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Information Uncertainty Impacting Vessel Traffic Planning on the Świnoujście–Szczecin Fairway

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Abstract:

Purpose: *Vessel traffic planning on the Świnoujście–Szczecin fairway in Poland is affected by information uncertainty that impacts decision-making process carried out by Vessel Traffic Service Operators (VTSOs). The article aims to identify and analyse the groups of information associated with uncertainty occurring during vessel traffic planning on the dredged Świnoujście–Szczecin fairway.*
Design/Methodology/Approach: *The study was conducted using a questionnaire-based research method. The survey was carried out among VTSOs employed at the Vessel Traffic Services (VTS) centres in Szczecin and Świnoujście. Moreover, the case study showing information uncertainty impact on the vessel entering the fairway was analysed.*
Findings: *The analysis of the research results indicated that, according to VTSOs, information on visibility and wind force is subjected to significant uncertainty during vessel traffic planning. The case study analysis revealed that information uncertainty may impact the significant delay for ship entering the fairway.*
Practical Implications: *The findings of this study may provide valuable insights for VTSOs, seaport authorities, maritime administration bodies, and other stakeholders responsible for the planning and organization of vessel traffic on the fairways.*
Originality/Value: *The groups of information associated with uncertainty occurring while vessel traffic planning on the Świnoujście–Szczecin fairway were identified and assessed. Recommendations for reducing information uncertainty in the decision-making process related to vessel traffic planning on the analysed fairway were proposed.*

Keywords: *Decision-making, vessel traffic planning, vessel traffic services (VTS) operator, Świnoujście–Szczecin fairway, information uncertainty, maritime transport.*

JEL codes: *C8, L9, R4.*

Paper type: *Research article.*

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1. Introduction

The safe and efficient traffic of vessels along fairways and coastal areas depends on the availability of reliable and timely information (Heikkilä *et al.,* 2024). Vessel traffic planning is a complex decision-making process in which information must be continuously acquired, processed, and interpreted (Durczak and Filina-Dawidowicz, 2025).

Therefore, the quality of decisions made by Vessel Traffic Service Operators (VTSOs) is strongly dependent on the accuracy, completeness, and timeliness of the information available to them (Baldauf *et al.,* 2023; Kotkowska and Marcjan, 2021). Any discrepancies, delays, or gaps in the available information may increase uncertainty and consequently affect the effectiveness and reliability of vessel traffic planning (Karmelić *et al.,* 2025). Information uncertainty in vessel traffic planning may result from the dynamic nature of vessel movements, limitations of monitoring and communication systems, inaccuracies in navigational data, changing environmental conditions, and differences between predicted and actual vessel behaviour (Ksciuk *et al.,* 2023).

In particular, parameters such as visibility, wind force, water level, and other may change over relatively short periods and are not always known with sufficient accuracy when traffic planning decisions are made (Durczak and Filina-Dawidowicz, 2025). Consequently, the planning of vessel traffic inherently involves decision-making under uncertainty, as the information available to decision-makers may vary in terms of its accuracy, completeness, and timeliness. The problem is particularly relevant to the dredged Świnoujście–Szczecin fairway as an important maritime transport route connecting the Baltic Sea with the ports in Świnoujście, Police and Szczecin. In July 2022 this fairway was commissioned and vessels with maximum parameters of up to 260 m in length and 11 m in draft were permitted to use it (Gucma *et al.,* 2021).

Consequently, new vessel traffic rules were implemented (Order, 2023) that impacted operational challenges for VTSOs, who are responsible for making day-to-day decisions regarding the safe vessel traffic on the fairway. Therefore, the quality of information available to VTSOs plays an important role in planning the safe vessel traffic within the fairway.

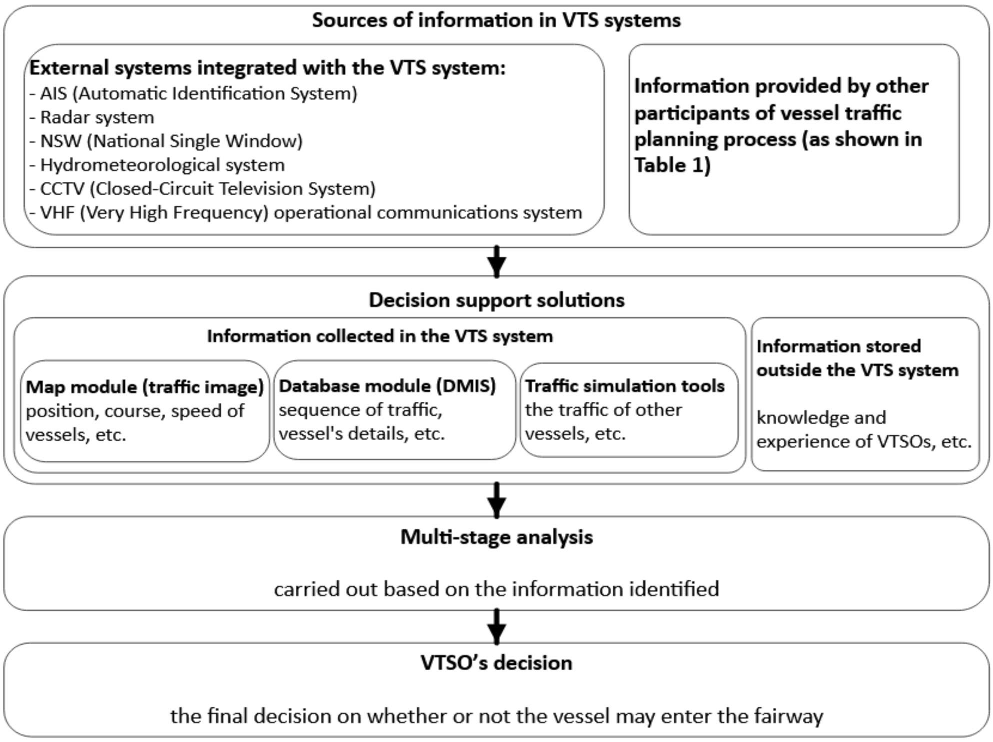
Although various aspects of vessel traffic management, maritime safety, and navigational risk have been extensively investigated in the available literature, the role of information uncertainty in vessel traffic planning remains insufficiently explored. Existing approaches frequently focus on the availability of information or on the accuracy of individual data sources, while less attention is given to the combined impact of uncertain information on the decision-making process carried out by VTSOs.

