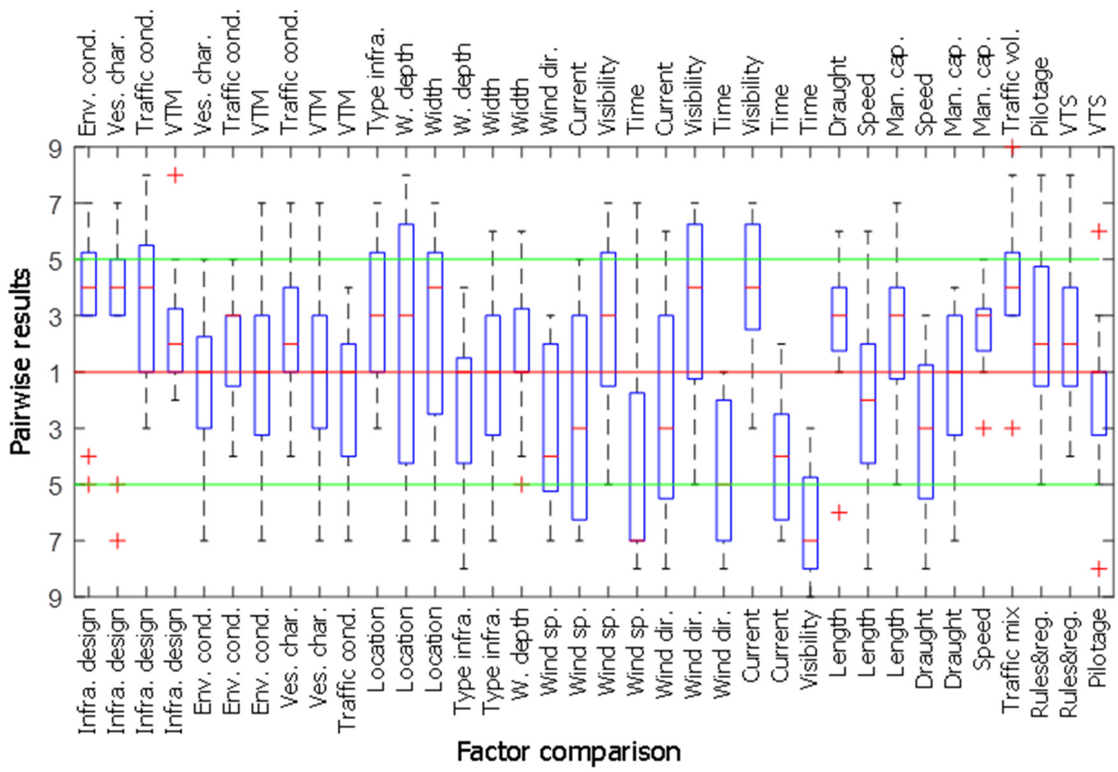


Figure 4. Boxplot answers for Maasvlakte (A1).

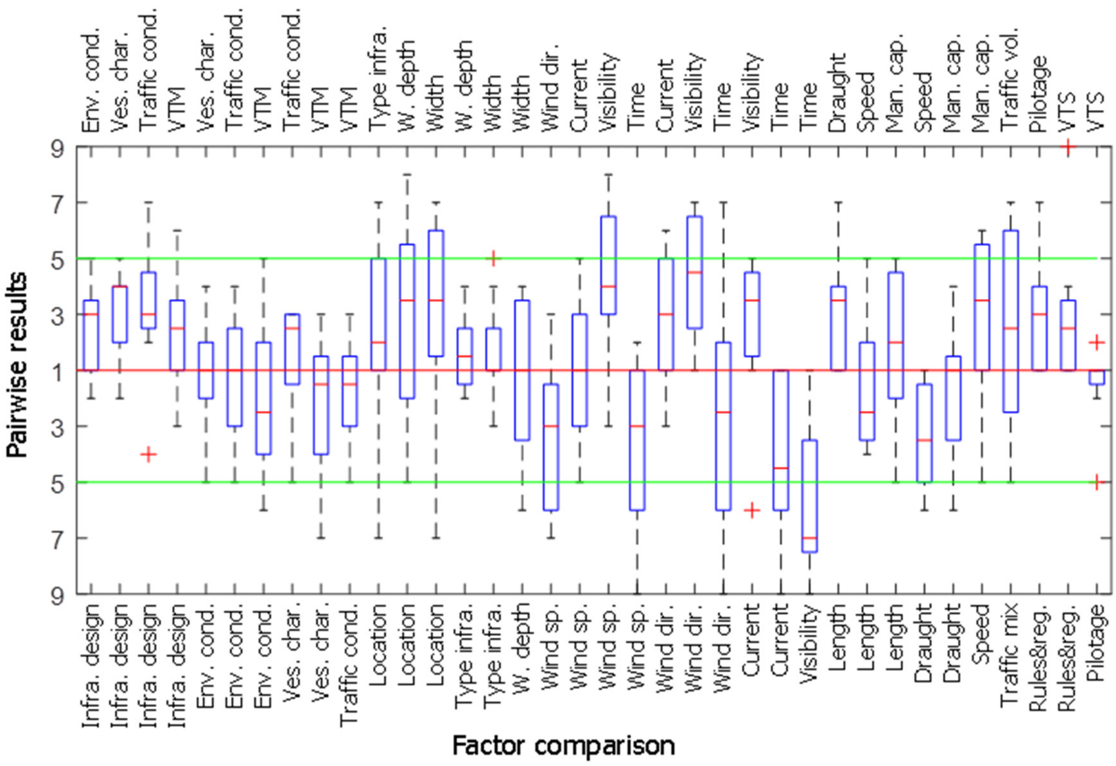


Figure 5. Boxplot answers for Petroleumhaven (A2).

3.1.2. ANP Results

The ANP software *Superdecisions* is used to calculate the risk perception weights for the risk criteria by considering the data collected. The software calculates the weights based on a set of results, and since there are two groups of experts in this research, VTS operators and pilots, we considered all the answers as one single dataset for each area. In the next section, a sensitivity analysis is performed considering two independent groups of respondents for the risk perception weight calculation. The software used considers the network formed by relating the different criteria and uses the input from the experts to calculate the comparison matrices described in Section 1.

