A Cross-Domain Scientometric Analysis of Situational Awareness of Autonomous Vehicles With Focus on the Maritime Domain

KRZYSZTOF BOGUSŁAWSKI[1], JAN NASUR[1], JIE LI[2], MATEUSZ GIL[1,3], KRZYSZTOF WRÓBEL[1], AND FLORIS GOERLANDT[4]

[1]Research Group on Maritime Transportation Risk and Safety, Gdynia Maritime University, 81-345 Gdynia, Poland
[2]National Science Library, Chinese Academy of Sciences, Beijing 100045, China
[3]Marine Technology Group, Department of Mechanical Engineering, Aalto University, 02150 Aalto, Finland
[4]Maritime Risk and Safety Group, Department of Industrial Engineering, Dalhousie University, Halifax, NS B3H 4R2, Canada

Corresponding author: Krzysztof Wróbel (k.wrobel@wn.umg.edu.pl)

ABSTRACT Highly automated vehicles are making their way towards implementation in many modes of transportation, including shipping. From the safety perspective, it is critically important that such vehicles or the operators overseeing them maintain their sense of the environment, also referred to as situational awareness. The present study investigates the worldwide research effort focusing on situational awareness for autonomous transport and explores how the maritime domain could benefit from it. The results indicate that most of the research originates from the automotive sector, but the topic is developing fast in other transportation modes too. Some findings have been shared across the modes of transportation, but only to a limited extent. Although technology development is performed based on the achievements within basic research domains, there has been little feedback from applied sciences. Similarly, collaborative research is not strongly developed.

INDEX TERMS Autonomous transportation, autonomous vehicles, safety of transportation, scientometrics, situation awareness.

I. INTRODUCTION

With the Fourth Industrial Revolution ongoing, more and more systems are being automated. This overall trend across industrial sectors has also led to intense activity in various transportation modes to develop and implement autonomous transport systems [1]. Regardless if one decides to call it automation or autonomy [2], the key defining features of these developments are the increased implementation of digital functions, the extensive interconnectivity, along with hardware and software making decisions and performing tasks (including safety-critical ones) without the direct control of a human operator. The envisaged benefits of these developments involve enhanced overall safety performance, more operational flexibility, increased profitability, as well

The associate editor coordinating the review of this manuscript and approving it for publication was Razi Iqbal.

as improved operators' safety and well-being often being highlighted [3].

There are already numerous exemplary developments toward vehicles having the capability to achieve their goals autonomously. For instance, several models of driverless cars have been admitted to regular traffic in the U.S. [4] and crewless suburban trains and Autonomous Underwater Vehicles (AUVs) have been operationally deployed as well [5], [6]. There are other more or less market-ready solutions [7]. Some technical solutions do not require a qualified driver to be on board (trains, AUVs), while others enable an operator to relax his/her mental workload from the actual operation. While this allows for transferring the operator's attention to different tasks, there still remains a question about the role and performance of human intervention in the system. Of particular importance are situations where specific external or internal conditions are met, which cannot be handled by an automated control system [8]. In such cases, a hand-over

of control to the operator is required to maintain the safety of the system [9].

A necessary condition for a successful hand-over in such situations is that the operator maintains a suitable degree of situational awareness (SA) [10]. The same is a prerequisite in other circumstances including routine supervision and emergencies [11]. SA is usually understood as *a perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future* [12]. However, alternative definitions exist, too [13]–[15]. Research on this phenomenon is multi-faceted and investigates the very nature of SA and cognitive processes involved [16], as well as conditions for maintaining or gaining it [17].

Situational awareness has been considered a critical aspect of the safe operation of autonomous transportation systems [18]. However, there currently is no work that provides a comprehensive overview of the various topics addressed within this research domain. In particular, there is a lack of work aimed to bridge the different research communities. Meanwhile, knowledge about developments and findings made in other domains can be beneficial to accelerate developments and avoid duplication of research efforts.

Considering the above, this article aims to analyze and map research trends in situational awareness of autonomous vehicles. While our scope includes all transportation modes, we will focus on the maritime domain, as the implementation of autonomous solutions in commercial shipping is lagging behind other modes of transportation [19]. Certain existing solutions and insights obtained in other domains could potentially be adopted in other ones [20] including maritime, perhaps with necessary modifications [21]. To facilitate this cross-domain information exchange, and to spur developments as well as new lines of research in the maritime domain, this article presents a high-level analysis of the research on situational awareness for autonomous transportation systems and a subsequent discussion on research directions for the maritime domain.