The article aims to identify and analyse the groups of information associated with uncertainty occurring during vessel traffic planning on the Świnoujście–Szczecin fairway. Particular attention is given to the information used by VTSOs during the planning and organisation of vessel movements and to the sources impacting the reliability of this information The groups and categories of information associated with uncertainty were identified. The analysis was carried out using the questionary survey among VTSOs planning vessel traffic on the Świnoujście–Szczecin fairway. In order to show the impact of information uncertainty on the vessel traffic planning, the case study was analysed. Recommendations to reduce information uncertainty during considered decision-making process were proposed.

2. Information Uncertainty During Decision-Making Process Related to Vessel Traffic Planning

The vessel traffic planning within the Świnoujście–Szczecin fairway is a complex process (Filina-Dawidowicz and Durczak, 2023; Filina-Dawidowicz and Durczak, 2025b). Although the Vessel Traffic Services (VTS) system, Decision Management Information System (DMIS) and other systems provide essential information for the vessel traffic planning, decision-making requires the integration of information obtained from multiple sources (Figure 1).

Figure 1. *Sources and flow of information in the VTSOs' decision-making process*



Source: *Own elaboration.*

The decision-making process under consideration comprises a number of activities involving various stakeholders (Table 1).

Table 1. *Roles of individual participants in the process of vessel traffic planning on the Świnoujście–Szczecin fairway*

Activity	**Individual participants of the process** *									
	Ship' s Agent	**Duty Officer Szczecin**	**Duty Officer Świnoujście**	**Port Dispatcher**	**Tugboat Company**	**Mooring Company**	**VTS Operator Świnoujście**	**VTS Operator Szczecin**	**Pilot**	**Pilot Station Dispatcher**
Approval of the FAL/PreArrival document for the Szczecin/Police ports	-	R	-	-	-	-	-	-	-	-
Approval of the FAL/PreArrival document for the Świnoujście port	-	-	R	-	-	-	-	-	-	-
Monitoring of vessel traffic to and from Świnoujście	-	-	C	-	-	-	R	-	-	-
Monitoring of vessel traffic to and from Szczecin	-	C	-	I	-	-	R	R	-	-
Passing manoeuvre planning with Ro-Ro vessels	-	-	-	-	-	-	R	C	-	-
Passing manoeuvre planning on Zalew passing place	-	-	-	-	-	-	C	R	-	-
Submission of IMO FAL documents	R	A	A	-	-	-	I	I	-	-
Allocation of anchorage for a vessel	-	I	I	I	-	-	R	C	-	-
Dispatching a pilot to the vessel	-	-	-	-	-	-	R	C	I	-
Towing assistance	-	A	A	-	R	-	A	A	-	-
Permission for a vessel to enter/leave Szczecin port	-	R	-	-	-	-	-	I	-	-
Permission for a vessel to enter/leave Świnoujście port	-	-	R	-	-	-	I	-	-	-
Sending the pilot boat	-	-	-	-	-	-	-	-	-	R
Mooring/unmooring a vessel in Szczecin	-	I	-	I	-	R	-	I	A	-
Mooring/unmooring a vessel in Świnoujście	-	-	I	I	-	R	I	-	A	-
Permission for vessels to join the traffic to/from Szczecin port	-	-	-	C	-	-	C	R	I	-
Permission for vessels to join the traffic to/from Świnoujście port	-	-	-	C	-	-	R	C	I	-

Note: **where: R – responsible for process execution, A – supervising for the result, C – consulted, I – informed.*
Source: *Own elaboration.*

The process of planning a vessel's entry into the Świnoujście–Szczecin fairway is based on information concerning the vessel, the fairway, the port, hydrometeorological and traffic conditions, the availability of support services, and other. This information forms the basis for assessing the possibility to perform individual activities.