Some intermediate steps from the ANP calculation were performed, leading to the final weights. First, the unweighted supermatrix containing the local priority values for each cluster is built for each area (see Appendix A, Table A1 for Maasvlakte (A1) and Table A4 for Petroleumhaven (A2)). The cluster priorities are used to generate the weighted supermatrix (see Appendix A, Table A2 for A1 and Table A5 for A2). Raising this supermatrix to powers until the weights converge, the limit supermatrix is obtained (see Appendix A, Table A3 for A1 and Table A6 for A2).

Finally, Figure 6 summarizes the resulting priorities for each criterion. It can be seen in both areas that the traffic volume and the visibility are the two criteria that most contribute to risk. The main differences between the two study areas are that, in A1, the factors type of infrastructure, wind speed, wind direction, and traffic volume have a slightly higher weight, probably due to the larger size of the vessels in the area. On the other hand, the width of the infrastructure and the current have more influence in the final weights in A2, due to the narrow basins and sharper bends connecting with the river area. The results for each criterion will be used for the NPRI calculation.

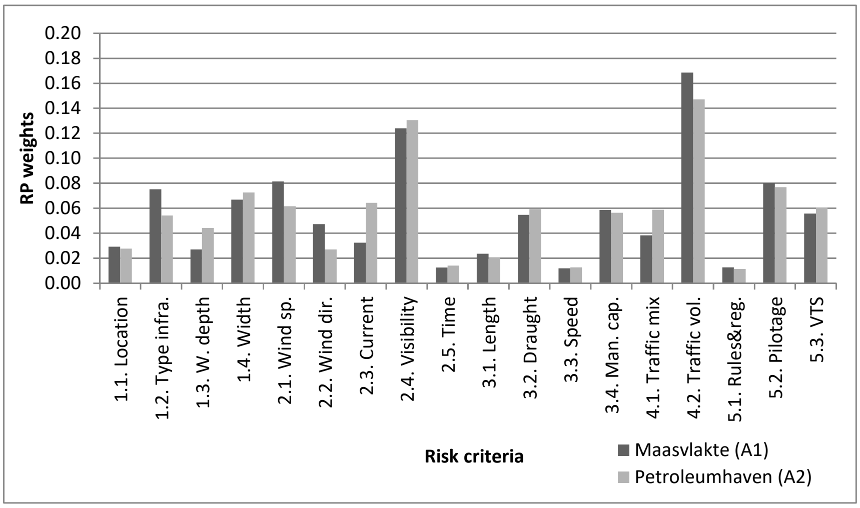


Figure 6. Factor weights of the research areas.

3.1.3. ANP Sensitivity Analysis

Since VTS operators and pilots might have different risk perceptions, we tested how sensitive the ANP method is to the aggregation of the answers as a unique group of experts. For that, we derived the weights using ANP by considering two sets of answers, one for each group of experts. From the results obtained for each port (see Figures 7 and 8), the weights for each factor have slight differences. In Figure 7, the weights for A1 show that VTS operators perceive that the type of infrastructure and the visibility have a stronger contribution to the navigational risk since they have to guide vessels when they do not have a clear view during their navigation in the port. On the other hand, pilots give more relative importance to the width of the fairways and the wind direction due to the big size of the vessels. Hence, their risk perception is different probably due to their different role in the vessel navigation in the port.

For A2 (shown in Figure 6), the main differences between pilots and VTS operators are that the depth and width of the fairway and the vessel draught have a slightly higher contribution to risk according to VTS operators, while the type of infrastructure and the manoeuvrability have more relative importance to pilots.

The resultant risk perception weights have, on average, less than 10% difference compared to the combined results from Section 3.1.1, and the importance of the weights is really similar to the previous results. Since the slight difference in perception does not outweigh the benefits of having a larger sample, we consider the experts as a single group of respondents, and the case study will be based on the results described in the previous section.

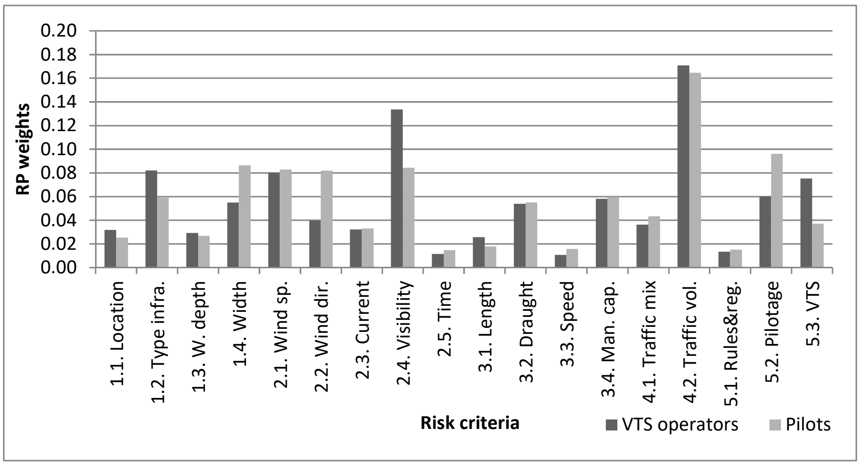


Figure 7. Weights for each expert group in Maasvlakte (A1).