To this end, the focus is on answering the following specific research questions (RQs):

RQ1: What are the general trends in situational awareness research related to autonomous transport?

RQ2: How did the research topics on situational awareness in the context of autonomous transportation evolve over time?

RQ3: What are the apparent research gaps in the maritime domain in comparison with other transportation modes?

RQ4: What journals and scientific disciplines have contributed to the research domain on situational awareness for autonomous transportation systems?

RQ5: What cooperation patterns can be identified between institutions active in SA-related research focusing on maritime autonomous transport systems?

In order to answer these questions, a scientometric analysis methodology is applied to a dataset of research papers focusing on SA of autonomous vehicles across various modes of transportation. In the scientific transportation literature,

several studies utilizing a scientometric [22]–[24] or bibliometric [25] approach can be found. Nevertheless, the vast majority of those are related to one, selected transportation mode. These works are mainly focused on safety-related issues [26]–[28] and environmental protection [29]–[32].

Concerning transportation research, some authors have applied a scientometric approach to obtain insights into various aspects of the evolution of these domains of research. These however more generally address Intelligent Transportation Systems (ITS) and autonomous vehicles [1], [33] without a specific focus on situational awareness. In the maritime domain, scientometric analyses have also been conducted mainly concerning environmental protection and safety [27], [34], [35] as well as some very specific topics of port logistics [36], [37] and hydrodynamics [38]. To the authors' best knowledge, there are no scientometric or bibliometric attempts to the situational awareness problem to date, particularly in a transportation cross-domain setup.

The remainder of this article is organized as follows. Section 2 presents the materials and methods, setting the stage for obtaining the results, which are presented in Section 3. A discussion is provided in Section 4, whereas Section 5 concludes.

II. DATA AND METHODS

A. DATASET CONSTRUCTION

The approach to establishing a suitable dataset for subsequent scientometric analysis in this article follows the framework and associated best practices as elaborated in [39]. In line with this, the adopted research procedure is schematically depicted in Figure 1. This can be divided into three consecutive stages: i) preliminary research and query design; ii) data gathering process; iii) data filtering process. Web of Science (WoS) was used as a source of the papers' metadata. WoS is widely recognized as a reliable and high-quality database containing bibliographic information of scientific literature [40]. It was previously used in many scientometric [41], [42] as well as transportation studies [23]. The three stages of Figure 1 are briefly elaborated on next.

First, an exploratory search using various keywords related to the topic of the study was made. Afterwards, the initial results obtained using the selected keywords were manually validated. This allowed for considering various lexical forms of each keyword used and eventually preparation of an appropriate notation using wildcards. Subsequently, the query given below in WoS-syntax [43] was adopted. This search combines three subsets concentrated on the matters essential for the study, i.e., research on situational awareness in the context of autonomous transportation systems.

```
TS = ((semi-autonom* OR autonom* OR
automat* OR remot* OR unmanned OR
*actuated OR driverless OR uncrewed OR
crewless) AND (ship$ OR vessel$ OR
vehicle$ OR drone$ OR robot* OR craft$ OR
```

FIGURE 1. The procedure of data collecting and filtering.

```
train$ OR *bus$ OR car$ OR  *plane$)  AND
(situation* AND aware*))
```

This search query was adopted in the preliminary research stage to increase the relevance of the obtained dataset of the papers, as well as to reduce workload in the subsequent stages. The initial search was conducted in the first week of 2021 through the WoS Core Collection SCI-EXPANDED, SSCI, CPCI-S, and CPCI-SSH indexes. The topic search (TS) tag was used to provide a wide range of target fields among WoS, namely titles, abstracts, author keywords, and Key-Words Plus.

The second phase of the dataset construction process consists of performing a final search in the WoS database. This resulted in 2,043 papers. This number contains documents published up until the end of 2020. Early access papers (22 items) have been omitted.