In practice, the decision-making process considered in this study is inherently dynamic. For example, a vessel may meet the technical and formal requirements, but its entry may be delayed due to deteriorating weather conditions, the unavailability of a pilot, the quay being occupied, a change in the order of traffic, or incomplete information in DMIS.

Similarly, the correct planning of a passing manoeuvre between two vessels requires simultaneous consideration of their size categories, the passing place, the availability of a fairway, visibility conditions, the vessels' speeds and the estimated time of arrival at the relevant section of the fairway. Although decision-support systems provide information, warnings, forecasts or recommendations (Durczak and Filina-Dawidowicz, 2025a; Schäfer *et al.,* 2025), the final decision on whether to let a vessel enter the fairway remains with the VTS operator (Filina-Dawidowicz and Durczak, 2023).

It is particularly important to distinguish between certain and uncertain information (Park, 2026; Sun and Zheng, 2018; Torok *et al.,* 2024). Relatively certain information in vessel traffic planning includes, i.e., fairway parameters, permanent infrastructure constraints, basic vessel parameters and applicable regulations. On the other hand, variable information includes hydrometeorological conditions, predicted arrival and departure times, the availability of quays, pilots and tugs, the current traffic pattern, and information provided by participants involved in the process. The changing nature of the available information necessitates continuous monitoring and periodic revision of the vessel traffic plan.

Decision-making uncertainty arises when a VTS operator must make a decision despite having incomplete, variable or ambiguous information. This applies in particular to hydrometeorological forecasts, the predicted time of a vessel's readiness, the assessment of future traffic conditions, and the possibility of delays. Therefore, the VTS operator may make a decision considering anticipated development of the situation over time.

For this reason, the planning of vessel traffic on the Świnoujście–Szczecin fairway should be regarded as a multi-criteria, dynamic process associated with uncertainty. This uncertainty does not imply a lack of data, but rather the need to interpret data with varying degrees of certainty, timeliness and precision. The uncertainty of information in the process of planning a vessel's entry into the Świnoujście–Szczecin fairway stems from the fact that the VTS operator makes decisions based on data from multiple sources, provided by various entities and updated at different times (Nasution *et al.,* 2025). This information may be incomplete, delayed, inconsistent, imprecise or possible to change during the course of the process. This applies to vessel, hydrometeorological, organisational, operational and traffic-related information (Table 2).

Table 2. *Identified sources of information and possible consequences of its uncertainty during planning a vessel's entry into the fairway by VTSOs*

Sources of information	**Examples of information provided**	**Possible consequences of information uncertainty**
Captain of the vessel	the vessel's readiness, current draught, possible speed of transit, malfunctions and technical limitations	delayed notification of changes, incomplete information, incorrect assessment of the vessel's capabilities, change in technical condition
Ship's agent	Pre-Arrival and FAL documentation, vessel particulars, estimated time of arrival or departure, services requested	incorrect data entry, failure to update, data discrepancies, late submission of information
Pilot and pilot station dispatcher	availability of a pilot, time taken to man the vessel, feasibility of providing the service under the given conditions	change in availability, suspension of the pilot scheme, delay to the pilot scheme, different assessment of conditions
Harbour master's duty officers	approval of documentation, permission to enter, special conditions	delays in decision-making, the need for further consultations, changes to the conditions for authorisation
Port dispatcher	berth availability, vessel priorities, port service timetable	changes to the order of operations, delays in port operations, occupation of the quay, lack of up-to-date data
Towing and mooring companies	availability of tugboats and mooring staff, standby time	lack of resources, delay, breakdown of a unit or equipment, change to the schedule
Operating systems	DMIS, NSW, AIS, radar, cameras, hydrometeorological system	system failure, transmission delay, incorrect recording, lack of data synchronisation, communication disruptions
Operating environment (other participants of the process)	ferry traffic, vessels traffic in opposite directions, track and passing lane occupancy, navigational restrictions	a significant change in traffic conditions, the arrival of an additional vessel, the closure of a section of the waterway, a change in navigation conditions

Source: *Own elaboration.*

Uncertainty in information may result from both a lack of data and its variability, inconsistencies or imprecise nature. In the traffic planning process, information concerning vessel parameters, the anticipated time of vessel's readiness, the current and forecasted hydrometeorological conditions, the availability of pilots, tugs and quays, as well as the expected traffic pattern on the fairway, is of particular importance (Hsieh *et al.,* 2024; Petranović and Parunov, 2025).