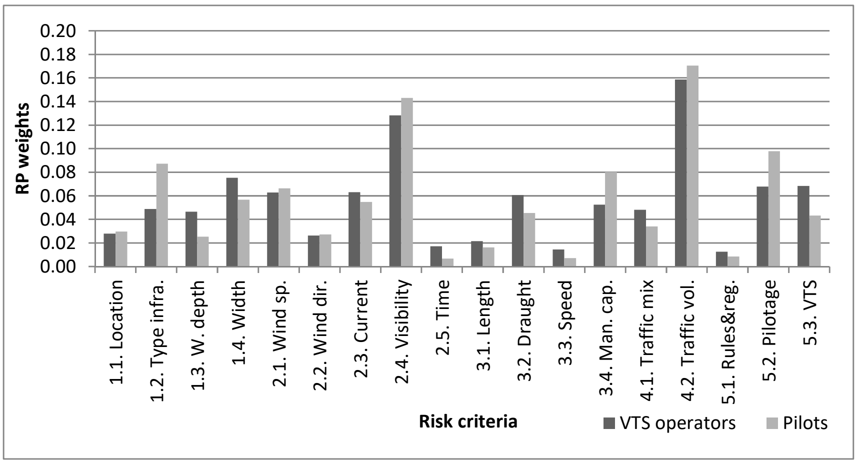


Figure 8. Weights for each expert group in Petroleumhaven (A2).

3.2. Consequence Scale for the Port of Rotterdam

After obtaining the contribution to the navigational risk in ports of each of the criteria according to expert judgement, the consequences related to each of them should be defined to calculate the NPRI. As explained before, the consequences should be defined by port risk experts. For this research, experts from the Port of Rotterdam were interviewed to define a suitable scale of consequences for each of the study areas, based on their knowledge of the port and the impact scale that they considered adequate for the risk assessment.

Although the Port of Rotterdam has high vessel traffic volumes, the aggregation period for the traffic volume quantification chosen is 3 hours. According to the experts, this is because the average time of many of the vessel trips is around 2.5 hours, and shorter periods would not provide valuable insight into the real amount of vessel traffic.

Table 6 describes the different consequence values from very low (1) to very high impact (5) for each of the criteria for A1. For A2, the consequences have been scaled in two groups, one for the river area, where there is more traffic with higher speeds and wider nautical space and one for the inner basins (see Table 7).

Table 6. Consequence table for Maasvlakte (A1).

	Criteria		Sub-Criteria	Very Low Impact	Low Impact	Medium Impact	High Impact	Very High Impact
1	**Infrastructure design**	1.1	Location (high/flat landscape/buildings)	Low	-	Medium	-	High
		1.2	Type of infrastructure	Straight	-	Bend	-	Crossing
		1.3	Water depth [m]	>25	25–21	21–17	17–15	<15
		1.4	Width [m]	>500	500–425	425–350	350–300	<300
2	Environmental conditions	2.1	Wind speed [m/s]	<=5.5	5.5–8	8–10.7	10.7–13.8	>=13.8
		2.2	Wind direction	Bow/sternwind (<20°)	20°–35°	Diagonal (35°–55°)	55°–80°	Crosswind (>80°)
		2.3	Current [knots]	<1	1–1.5	1.5–2	2–2.5	>2.5
		2.4	Visibility [m]	>1500	1500–1200	1200–900	900–500	<500
		2.5	Time of the day	Day	-	Dawn/Dusk	-	Night
3	Vessels characteristics	3.1	Length [m]	<100	100–150	150–225	225–300	>300
		3.2	Draught [m]	<12 m.	12–13	13–14	14–15	>15 m.
		3.3	Speed [knots]	<5	5–6	6–7.5	7.5–10	>10
		3.4	Manoeuvring capability	1	2	3	4	5
4	Traffic conditions	4.1	Traffic mix (same or different types)	1	2	3	4	5
		4.2	Traffic volume [ves/h]	<1.7	1.7–4.3	4.3–6.7	6.7–8.3	>8.3
5	Vessel Traffic Managment	5.1	Traffic rules and port regulations	100% Goal based	-	50	-	100% Rule based
		5.2	Pilotage	>90%	90–80%	80–70%	70–60%	<60%
		5.3	VTS assistance	X	-	-	-	-

Table 7. Consequence table for Petroleumhaven (A2) (*River area and, between brackets, basins).

	Criteria		Sub-Criteria	Very Low Impact	Low Impact	Medium Impact	High Impact	Very High Impact
1	**Infrastructure design**	1.1	Location (high/flat landscape/buildings)	Low	-	Medium	-	High
		1.2	Type of infrastructure	Straight	-	Bend	-	Crossing
		1.3	Water depth [m]	>16 (>15)	16–14.5 (15–13.5)	14.5–13 (13.5–12)	13–12 (12–11)	<12 (<11)
		1.4	Width [m]	>300 (>250)	300–250 (250–200)	250–180 (200–140)	180–150 (140–100)	<150 (<100)
2	Environmental conditions	2.1	Wind speed [m/s]	<=5.5	5.5–8	8–10.7	10.7–13.8	>=13.8
		2.2	Wind direction	Bow/sternwind (<20°)	20°–35°	Diagonal (35°–55°)	55°–80°	Crosswind (>80°)
		2.3	Current [knots]	<1	1–1.5	1.5–2	2–2.5	>2.5
		2.4	Visibility [m]	>1500	1500–1200 (1500–1000)	1200–900 (1000–750)	900–500 (750–400)	<500 (<400)
		2.5	Time of the day	Day	-	Dawn/Dusk	-	Night
3	Vessels characteristics	3.1	Length [m]	<100	100–150	150–225	225–300	>300
		3.2	Draught [m]	<8	8–10	10–11	11–12	>12
		3.3	Speed [knots]	<5 (<4)	5–6 (4–5)	6–7.5 (5–6.5)	7.5–10 (6.5–8)	>10 (>8)
		3.4	Manoeuvring capability	1	2	3	4	5
4	Traffic conditions	4.1	Traffic mix (same or different types)	1	2	3	4	5
		4.2	Traffic volume [ves/h]	<1.7	1.7–4.3 (1.7–2.7)	4.3–6.7 (2.7–3.3)	6.7–8.3 (3.3–4)	>8.3 (>4)
5	Vessel Traffic Managment	5.1	Traffic rules and port regulations	100% Goal based	-	50	-	100% Rule based
		5.2	Pilotage	>90%	90–80%	80–70%	70–60%	<60%
		5.3	VTS assistance	X	-	-	-	-

3.3. NPRI Calculation

This subsection describes the NPRI calculation steps for the two case studies previously described. The first step was to collect the necessary data to determine the NPRI, and The Port of Rotterdam provided several datasets needed for each criterion from the year 2014. These data include weather, current, and traffic, as well as the infrastructure design details. By combining all the data and processing them, we use it to calculate the NPRI. The dataset include 12 areas for Maasvlakte area (A1) and 8 for Petroleumhaven (A2) (see Figure 11). For each area, there is an individual recording of each passing vessel during a specific time period.