Thirdly, an expert validation process has been performed to gather the final data sample containing solely the documents related to the topic of the research. This was made manually by the first and second authors, by browsing titles, abstracts, and keywords of the papers. This allowed considering the polysemy phenomenon (multiple meanings of a single word) for the keywords used in the search query. As some words may have different meanings despite the same spelling, it is necessary to reject the papers which were collected using the search query but are unrelated to the topic of the study. A prime example occurring in this paper is the word vessel. It can appear, for instance, in both the maritime (autonomous vessel, stand-on vessel, etc.) and medical (blood vessel, collateral vessel, etc.) professional lexicon. Therefore, only the documents that were related explicitly to SA and transportation utilizing intelligent vehicles were added to the final dataset after manual validation. The papers assessed as irrelevant due to their main topic (e.g., surgery, general psychology, surveillance/reconnaissance usage of autonomous agents) were removed at this stage.

The finally resulting data sample containing 659 articles was obtained, with characteristics as analyzed using the R package Bibliometrix [44], depicted in Table 1. It is seen that the articles originate from a very wide variety of journals,

TABLE 1. Descriptive information of the dataset on situation awareness research.

Description	Results
Documents	659
Sources (Journals, Books, etc.)	421
Keywords Plus (ID)	536
Author's Keywords (DE)	1580
Period	1995 - 2020
Average citations per document	6.956
Authors	2168
Author Appearances	2644
Authors of single-authored documents	34
Authors of multi-authored documents	2134
Single-authored documents	38
Documents per Author	0.304
Authors per Document	3.29
Co-Authors per Documents	4.01
Collaboration Index	3.44

with many authors contributing to the articles. This suggests that research on SA for automated transport is rather dispersed. Finally, the collaboration index is comparatively high, and articles are frequently authored by multiple authors, which may suggest that the research is performed through multidisciplinary teams.

As a final step, all papers are assigned to a specific transportation mode (road, rail, air, space, maritime). Papers belonging to more than one domain, or those which cannot be directly assigned to only one transportation mode were preliminarily marked as mixed. These are later assigned to each mode mentioned within the main body of the article text. The documents which were found relevant for this study but did not directly mention any mode of transportation (but

could be applied to SA in unmanned vehicles in general) were assigned to the general group.

B. ANALYSIS METHODS

Several scientometrics methods have been applied to obtain answers to the research questions listed in Section 1. As explained in more detail in [39], scientometric analysis concerns the application of quantitative methods to detect patterns, trends, and developments of a scientific body of work. These quantitative methods rely on the calculation of specific metrics, which are subsequently visualized or tabulated, allowing an interpretation of the contents, structure, and developments of aspects of interest concerning the research domain.

General publication trends associated with the research outputs (RQ1) are obtained using simple counts of publications per year and per transportation mode category. These are visualized using elementary diagrams. The high-level narrative patterns in and temporal evolution of the research domain (RQ2) are identified using the visualization of similarities technique [45]. This technique quantitatively analyzes similarities between the documents in the dataset, according to the selected data category, in this case, the author keywords. The VOSviewer software [46] determines citation networks in which the distance between the nodes indicates how closely these are linked, while the size of the nodes corresponds to the number of documents associated with that node. A colour overlay is applied to the nodes and links in this network, which provides insight into when the keywords appeared in the dataset. This is calculated based on the average publication year of the documents in which a keyword occurs. The gap in the SA-related research in the maritime domain compared to other research domains (RQ3) is identified by a cross-domain analysis of the top keywords. The identification of the journals and scientific disciplines contributing to the research domain of SA for autonomous transport systems (RQ4) is performed using the dual-map overlay analysis [47]. This map shows the interconnections between over 10,000 journals, which are visually clustered in regions representing scientific disciplines. The dual-map overlay enables one to obtain insights into how specific domains of knowledge (citing articles) are influenced by other domains (cited articles), where the latter can be regarded as the intellectual basis of the research domain in focus. This analysis is performed using CiteSpace [48] using an existing journal-based dual-map overlay [49]. The visualization is performed using VOSviewer [46]. Finally, the cooperation patterns between countries and institutions active in SA-related research for maritime autonomous transportation systems (RQ5) are identified by manually aggregating data on authors' affiliations.