For the purposes of this study, four types of information uncertainty were adopted:

1. Incomplete data. This occurs when the operator does not have all the information necessary to make a decision, or when some of the data requires confirmation by the vessel, an agent, a pilot, a port dispatcher or the harbour master's duty officer (Di Francesco *et al.,* 2021; Jurkovič and Satler, 2025).
2. Timeliness of data. This occurs when the information available in planning systems may be out of date compared with the actual situation. This applies, amongst other things, to the estimated time of arrival or departure of a vessel, the completion of port operations, quay readiness, pilot availability or changes to the port service schedule (Ristov *et al.,* 2013; Pilgrim *et al.,* 2024; Torok *et al.,* 2024).
3. Forecast uncertainty. This is particularly significant when assessing hydrometeorological conditions and predicting the development of traffic conditions. Weather forecasts are often interval-based and descriptive, indicating possible ranges of wind strength, gusts, changes in direction, reduced visibility or the occurrence of hazardous phenomena. The VTSOs must therefore assess whether the predicted development of conditions throughout the vessel's passage will remain within acceptable limits (Guo *et al.,* 2026; Zhao *et al.,* 2025).
4. Interpretative uncertainty. This applies to situations where data is available, but its relevance to the decision-making process is not clear-cut. An example might be assessing whether the forecast increase in wind strength is still within acceptable limits, or whether it has already reached the threshold for a specific group of vessels, or whether the planned passing manoeuvre between two vessels on a given section of the route should be approved, taking into account the current traffic pattern (Bąk *et al.,* 2024; Marjanović *et al.,* 2025; Sun and Zheng, 2018).

On the basis of the available literature review carried out, it can be concluded that:

- The uncertainty of information in the process of planning vessels traffic within the fairway affects the effectiveness of decisions taken by VTS operators.
- A significant part of the existing research focuses on monitoring vessel traffic, detecting hazardous situations, predicting vessel trajectories, and assessing navigational risk, whereas considerably less attention is given to the decision-making process preceding a vessel's entry onto a fairway.
- The literature lacks a comprehensive analysis of information uncertainty occuring during planning of vessel traffic.

Therefore, there is a need to identify and analyse the groups of information that may face uncertainty while vessel traffic planning on the Świnojście–Szczecin fairway.

3. Research Methodology

The study was designed to answer the following three research questions:

RQ1: What groups of information are associated with uncertainty and are faced by VTSOs while planning the vessel traffic on the Świnoujście–Szczecin fairway?
RQ2: What categories of information are perceived as the most uncertain?
RQ3: How did information uncertainty impact the vessel traffic planning?

Based on consultations with VTSOs and a review of the relevant literature, a questionnaire was developed. The survey was conducted between July and September 2024 among VTSOs involved in vessel traffic planning on the Świnoujście–Szczecin fairway. The questionnaire was filled in by VTSOs employed in VTS Centre Szczecin (12 respondents) and VTS Centre Świnoujście (7 respondents). VTSOs were asked to rate identified categories of information considering their uncertainty. The collected data were subsequently analysed, the risk of uncertainty occurrence within particular information categories was identified.

To show the way information uncertainty may impact the vessel traffic planning by VTSOs, the case study of vessel 'Bolten Singapore' waiting for the decision to enter the Świnojście–Szczecin fairway was considered. The sources of the delay were identified and analysed.

Based on the findings, recommendations were proposed to mitigate the impact of the identified information uncertainty on the decision-making process.

4. Results

4.1 Information Uncertainty During Vessel Traffic Planning by VTSOs

As a part of the conducted research the groups and categories of information associated with uncertainty during vessel traffic planning on the Świnoujście–Szczecin fairway were identified (Table 3). The identified information was classified into three main groups: organizational, technical and technological, as well as environmental information. Specific information categories were linked to particular types of uncertainty (incomplete data, timeliness of data, forecast uncertainty, interpretative uncertainty).

Table 3. *Identified information groups and categories that may be associated with uncertainty while vessel traffic planning on the Świnoujście–Szczecin fairway*

Groups of information	Identified information categories associated with uncertainty	Type of uncertainty*
Organizational	I1: Actual vessel entry time onto the fairway	1,3
	I2: Entry schedule for notified vessels	1,2
	I3: Ferry traffic schedule	3
	I4: Traffic of other vessels on the fairway	1,2
	I5: Navigation restrictions	3
	I6: Restrictions due to water area occupancy	2,3
	I7: Berth availability	1,4
	I8: Tug availability	2
	I9: Harbour Master's permission for enter/departure	4
	I10: Special conditions imposed by the Harbour Master	4
	I11: Suspension of tug service	2
	I12: Suspension of pilot service	2
Technical and technological	I13: Vessel speed	1,2,3
	I14: Vessel draught	1,2,3
	I15: Vessel type	1
	I16: Vessel dimensions (length, width)	1
	I17: Water level in the harbour	3
	I18: Vessel failure reports	2,4
Environmental	I19: Wind force	3,4
	I20: Visibility	3,4
	I21: Current strength	3,4