For the calculations, the period considered is 3 hours and all criteria are averaged. For example, the vessel characteristics of all passing vessels through each area during each 3-hour period are recorded and averaged, as if all vessels had the same average characteristics, except the traffic mix that counts the different types of vessels for that period.

Figure 9 shows the number of observations for each area (shown in Figure 11), meaning that in case of no traffic during that period, there is no observation. The first four areas have a low number of observations due to the low vessel traffic in that area, which shows that in those areas there were many 3-hour periods without any traffic. Other areas with few observations show that they have traffic only for a limited amount of the time.

The vessel draught data is manually included as it is not part of the automatic information system (AIS) data. Because of this, we found out that only 65% of the data have a non-zero vessel draught. The missing values are considered as average draught in this research.

Once all the data have been cleaned and properly structured, the NPRI is calculated for each area by multiplying the RP weights obtained from the ANP model times and the consequence value for each specific sub-criteria, according to the characteristics of each area. The NPRI value is calculated for each period of time when vessel traffic exists for each area. In Figure 10a, the results for A1 are represented in a normalized scale, where the NPRI values are ordered from lowest to highest. It can be seen that there is a large difference between the lower and higher risk values in each area. The difference appears due to the relation between the RP weights and the consequence values in each period. When the environmental conditions are favourable and the vessel characteristics and the traffic conditions are small, the risks appear to be low, while the highest risk values appear when the environmental conditions are not so favourable and the other factors are higher too. Figure 10b shows all the results for A2, where a substantial difference in the NPRI exists between the three areas from the inner basins and the others from the river. Because of the high vessel traffic in the river and the high weight of this criterion, the risks are higher.

Even though NPRI values are high for the worst situations, the maximum values do not reach even three out of five, which represents a total low risk and shows the safety of these two areas from the Port of Rotterdam. According to risk experts from the Port of Rotterdam, the results are representative of the current situation in the port and proves the validity of the methodology introduced.

Once all the NPRI values are calculated for all samples, they have been ordered from low to high and normalized to 100%, which are shown in Figure 10 for both areas. To avoid taking an overestimated risk for a single casualty that could be considered an outlier, the 95 percentile NPRI value is selected for each area to assess the situation among the different areas, represented with a dashed vertical line in Figure 10. The results are summarized in Table 8 and, for a clearer representation, they are presented in a risk map for each port (see Figure 11).

When looking at the final NPRI values, it can be seen that the highest risks in A1 are in the areas 6, 8, and 9, which correspond to slightly narrower basins compared with the rest of the area. In A2, the highest risks appear in the crossing area 13 and two of the inner basin areas 15 and 18.

The results show that the risk level in the Port of Rotterdam in 2014 had a medium risk level with the combination of all the criteria considered. Even though the results are not extreme, decision makers should define a threshold for the unacceptable NPRI and assess the need for further safety measures if they would like to reduce the risks in specific areas.

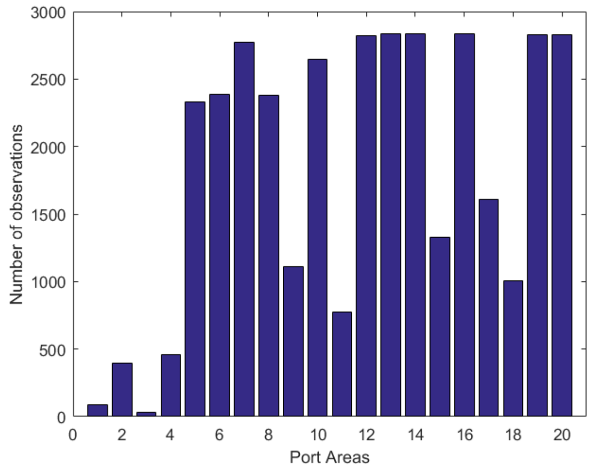


Figure 9. Number of observations per area.

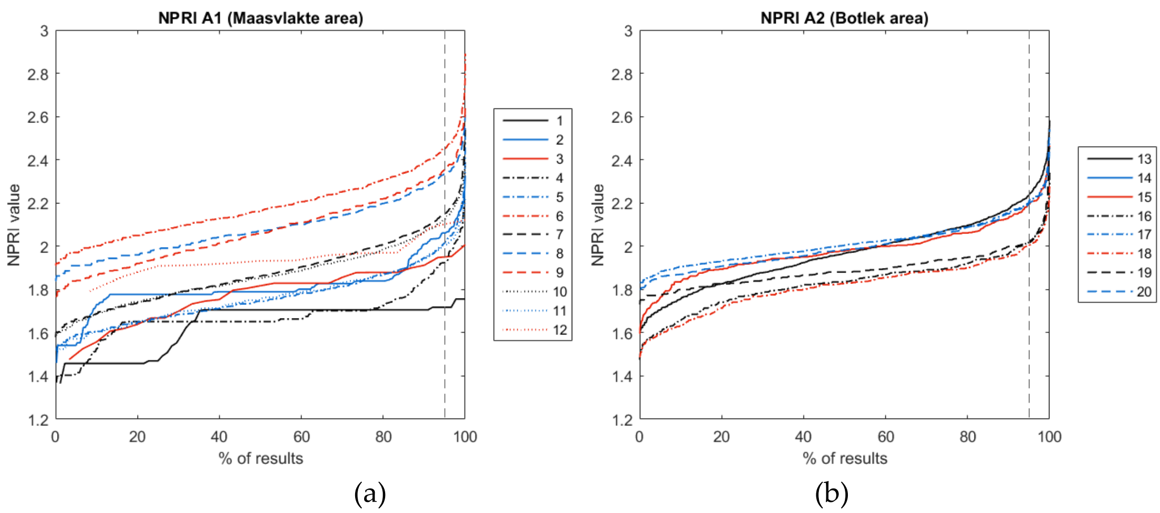


Figure 10. NPRI cumulative values per port: Maasvlakte (A1) (**a**), and Petroleumhaven (A2) (**b**).