III. RESULTS AND ANALYSIS

In this section, the results of the scientometric analysis are presented. Firstly, the high-level overview of publication trends among all transportation modes is elaborated. This has been made with respect to the breakdowns into relevant transportation modes. Secondly, the temporal evolution of the keywords is presented in order to determine the key research themes and focus topics, which have attracted the most attention in the scientific community. An analysis of keywords represented in the maritime domain compared to other transport modes is made to identify gaps and research opportunities in the maritime domain. Thence, the main journals and the information flow between scientific disciplines relevant to the research on SA of autonomous transport are identified. Finally, the collaboration between countries and institutions was investigated with a focus on the maritime domain.

A. GENERAL PUBLICATION TRENDS OF THE RESEARCH DOMAIN

The first scientific articles relevant to the current study are indexed in the WoS database in 1995, see Figure 2. Within the next 20 years, the number of articles increased by around 20 per year. In 2016, there was a major leap in the number of publications, reaching an annual number of about 80 articles. Throughout the period 2016-2019, the total number of scientific papers has tripled, from about 200 in 2015 to over 600 in 2019. In 2020, the number of research papers went down to 46, but this can be attributed, at least to some extent, to delays in WoS indexing.
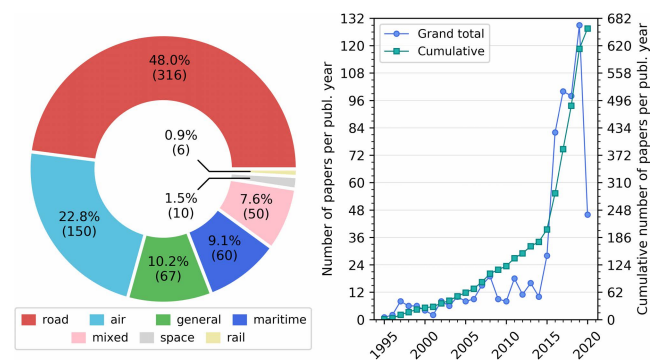
FIGURE 2. The breakdowns of the SA-related papers on autonomous systems, per transportation mode, and the temporal evolution of their total number.

This general yearly upward trend may be explained by the progressive technology development and maturing of autonomous technologies. Another explanation can be found in the overall increase in scientific output across academic disciplines [48], which has been observed as well in other subdomains of transportation (Modak *et al.* 2019) and safety research [37]. As much attention has recently been dedicated to autonomous vehicles both by industry and academia [49], the increased number of research papers related to situational awareness is not particularly surprising.

As can be seen in Figure 2 and Figure 3, almost half of all the research concerning SA related to autonomous transportation is focused exclusively on road transport (316 articles, 48%). A significant number of articles have also been devoted to studying the subject of aviation
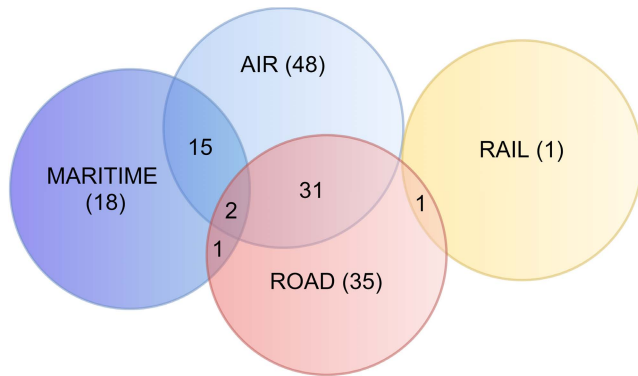
FIGURE 3. Breakdown of SA-related papers reporting on multiple transportation domains.

(150 papers, 22.8%). Around 50 (7.6%) articles concerned more than one form of transportation (the 'mixed' category). These articles were then assigned to the relevant modes concerned, based on information in the main body of text. Only 60 articles (9.1%) originate from the maritime application domain.

As can be observed from Figure 4, throughout the first 20 years, most focus on SA for autonomous systems was given in the aviation (93) and road (87) transportation modes. Since 2016, the 'road' category has consistently dominated the others, with the number of articles on this transport mode seeing an especially marked increase. The figure also shows that research activity on automation and situational awareness in the maritime domain dates back as far as 1995, but significant activity has only been given to the topic from 2016 onwards. This coincides with the period in which several major industrial and academic projects on autonomous vessels were implemented [50].