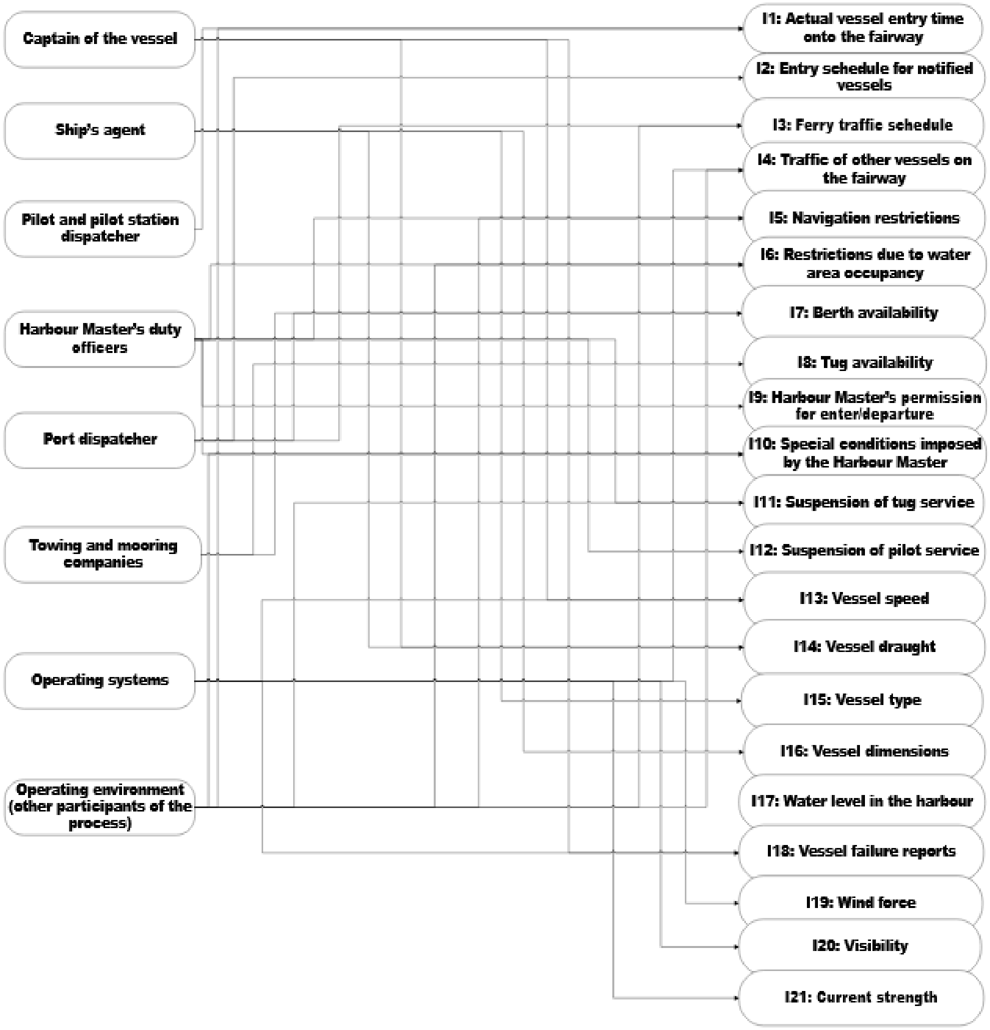
Note: ** where uncertainty is related to: 1 – incomplete data, 2 – timeliness of data, 3 – forecast uncertainty, 4 – interpretative uncertainty.*
Source: *Own elaboration.*

The organizational group of information is the largest, comprising as many as 12 of the 21 identified information categories. This indicates that the vessel traffic planning process on the fairway is highly dependent on human factor, established procedures, and coordination among multiple stakeholders. Within the technical and technological information group, particular attention is paid to the dynamic parameters of vessels, which directly influence the safety of vessel movement along the Świnoujście–Szczecin fairway. Although the environmental group is the least numerous comprising three category, it is of fundamental importance for navigational safety.

It should be noted that information on vessel speed (I13) and vessel draught (I14) may be associated with incomplete data, timeliness of data and forecast uncertainty. The combination of these uncertainties may increase the risk of discrepancies between the planned and actual vessel movement, requiring VTSOs to continuously verify and, where necessary, revise the traffic plan.

The connections between particular sources of information and identified information categories are presented in Figure 2.

Figure 2. *The connections between particular sources of information and identified information categories*



Source: *Own elaboration.*

4.2 Assessment of Information Uncertainty by VTSOs

VTSOs assessed the identified information categories considering possibility of uncertainty occurrence and its impact on the decision-making process, using the scale from 1 to 100 (Table 4). The application of this scale allowed for a more precise differentiation between the assessed information categories and facilitated the identification of those characterised by the highest level of uncertainty.