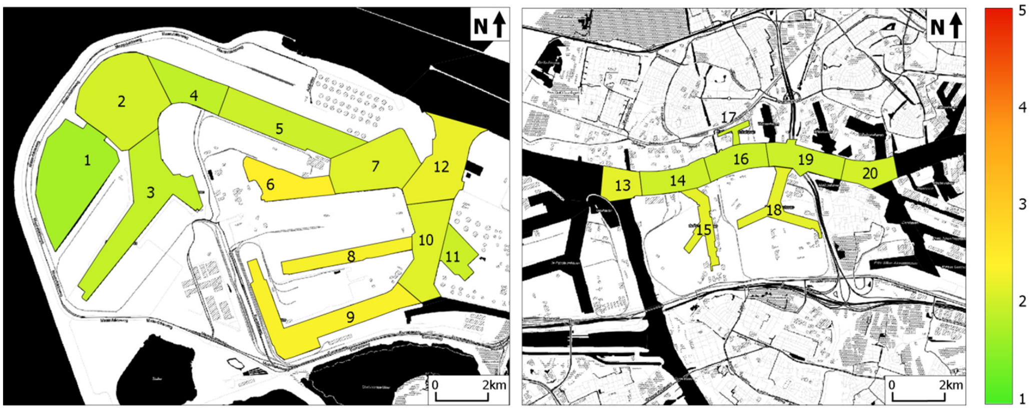
Table 8. NPRI results.

Area	95% NPRI	Area	95% NPRI
1	1.72	13	2.20
2	2.06	14	2.02
3	1.95	15	2.21
4	1.92	16	2.00
5	2.01	17	2.02
6	2.45	18	2.20
7	2.15	19	2.01
8	2.33	20	2.06
9	2.35		
10	2.12		
11	2.00		
12	2.24		

3.4. Sensitivity Analysis

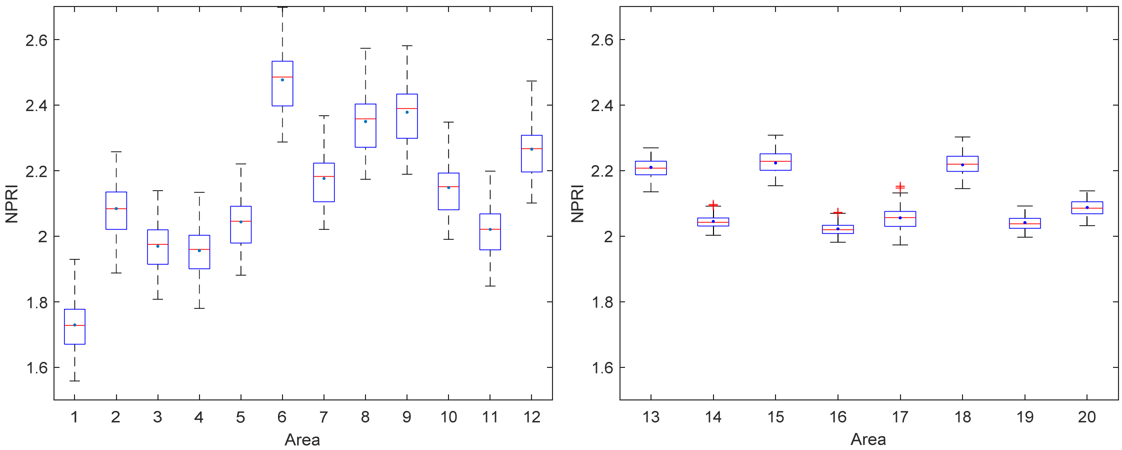
As previously introduced, the weighting values for the RP are obtained from pairwise comparisons from experts' judgement. These priorities have a strong influence on the final NPRI calculation. For this reason, it is of great importance to check the robustness of the ANP model used to make the final risk calculation. The model would be robust when small changes in the RP values do not lead to big changes in the final NPRI values.

In order to test the robustness of this research, a sample of 100 random scenarios was created, where the RP values are randomly generated with a normal distribution. The distribution considered has the result obtained from the ANP model as mean value, and a 10% standard deviation from the mean value. In Figure 12, the dots show the NPRI values and the boxplots the variation of results from the random scenarios generated. The variation appears to be larger in A1 (Figure 12b) than in A2 (Figure 12a). This difference is mainly caused by larger variation between vessel types and flows within different time periods. In A1, the interquartile range, corresponding to the 50% of the results, is always in a similar position as the original result. The largest variation is less than 0.1, which represents a variation smaller than 2.5% on the overall scale. When looking at the whole set of results, the highest variation appears to be less than 0.25. For A2, the variation is really small, with a maximum variation of less than 0.1 (see Figure 12b). The results for this study area appear to be less sensitive to variations of the RP weights.



(a) (b)

Figure 11. Risk maps: Maasvlakte (A1) (**a**), and Petroleumhaven (A2) (**b**).



(a) (b)

Figure 12. Results variation for Maasvlakte (A1) (**a**), and Petroleumhaven (A2) (**b**).

This analysis proves the robustness of the developed methodology, as well as the effect that different consequence scales might have on the final result.

4. Conclusions

In this research, a new methodology to assess nautical risks in ports has been presented. By combining knowledge from navigational experts and risk experts, we have developed a methodology to quantify the risk in different areas of any port, with the calculation of the Nautical Port Risk Index

(NPRI). The navigational experts have contributed to the definition of the risk perception weights for each criterion by using the ANP method to derive them, and the consequence scale is defined by the risk experts.

This new index allows the quick assessment of the nautical risks within a port, based on its specific characteristics. As an advantage with respect to most of the previous risk assessment methods, for vessel navigation, this method can be based on historical as well as simulated data, and it can be used to assess current or future risks in existent or future ports. The method presented can be used by port stakeholders to assess the nautical risk in different situations at different levels and time periods, in order to identify problems or high risks at different moments in time.