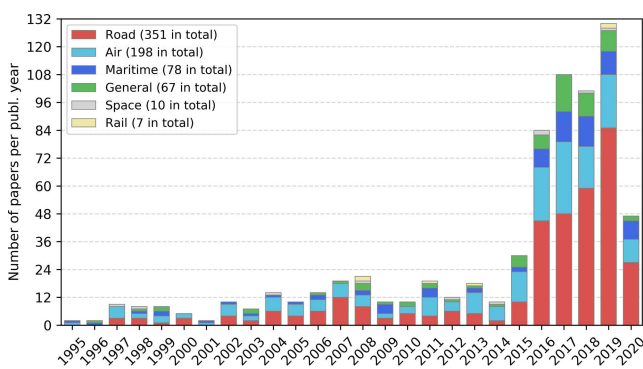**FIGURE 4.** Breakdown of the evolution of SA-related papers on autonomous systems, per transportation mode.

B. RESEARCH TOPICS ANALYSIS

As seen in Figure 5, the earliest occurring keywords, until 2012, concerned general terms such as 'human-robot interaction' (20 occurrences), 'unmanned (vehicle)' (16), 'supervision' (13), or 'robotics' (5). With time, some less robot-related and more automation- and autonomy-oriented keywords started to occur more frequently, such as: 'autonomy' (19), 'autonomous' (9), and 'autonomous systems' (8). Subsequently, research appears to have concentrated on aspects related to the specific modes of transportation. The early focus was mainly on aerial and underwater vehicles, while later on research concerning road vehicles dominated. This can be observed by inspecting terms like 'UAV (Unmanned Aerial Vehicle)' (65), 'autonomous/automated driving' (57), 'unmanned aerial systems' (18), 'autonomous underwater vehicle' (11), and 'conditionally automated driving' (6). From 2014 onwards, issues related to human presence in automated transportation systems have increasingly been explicitly explored, as can be observed through terms such as 'situation awareness' (79), 'human automation interaction' (28), 'human factor' (25), and 'human-machine interface' (12).

Looking beyond the generic terms related to automation, the human element, and specific terms within transport domains, several high-level research themes can be observed in the study domain. The first theme concerns situation prediction and data science, with terms such as 'scene perception', 'object detection', and 'deep learning'. A second important theme is collision avoidance, with terms such as 'obstacle avoidance', 'path planning', and 'swarm robotics'. The recent cluster associated with the road transport domain, with key terms around automated driving and take-over, contains a number of experiment-oriented focus topics related to 'driver behavior', 'driving simulation', 'eye-tracking', and 'secondary tasks'. It also contains psychological aspects related to trust in automation, with keywords such as 'trust', 'mental model', and 'acceptability'. Perhaps somewhat surprising are terms associated with the safety of autonomous transportation. For instance, 'safety' and' 'reliability' have only very recently become explicit focus issues in the domain.

C. RESEARCH GAPS IN THE MARITIME DOMAIN

As one of the key aims of this study is to identify the position of autonomy-related maritime situation awareness research in relation to other transportation modes, the most frequently found keywords used within the maritime domain are given separately in Table 2. Therein, the keywords are ranked by the frequency of their appearance in the documents.