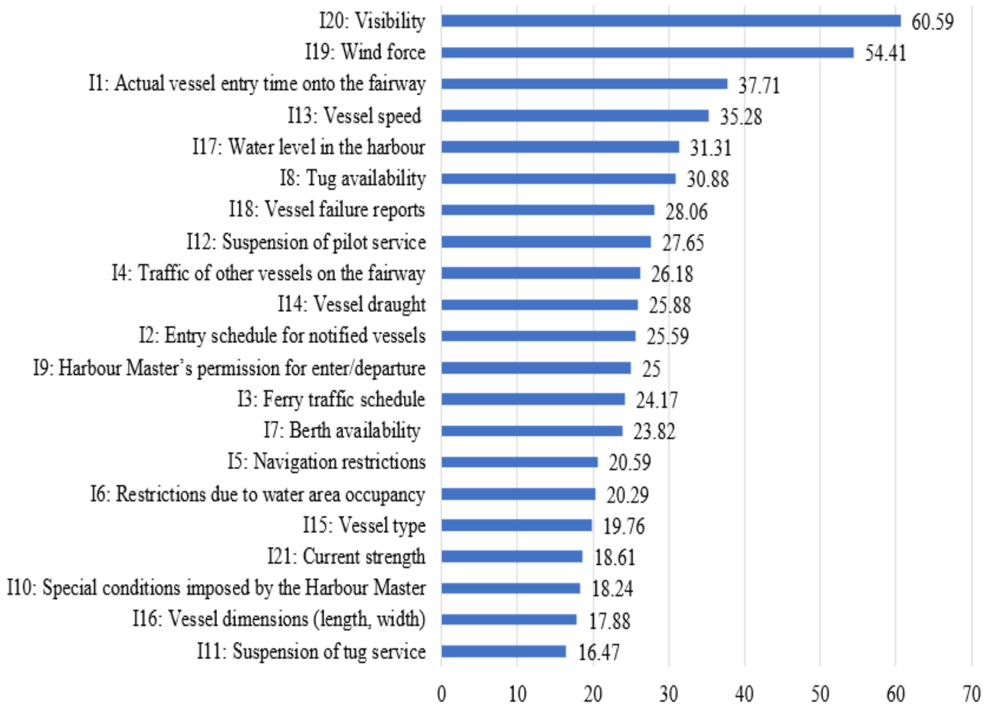
Table 4. *Scale used to assess information uncertainty that may impact decision-making process while vessel traffic planning*

Numerical value	Scale	Possibility of information uncertainty occurrence	Impact of information uncertainty on decision-making process
1	0-10	Insignificant or very low possibility (the information is certain)	Insignificant or very low impact (uncertainty in the information does not affect decisions on vessel traffic planning)
2	11-25	Low possibility	Low impact
3	26-50	Moderate possibility	Moderate impact
4	51-75	High possibility	High impact
5	76-100	Very high possibility (uncertainty is always present to a very large extent)	Very high impact (uncertainty in the information significantly affects the decisions taken)

Source: *Own elaboration.*

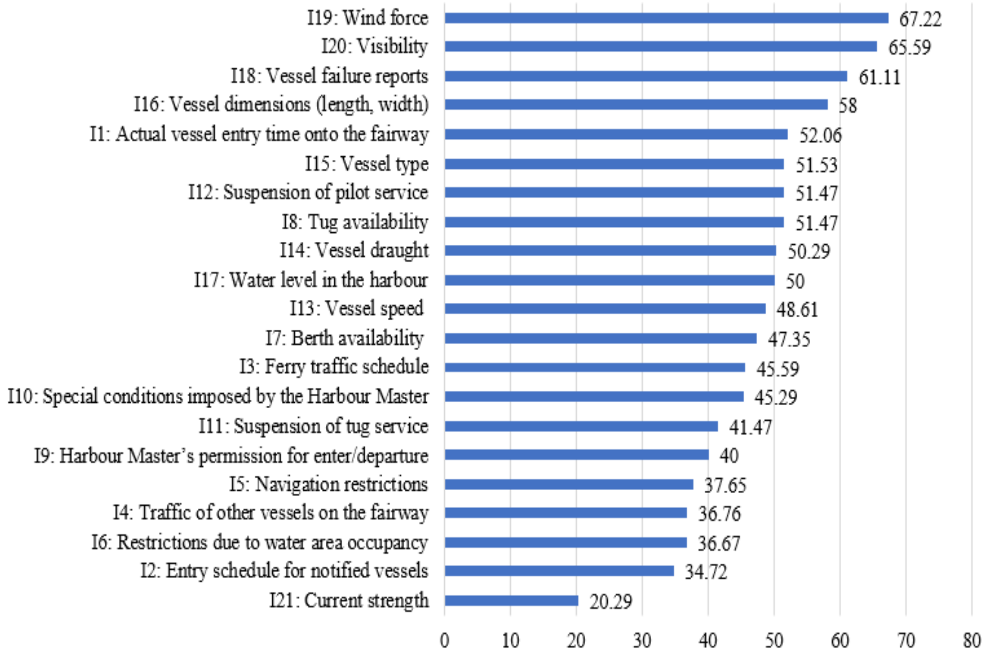
The results of VTSOs assessments are presented in Figures 3 and 4. The obtained scores provide a basis for identifying the information categories that require particular attention during the vessel traffic planning process.

Figure 3. *Assessment of the possibility of information uncertainty occurrence, mean values*



Source: *Own elaboration.*

Figure 4. *Assessment of the impact of information uncertainty on decision-making process, mean values*



Source: *Own elaboration.*

Multiplication of obtained values related to possibility of information uncertainty occurrence and the impact of the uncertainty on the decision-making process made it possible to assess the associated risks (Figure 5).