The implementation of this method with simulated data or historical data would provide a dynamic NPRI to forecast port risks for any desired scenario and time period, which would allow a dynamic and proactive port risk assessment to decision makers. It has several applications since it could be used for planning new ports or port expansions in the design phase, or to assess the current risks in existing ports or assess new traffic management solutions.

Future research could focus on the application of this methodology in other ports, with other navigational experts and port decision makers to see how the risk perception changes in different places of the world. In addition, the methodology could also be developed for different time periods to assess different scenarios, such as seasonality risks or the evolution of risk along several years.

Managerial Implications

This research structures and develops the different steps for a port risk assessment that can be applied by practitioners. By using expert knowledge from navigators combined with the scientific methods, port stakeholders can gain insights into the current or future risks of their ports. This research allows the application of this methodology to current as well as future vessel traffic situations (based on the availability of a simulation tool). These can also help identify hot spots within a certain port or to consciously define a certain port design for the future to mitigate certain risks that could arise without performing this risk assessment. The methodology brings together all the steps and possible methods that they can apply to perform each step of the evaluation of vessel traffic within the area.

Applying the structured methodology presented in this research, port stakeholders can assess current and future scenarios and assess port navigation. This provides comparative values between different scenarios that will allow them to anticipate current or future problems, such as accidents or near misses, or save money when building a safer port.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.B.O., W.D., T.V., S.P. Hoogendoorn; methodology, X.B.O., W.D., T.V. and S.P.H.; software, X.B.O.; validation, X.B.O., W.D.; formal analysis, X.B.O., W.D.; investigation, X.B.O., W.D.; resources, X.X.; data curation, X.B.O.; writing—original draft preparation, X.B.O.; writing—review and editing, X.B.O., W.D., T.V. and S.P.H.; visualization, X.B.O.; supervision, W.D., T.V. and S.P.H.; funding acquisition, W.D. All authors have read and agreed to the published version of the manuscript All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Unweighted supermatrix for A1.

	0	1	2	3	4	5	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3
0. Risk in navigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1. Infrastructure design	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. Envionmental conditions	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3. Vessel characteristics	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Traffic conditions	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5. Vessel characteristics	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.1. Location environment	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.18	0.16	0.15	0.16	0.16	0.11	0.16	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.2. Type of infrastructure	0.00	0.37	0.00	0.00	0.00	0.00	0.43	0.00	0.46	0.55	0.46	0.46	0.37	0.46	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.3. Water depth	0.00	0.20	0.00	0.00	0.00	0.00	0.20	0.33	0.00	0.29	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.4. Width	0.00	0.32	0.00	0.00	0.00	0.00	0.37	0.49	0.39	0.00	0.39	0.39	0.32	0.39	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.1. Wind speed	0.00	0.00	0.26	0.00	0.00	0.00	0.26	0.26	0.57	0.26	0.00	0.00	0.00	0.00	0.00	0.26	0.26	0.26	0.26	0.26	0.26	0.00	0.26	0.26
2.2. Wind direction	0.00	0.00	0.15	0.00	0.00	0.00	0.15	0.15	0.27	0.15	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	0.15	0.15	0.00	0.15	0.15
2.3. Current	0.00	0.00	0.11	0.00	0.00	0.00	0.11	0.11	0.16	0.11	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.11	0.11	0.11	0.11	0.00	0.11	0.11
2.4. Visibility	0.00	0.00	0.44	0.00	0.00	0.00	0.44	0.44	0.00	0.44	0.00	0.00	0.00	0.00	0.00	0.44	0.44	0.44	0.44	0.44	0.44	0.00	0.44	0.44
2.5. Time of the day	0.00	0.00	0.04	0.00	0.00	0.00	0.04	0.04	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.04	0.04
3.1. Length	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.17	0.18	0.18	0.18	0.00	0.00	0.17	0.28	0.00	0.00	0.00	0.00	0.00
3.2. Draught	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.48	0.41	0.41	0.41	0.00	0.00	0.48	0.57	0.00	0.00	0.00	0.00	0.00
3.3. Speed over ground	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.11	0.11	0.11	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00
3.4. Maneuvering capability	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.35	0.31	0.31	0.31	1.00	1.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00
4.1. Traffic mix	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.00	0.00	0.19	0.19	0.19
4.2. Traffic volume	0.00	0.00	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.00	0.00	0.81	0.81	0.81
5.1. Traffic rules and port regulations	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.26
5.2. Pilotage	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.64	0.00	0.00	0.74
5.3. VTS information and navigational assistance	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.36	0.00	0.71	0.00

Table A2. Weighted supermatrix for A1.