Further analysis of the keyword occurrences within each transportation mode enabled listing the terms which appeared in other modes but are missing in the maritime category. Table 3 collates those, ranked by their occurrences. The table is limited only to the keywords with at least 8 occurrences. Some of the keywords listed are mode-specific (e.g., 'automated driving', 'unmanned aerial systems'), and their lack of appearance in the maritime domain is understandable. However, several aspects of automation and situation awareness can be related to the maritime domain, but have not yet received explicit research attention in this domain. This concerns topics such as 'human-computer interaction', 'situation prediction', 'take-over', and 'scene perception'. Methodological topics such as 'eye-tracking' and 'driving simulation',
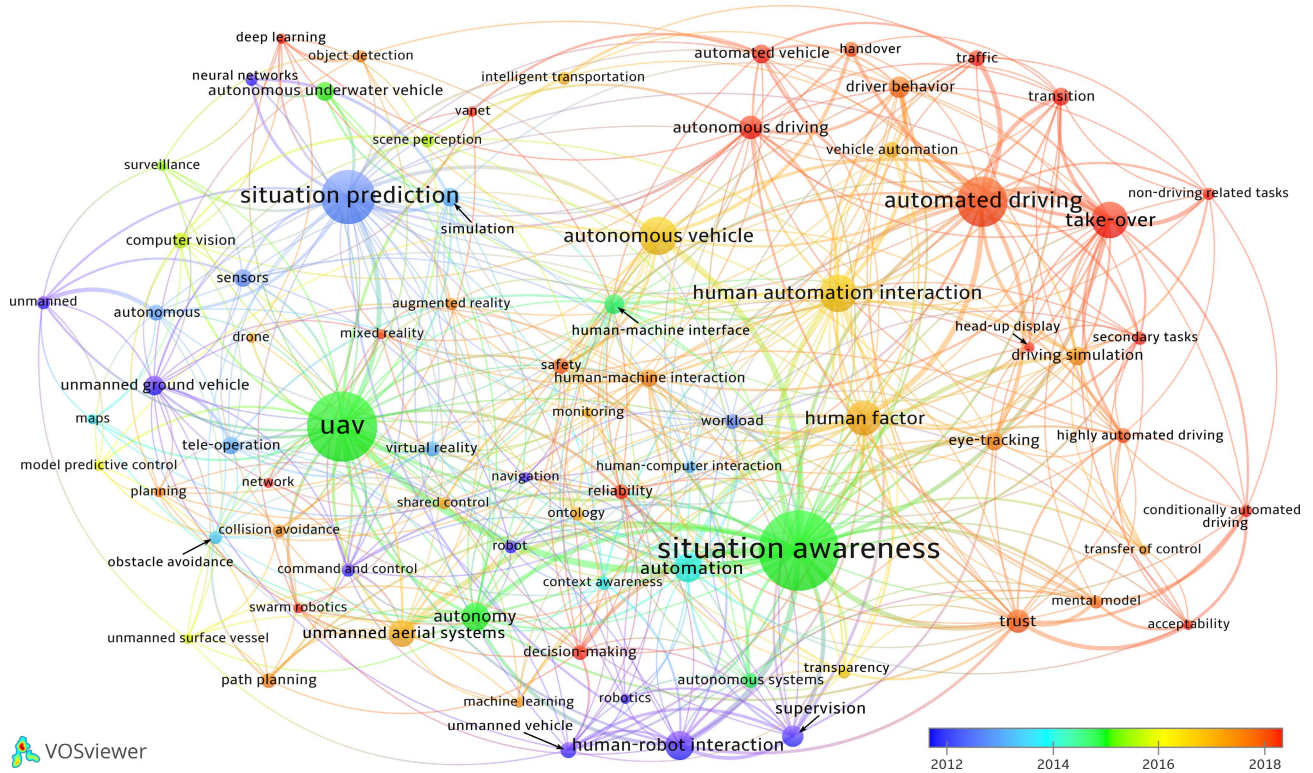
FIGURE 5. Keywords map of SA-focused research on autonomous transportation systems, color overlay according to the average publication year; dataset as in Section 2.1, terms with minimum 5 occurrences.

TABLE 2. The keywords used in maritime transportation-focused papers on SA and autonomy.

Keywords	Number of occurrences
autonomous underwater vehicle	12
UAV*	7
unmanned surface vessel	5
simulation	4
autonomous surface vessels	3
mission planning	3
shore control centre	3
unmanned underwater vehicles	3

Notes: * *UAV* (*Unmanned Aerial Vehicle*) was indexed as belonging to maritime due to their appearance in MIXED category papers concerning both SEA and AIR

and psychological issues of user and public acceptance, such as 'trust' have also not been given much attention in the maritime domain, and could therefore be given more focus.

D. JOURNALS' DISTRIBUTION AND INTELLECTUAL BASE OF THE RESEARCH DOMAIN

A dual-overlay analysis is made to identify highly productive and highly cited journals in the research domain on situational awareness for autonomous transport systems, as well as the associated scientific disciplines. The results are shown in Table 4 and Figure 6.

Table 4 shows that both the top-10 productive and cited scientific sources include journals and conference proceedings that focus on psychological aspects of SA as well as on the various technical dimensions. Journals such as 'Transportation Research Part F – Traffic Psychology and Behaviour', 'Human Factors', 'Accident Analysis and Prevention', 'Applied Ergonomics', and 'Transportation automation in transport is published in conference proceedings, of which the 'International Conference on Intelligent Transportation Systems' is the most influential.

This indicates that the rapidly developing field of automation in transport is widely discussed in face-to-face circumstances, with the associated results published and recognizable worldwide.