Figure 5. *Risks related to information uncertainty occurrence within specific information categories*

Possibility assessment	**Possibility**	**Possibility expressed numerically**	**Risk**				
	Very high	5					
	High	4				I19, I20	
	Medium	3			I2, I4, I13, I17,	I1, I8, I12, I18,	
	Low	2		I21	I3, I5, I6, I7, I9, I10, I11, I14,	I15, I16,	
	Very low or impossible	1					
Impact expressed numerically			1	2	3	4	5
Impact			Insignificant	Low	Medium	Large	Very large
			Impact assessment				

Source: *Own elaboration.*

Based on the results presented in Figures 3-4, it can be concluded that VTSOs identified uncertainty related to environmental information group (wind force (I19) and visibility (I20)) as the most possible and impacting the decisions made during vessel traffic planning. It should be also noted that uncertainty is also very significant within organizational information group (actual vessel entry time onto the fairway (I1), tug availability (I8), suspension of pilot service (I12)), as well as technical and technological information group (vessel failure reports (I18)).

4.3 Case Study Analysis

In order to determine the impact of information uncertainty on the vessel traffic planning, a case study related to the excessive delay in the entering the Świnoujście-Szczecin fairway by bulk cargo vessel 'Bolten Singapore' was considered (Table 5).

Table 5. *Case study description*

Element of analysis	**Description**
Operational situation	The vessel "Bolten Singapore", with a length of 199.9 m, a breadth of 32.3 m and a draught of 7.6 m on arrival and 9.1 m on departure, had been waiting at anchor since 7 January 2024. The Harbour Master specified special conditions for the vessel's manoeuvres at Górnośląskie Quay: daylight operation, visibility of at least 1 NM and wind force not exceeding 5 B. The vessel berthed in port on 16 January 2024 and departed the port on 26 January 2024. The total time from anchoring to departure from the port was 18 days and 11 hours.
Decision-making event	Assessment of the feasibility of the vessel's entry and departure based on the special conditions specified by the Harbour Master, IMGW hydrometeorological forecasts, berth readiness and the available daylight manoeuvring window.
Information sources	Harbour Master's decision, IMGW forecasts, actual wind measurements from the VTS station at Dąbrowieckie Quay, information on berth availability, NSW and DMIS data, as well as communications provided by the port, the vessel's agent and the vessel.
Problem identified	The main problem was the discrepancy between the forecast and actual wind force. According to IMGW forecasts, suitable entry conditions during the analysed period occurred only within very limited time windows, whereas local VTS measurements showed that the 5 B threshold, corresponding to a wind speed of approximately 8.0–10.7 m/s, was significantly exceeded mainly on 24 and 25 January 2024. An additional constraint was the requirement for daylight operation, which during the winter period considerably reduced the available manoeuvring time. Moreover, when weather conditions were suitable, the berth was not always ready to receive the vessel.
Type of uncertainty	Forecast uncertainty, discrepancy between information sources, interpretative uncertainty, information obsolescence, variability of the decision-making environment, and organisational uncertainty.

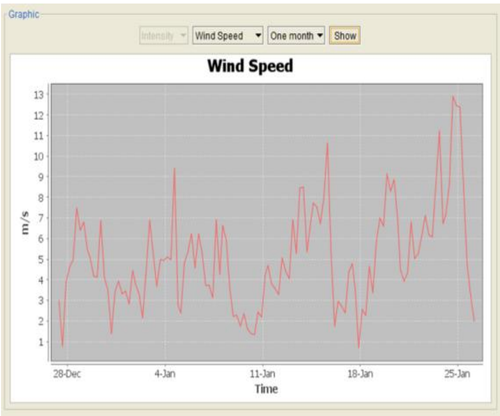
Impact on the decision	The VTS operator made planning decisions on the basis of a forecast indicating considerably fewer favourable weather conditions than were subsequently identified from actual measurements. At the same time, the occurrence of suitable wind conditions did not guarantee vessel entry, as the remaining criteria also had to be met simultaneously: daylight operation, required visibility, berth readiness and availability of port services. The cumulative effect of these constraints resulted in successive postponements of the planned entry and departure times.
Direct consequences	The consequences of the analysed delay extended beyond the vessel's waiting time itself. They included financial losses for the shipowner that are difficult to estimate precisely, as well as potential reputational consequences for the port. Prolonged and persistent unpredictability of port services may reduce the port's competitiveness, particularly where shipowners have the option of diverting vessels to alternative ports. Assuming that the average port stay of a vessel with similar parameters is approximately 5 days, the excess port stay of "*Bolten Singapore*" amounted to approximately 13 days. The additional economic burden on the shipowner may be estimated at approximately PLN 1.0–1.6 million.
Method of reducing uncertainty	Parallel use of IMGW forecasts and real-time local measurements; establishment of rules for updating decisions in the event of discrepancies between forecasts and measurements; implementation of short-term local forecasting for the manoeuvring area; continuous confirmation of berth readiness; and coordination of all constraints within a single integrated operational plan.

Source: *Own elaboration.*

The differences in wind speed forecasts provided by the Institute of Meteorology and Water Management (IMGW) and the actual measurements coming from the VTS system while the vessel 'Bolten Singapore' was at berth are shown in Figure 5.