	0	1	2	3	4	5	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3
0. Risk in navigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1. Infrastructure design	0.072	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2. Envionmental conditions	0.224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3. Vessel characteristics	0.173	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4. Traffic conditions	0.346	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5. Vessel characteristics	0.185	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1. Location environment	0.000	0.114	0.000	0.000	0.000	0.000	0.000	0.089	0.079	0.077	0.052	0.052	0.038	0.052	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.2. Type of infrastructure	0.000	0.374	0.000	0.000	0.000	0.000	0.213	0.000	0.228	0.277	0.152	0.152	0.125	0.152	0.152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.3. Water depth	0.000	0.197	0.000	0.000	0.000	0.000	0.100	0.164	0.000	0.146	0.000	0.000	0.066	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4. Width	0.000	0.315	0.000	0.000	0.000	0.000	0.187	0.246	0.194	0.000	0.129	0.129	0.105	0.129	0.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.1. Wind speed	0.000	0.000	0.259	0.000	0.000	0.000	0.130	0.130	0.287	0.130	0.000	0.000	0.000	0.000	0.000	0.086	0.086	0.086	0.086	0.130	0.130	0.000	0.086	0.086
2.2. Wind direction	0.000	0.000	0.154	0.000	0.000	0.000	0.077	0.077	0.134	0.077	0.000	0.000	0.000	0.000	0.000	0.051	0.051	0.051	0.051	0.077	0.077	0.000	0.051	0.051
2.3. Current	0.000	0.000	0.107	0.000	0.000	0.000	0.053	0.053	0.079	0.053	0.000	0.000	0.000	0.000	0.000	0.036	0.036	0.036	0.036	0.053	0.053	0.000	0.036	0.036
2.4. Visibility	0.000	0.000	0.437	0.000	0.000	0.000	0.218	0.218	0.000	0.218	0.000	0.000	0.000	0.000	0.000	0.146	0.146	0.146	0.146	0.218	0.218	0.000	0.146	0.146
2.5. Time of the day	0.000	0.000	0.044	0.000	0.000	0.000	0.022	0.022	0.000	0.022	0.000	0.000	0.000	0.000	0.000	0.015	0.015	0.015	0.015	0.022	0.022	0.000	0.015	0.015
3.1. Length	0.000	0.000	0.000	0.177	0.000	0.000	0.000	0.000	0.000	0.000	0.059	0.058	0.059	0.059	0.059	0.000	0.000	0.058	0.092	0.000	0.000	0.000	0.000	0.000
3.2. Draught	0.000	0.000	0.000	0.408	0.000	0.000	0.000	0.000	0.000	0.000	0.136	0.159	0.136	0.136	0.136	0.000	0.000	0.159	0.192	0.000	0.000	0.000	0.000	0.000
3.3. Speed over ground	0.000	0.000	0.000	0.107	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.036	0.036	0.036	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000
3.4. Maneuvering capability	0.000	0.000	0.000	0.308	0.000	0.000	0.000	0.000	0.000	0.000	0.103	0.116	0.103	0.103	0.103	0.333	0.333	0.116	0.000	0.000	0.000	0.000	0.000	0.000
4.1. Traffic mix	0.000	0.000	0.000	0.000	0.185	0.000	0.000	0.000	0.000	0.000	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.000	0.000	0.185	0.062	0.062
4.2. Traffic volume	0.000	0.000	0.000	0.000	0.815	0.000	0.000	0.000	0.000	0.000	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.272	0.000	0.000	0.815	0.272	0.272
5.1. Traffic rules and port regulations	0.000	0.000	0.000	0.000	0.000	0.158	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.098	0.088
5.2. Pilotage	0.000	0.000	0.000	0.000	0.000	0.513	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.321	0.321	0.000	0.000	0.246
5.3. VTS information and navigational assistance	0.000	0.000	0.000	0.000	0.000	0.329	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.179	0.179	0.000	0.235	0.000

Table A3. Limit supermatrix for A1.

	0	**1**	**2**	**3**	**4**	**5**	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**5.1**	**5.2**	**5.3**
0. Risk in navigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1. Infrastructure design	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2. Envionmental conditions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3. Vessel characteristics	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4. Traffic conditions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5. Vessel characteristics	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1. Location environment	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
1.2. Type of infrastructure	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
1.3. Water depth	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
1.4. Width	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
2.1. Wind speed	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
2.2. Wind direction	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
2.3. Current	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
2.4. Visibility	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.124
2.5. Time of the day	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
3.1. Length	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
3.2. Draught	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
3.3. Speed over ground	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
3.4. Maneuvering capability	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
4.1. Traffic mix	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
4.2. Traffic volume	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169	0.169
5.1. Traffic rules and port regulations	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
5.2. Pilotage	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
5.3. VTS information and navigational assistance	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056

Table A4. Unweighted supermatrix for A2.

	0	1	2	3	4	5	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3
0. Risk in navigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1. Infrastructure design	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2. Envionmental conditions	0.269	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3. Vessel characteristics	0.244	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4. Traffic conditions	0.264	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5. Vessel characteristics	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1. Location environment	0.000	0.107	0.000	0.000	0.000	0.000	0.000	0.145	0.157	0.160	0.157	0.157	0.107	0.157	0.157	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.2. Type of infrastructure	0.000	0.221	0.000	0.000	0.000	0.000	0.237	0.000	0.338	0.339	0.338	0.338	0.221	0.338	0.338	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.3. Water depth	0.000	0.356	0.000	0.000	0.000	0.000	0.415	0.463	0.000	0.501	0.000	0.000	0.356	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4. Width	0.000	0.315	0.000	0.000	0.000	0.000	0.348	0.393	0.505	0.000	0.505	0.505	0.315	0.505	0.505	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.1. Wind speed	0.000	0.000	0.188	0.000	0.000	0.000	0.188	0.188	0.443	0.188	0.000	0.000	0.000	0.000	0.000	0.188	0.188	0.188	0.188	0.188	0.188	0.000	0.188	0.188
2.2. Wind direction	0.000	0.000	0.087	0.000	0.000	0.000	0.087	0.087	0.137	0.087	0.000	0.000	0.000	0.000	0.000	0.087	0.087	0.087	0.087	0.087	0.087	0.000	0.087	0.087
2.3. Current	0.000	0.000	0.200	0.000	0.000	0.000	0.200	0.200	0.420	0.200	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.200	0.200	0.200	0.200	0.000	0.200	0.200
2.4. Visibility	0.000	0.000	0.473	0.000	0.000	0.000	0.473	0.473	0.000	0.473	0.000	0.000	0.000	0.000	0.000	0.473	0.473	0.473	0.473	0.473	0.473	0.000	0.473	0.473
2.5. Time of the day	0.000	0.000	0.051	0.000	0.000	0.000	0.051	0.051	0.000	0.051	0.000	0.000	0.000	0.000	0.000	0.051	0.051	0.051	0.051	0.051	0.051	0.000	0.051	0.051
3.1. Length	0.000	0.000	0.000	0.155	0.000	0.000	0.000	0.000	0.000	0.000	0.155	0.166	0.155	0.155	0.155	0.000	0.000	0.166	0.225	0.000	0.000	0.000	0.000	0.000
3.2. Draught	0.000	0.000	0.000	0.451	0.000	0.000	0.000	0.000	0.000	0.000	0.451	0.530	0.451	0.451	0.451	0.000	0.000	0.530	0.615	0.000	0.000	0.000	0.000	0.000
3.3. Speed over ground	0.000	0.000	0.000	0.109	0.000	0.000	0.000	0.000	0.000	0.000	0.109	0.000	0.109	0.109	0.109	0.000	0.000	0.000	0.160	0.000	0.000	0.000	0.000	0.000
3.4. Maneuvering capability	0.000	0.000	0.000	0.285	0.000	0.000	0.000	0.000	0.000	0.000	0.285	0.304	0.285	0.285	0.285	1.000	1.000	0.304	0.000	0.000	0.000	0.000	0.000	0.000
4.1. Traffic mix	0.000	0.000	0.000	0.000	0.286	0.000	0.000	0.000	0.000	0.000	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.000	0.000	0.286	0.286	0.286
4.2. Traffic volume	0.000	0.000	0.000	0.000	0.714	0.000	0.000	0.000	0.000	0.000	0.714	0.714	0.714	0.714	0.714	0.714	0.714	0.714	0.714	0.000	0.000	0.714	0.714	0.714
5.1. Traffic rules and port regulations	0.000	0.000	0.000	0.000	0.000	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.250
5.2. Pilotage	0.000	0.000	0.000	0.000	0.000	0.487	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.600	0.600	0.000	0.000	0.750
5.3. VTS information and navigational assistance	0.000	0.000	0.000	0.000	0.000	0.371	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.400	0.400	0.000	0.750	0.000