Figure 6 shows the scientific disciplines on the dual-overlay global science map by [49]. These disciplines are grouped based on a clustering of the underlying journals. The connecting lines between the citing domains (e.g., '1. mathematics, systems, mathematical') and the cited domains (e.g., 'a. systems, computing, computer') provide insights into which scientific disciplines are represented in the research domain, and from which sources these draw their knowledge to create new applications and knowledge. Hence, this dual map overlay analysis provides insights into the

TABLE 3. Overview of top-cited and top-productive journals.

Keywords	Number of occurrences
automated driving	42
human-computer interaction	40
situation prediction	39
take-over	30
driver behavior	17
autonomous driving	15
eye-tracking	15
trust	15
supervision	14
unmanned aerial systems	13
driving simulation	11
intelligent transportation	11
automated vehicle	10
safety	10
transition	9
vehicle automation	9
handover	8
highly automated driving	8
robot	8
scene perception	8
traffic	8

intellectual basis of the domain of SA for automation in transport domains. The figure indicates that in this domain, psychology- and technology-related research mainly influences the same field through its citation patterns. Only some knowledge from psychology journals is used (cited) in the context of technology journals, but there does not appear to be a reciprocal relationship between these. This can be inferred from the thick lines (associated with high z-scores) between 'g. psychology, education, social' to '6. Psychology, education, health' and 'a. systems, computing, computer' to '1. mathematics, systems, mathematical' in the lower figure, and the weaker lines from 'g. psychology, education, social' to '1. mathematics, systems, mathematical' in the top figure. These results suggest that tighter integration between these fields could be beneficial to further developing the application domains.

Table 5 depicts the top-10 most-cited documents within the sample along with their scientific categorization as per WoS categories. Based on general scientometric practices [39], these articles can be seen as the key drivers for the domain in focus. These can serve as a good starting point for early career researchers and industrial developers to understand and explore influential developments and

knowledge underlying the field. It is seen that the most-cited documents are associated with psychology-related domains rather than engineering ones. The most significant WoS categories include 'Ergonomics', 'Behavioral Sciences', 'Applied Psychology', and 'Industrial Engineering', with categories related to transportation and engineering less represented. It is noteworthy that the more recently published articles have on average received more citations per year than the older ones, indicating the fast development of the field in recent years and a tendency to focus on recently published literature.

E. RESEARCH COLLABORATION

Usually, industrial and scientific work for advanced technology development and work on understanding human cognition is executed in public or private research institutions. Both institutional and national policies affect research trends and outputs [51]. It is therefore interesting to explore research collaborations between countries/regions and institutions, to identify leading contributors, and facilitate further collaborations. In particular, countries and institutions focusing on transport domains where the research has not yet been extensively developed can benefit from insights related to research collaborations to define policies and find research partners, see e.g., Cheng and Ouyang (2021). Referring to RQ5, these country-related and institutional trends are commonly quantified by investigating the affiliations of the authors of the papers [39].

Table 6 lists the countries contributing to the papers related to the work on situational awareness for autonomous systems in the maritime domain. As can be seen, the highest contributor is the United States of America, whose institutions have contributed to 27 out of 78 maritime papers in total. The second-ranked contributor was the United Kingdom with 12 documents, and Norway with 11. Only countries with at least three papers affiliated are listed.

Figure 7 depicts the country-level collaborations. The order of the countries is based on the ranking presented in Table 7. The numbers on the main diagonal state how many times the papers originated from an institution or institutions related solely to a certain country. As can be seen, institutions based in the USA tended to work either by themselves or cooperate with other US-based ones (22 times out of 27). The Norwegian-based institutions followed the same trend (8 documents out of 11). The country with the highest diversity in terms of cooperating institutions was Germany, having links with institutions from 8 different countries. It is of note that countries with relatively few papers assigned to their institutions published only in collaboration with institutions from other countries, for instance, France, Brazil, Bulgaria, Malaysia, Singapore, and Spain. Moreover, the most productive countries seldom cooperate with each other but rather involve less active ones in the cooperation network.