Figure 5. *A comparison of the wind speed forecasts provided by (a) the IMGW with the actual measurements from the VTS system (b) whilst the vessel 'Bolten Singapore' was at berth*

Weather conditions between 7 AM and 7 PM (based on IMGW forecasts)
12 January 2024: conditions met
13 January 2024: 5–6 B, periodically 7B
14 January 2024: 5–6 B, periodically 7B
15 January 2024: 5–6 B, periodically 7B
16 January 2024: 3–5 B, periodically 7B
17 January 2024: conditions met
18 January 2024: 4–5 B, with gusts of 7B
19 January 2024: 4–5 B, with gusts of 6 B
20 January 2024: 4–6 B, with gusts of 7 B
21 January 2024: 4–6 B, with gusts of 6 B
22 January 2024: 5–6 B, with gusts of 7 B
23 January 2024: 4–6 B, with gusts of 7 B
24 January 2024: 4–6 B, with gusts of 8–9 B
25 January 2024: 5–7 B, with gusts of 8 B, decreasing to 3–4 B



a) b)

Source: *Own elaboration based on Forecasts, 2024 and Maritime Office in Szczecin, 2024.*

The comparative analysis of data from two information sources revealed a significant discrepancy between forecast and actual weather conditions. According to IMGW forecasts, the permitted limitation (wind speed 5 B) was exceeded during 11 days of the analysed period, with the exception of 16–17 January, whereas actual VTS meteorological station measurements showed exceedances only on 15, 24 and 25 January. This indicates that actual conditions were substantially more favourable than those suggested by the information available to the VTSOs at the vessel traffic planning stage.

An additional source of uncertainty occurred when the forecast sustained wind remained within the acceptable 5 B limit, while gusts of 6–7 B were simultaneously predicted. The VTSOs could not determine whether such gusts would actually occur, when they would occur, or whether they would coincide with the vessel's transit or manoeuvring period. This increased interpretative uncertainty and the operator's decision-making burden, particularly in the context of pressure associated with vessel delay costs and the expectations of other stakeholders (Table 6).

Table 6. *The impact of particular types of uncertainty on the decision-making process*

Type of uncertainty	Manifestation in the analysed case	Impact on the decision-making process
Forecast uncertainty	IMGW forecasts indicated exceedance of 5 B during 11 days, whereas actual measurements confirmed such exceedances during only 3 days.	Reduction in the number of "weather windows" that could be considered available at the planning stage.
Interpretative uncertainty	Significant differences between IMGW forecasts and subsequent measurements from the local VTS meteorological station.	The operator had to make decisions based on forecast information whose accuracy could only be assessed ex post.
Interpretative uncertainty	Forecast sustained wind sometimes remained within the 5 B limit, while gusts of 6–7 B were predicted without precise information on when they would occur.	Need to assess the risk of exceeding the limit during a multi-hour operation, increasing the operator's decision-making burden.
Timeliness of data	Both weather conditions and the availability of other operational elements changed over time.	Favourable weather conditions alone did not guarantee that the operation could be carried out.
Uncertainty resulting from multi-stage information flow	The decision required coordination of information from IMGW, VTS, the Harbour Master, the port, the vessel and other participants of the process.	The final period for possible vessel traffic depended on simultaneous confirmation of multiple conditions and information sources.

Source: *Own elaboration.*

It should be highlighted that in analysed case study interpretative and forecast uncertainty, timeliness of data, as well as Uncertainty resulting from multi-stage information flow impacted decision-making process carried put by VTSOs.

5. Conclusions

Based on the conducted research, it was possible to identify:

- the key information groups and categories associated with uncertainty and influencing the process of planning vessel entry into the Świnoujście-Szczecin fairway,
- categories of information that are perceived by VTSOs as the most uncertain,
- the impact of information uncertainty on the vessel traffic planning based on case study analysis.

As a result of the research, the following recommendations can be formulated to reduce information uncertainty during vessel traffic planning on the Świnoujście–Szczecin fairway (Table 7).

Table 7. *Recommendations related to reducing the information uncertainty*

Recommendations	Description
Improve the reliability of weather-related decision support	Combine IMGW forecasts with real-time local VTS measurements and introduce short-term local forecasting for critical manoeuvring areas
Reduce the risk of information distortion during repeated consultations	Identify the primary source of each type of information and maintain a single operational version of the traffic plan
Standardize confirmation of key operational arrangements	Use closed-loop communication for critical decisions and require explicit confirmation in DMIS, VHF or other agreed communication channels
Develop scenario-based decision support tools	Use historical cases and "what-if" scenarios to assess the consequences of uncertain information occurrence
Introduce systematic post-operation review	Compare planned and actual vessel entry times, weather conditions, delays and causes in plan changes

Source: *Own elaboration.*

The findings may provide a basis for developing more robust decision-support approaches that explicitly account for uncertainty in the information available during vessel traffic planning. The authors' future research will focus on modelling decision-making processes associated with vessel traffic planning on the Świnoujście–Szczecin fairway.

The research results of this study may be of interest to VTSOs, as well as employees of port authorities, pilot stations, and maritime offices involved in decision-making processes concerning vessel traffic planning on the Świnoujście–Szczecin fairway and in other navigational areas.

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