Table A5. Weighted supermatrix for A2.

	0	**1**	**2**	**3**	**4**	**5**	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**5.1**	**5.2**	**5.3**
0. Risk in navigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1. Infrastructure design	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2. Envionmental conditions	0.269	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3. Vessel characteristics	0.244	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4. Traffic conditions	0.264	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5. Vessel characteristics	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1. Location environment	0.000	0.107	0.000	0.000	0.000	0.000	0.000	0.072	0.079	0.080	0.052	0.052	0.036	0.052	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.2. Type of infrastructure	0.000	0.221	0.000	0.000	0.000	0.000	0.119	0.000	0.169	0.170	0.113	0.113	0.074	0.113	0.113	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.3. Water depth	0.000	0.356	0.000	0.000	0.000	0.000	0.207	0.231	0.000	0.251	0.000	0.000	0.119	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.4. Width	0.000	0.315	0.000	0.000	0.000	0.000	0.174	0.196	0.252	0.000	0.168	0.168	0.105	0.168	0.168	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.1. Wind speed	0.000	0.000	0.188	0.000	0.000	0.000	0.094	0.094	0.221	0.094	0.000	0.000	0.000	0.000	0.000	0.063	0.063	0.063	0.063	0.094	0.094	0.000	0.063	0.063
2.2. Wind direction	0.000	0.000	0.087	0.000	0.000	0.000	0.043	0.043	0.069	0.043	0.000	0.000	0.000	0.000	0.000	0.029	0.029	0.029	0.029	0.043	0.043	0.000	0.029	0.029
2.3. Current	0.000	0.000	0.200	0.000	0.000	0.000	0.100	0.100	0.210	0.100	0.000	0.000	0.000	0.000	0.000	0.067	0.067	0.067	0.067	0.100	0.100	0.000	0.067	0.067
2.4. Visibility	0.000	0.000	0.473	0.000	0.000	0.000	0.237	0.237	0.000	0.237	0.000	0.000	0.000	0.000	0.000	0.158	0.158	0.158	0.158	0.237	0.237	0.000	0.158	0.158
2.5. Time of the day	0.000	0.000	0.051	0.000	0.000	0.000	0.026	0.026	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.017	0.017	0.017	0.017	0.026	0.026	0.000	0.017	0.017
3.1. Length	0.000	0.000	0.000	0.155	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.055	0.052	0.052	0.052	0.000	0.000	0.055	0.075	0.000	0.000	0.000	0.000	0.000
3.2. Draught	0.000	0.000	0.000	0.451	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.177	0.150	0.150	0.150	0.000	0.000	0.177	0.205	0.000	0.000	0.000	0.000	0.000
3.3. Speed over ground	0.000	0.000	0.000	0.109	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.036	0.036	0.036	0.000	0.000	0.000	0.053	0.000	0.000	0.000	0.000	0.000
3.4. Maneuvering capability	0.000	0.000	0.000	0.285	0.000	0.000	0.000	0.000	0.000	0.000	0.095	0.101	0.095	0.095	0.095	0.333	0.333	0.101	0.000	0.000	0.000	0.000	0.000	0.000
4.1. Traffic mix	0.000	0.000	0.000	0.000	0.286	0.000	0.000	0.000	0.000	0.000	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.000	0.000	0.286	0.095	0.095
4.2. Traffic volume	0.000	0.000	0.000	0.000	0.714	0.000	0.000	0.000	0.000	0.000	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.000	0.000	0.714	0.238	0.238
5.1. Traffic rules and port regulations	0.000	0.000	0.000	0.000	0.000	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.083
5.2. Pilotage	0.000	0.000	0.000	0.000	0.000	0.487	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.300	0.300	0.000	0.000	0.250
5.3. VTS information and navigational assistance	0.000	0.000	0.000	0.000	0.000	0.371	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.000	0.250	0.000

Table A6. Limit supermatrix for A2.

	0	**1**	**2**	**3**	**4**	**5**	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**5.1**	**5.2**	**5.3**
0. Risk in navigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1. Infrastructure design	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2. Envionmental conditions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3. Vessel characteristics	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4. Traffic conditions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5. Vessel characteristics	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.1. Location environment	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
1.2. Type of infrastructure	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
1.3. Water depth	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
1.4. Width	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
2.1. Wind speed	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
2.2. Wind direction	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
2.3. Current	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
2.4. Visibility	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
2.5. Time of the day	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
3.1. Length	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
3.2. Draught	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
3.3. Speed over ground	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
3.4. Maneuvering capability	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
4.1. Traffic mix	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
4.2. Traffic volume	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
5.1. Traffic rules and port regulations	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
5.2. Pilotage	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
5.3. VTS information and navigational assistance	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060

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