Table 7 depicts the contribution of specific institutions to SA-related research on autonomy in the maritime domain.
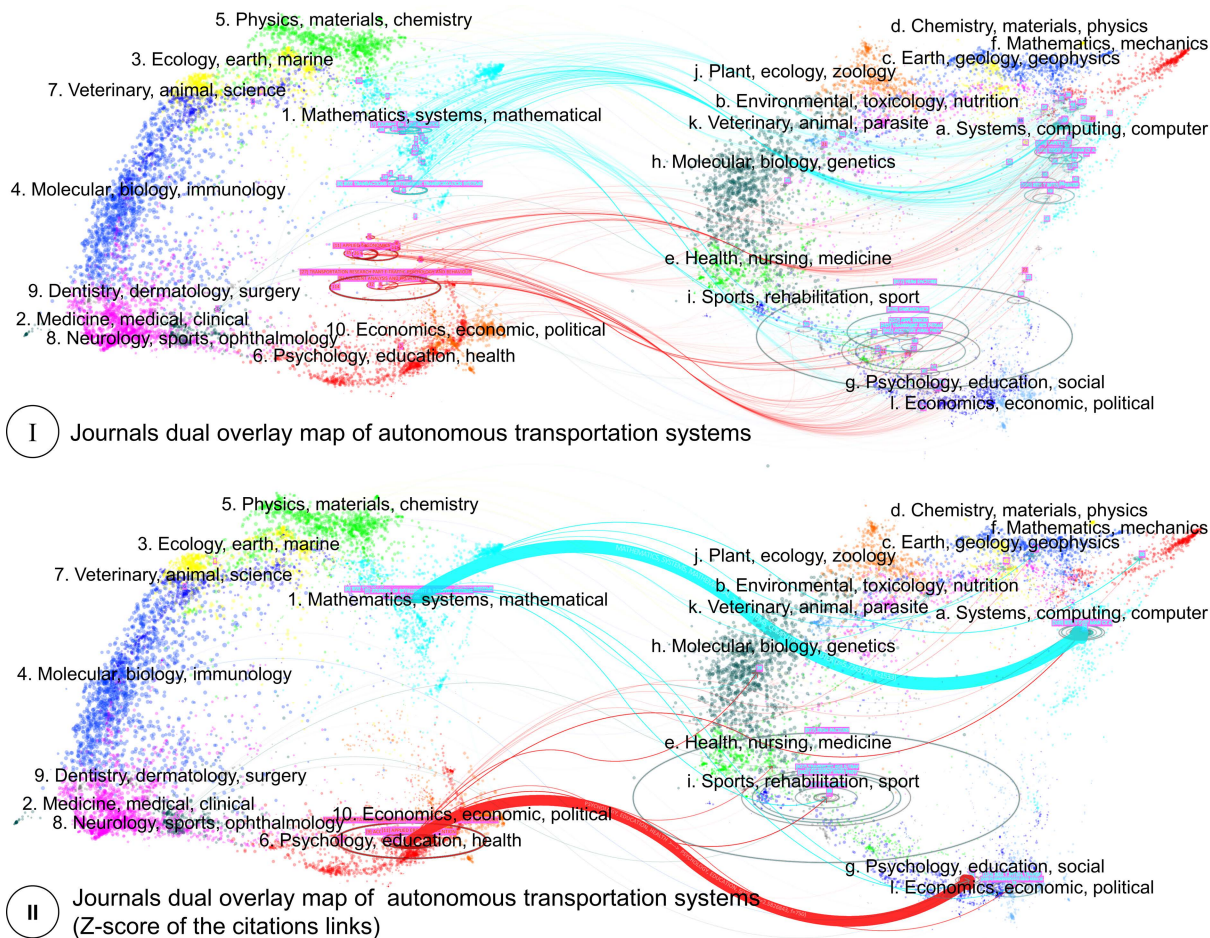
TABLE 4. The keywords used in maritime transportation-focused papers on SA and autonomy.

Highly productive journals	NP	Highly cited journals	TC
Transportation Research Part F – Traffic Psychology and Behaviour	27	Human Factors	501
Human Factors	12	Transportation Research Part F – Traffic Psychology and Behaviour	308
2018 21st International Conference on Intelligent Transportation Systems (ITSC)	11	Accident Analysis and Prevention	231
Applied Ergonomics	11	Transportation Research Part C – Emerging Technologies	178
IFAC Papers Online	11	Journal of Field Robotics	173
Ergonomics	10	Ergonomics	138
Accident Analysis and Prevention	9	Proceedings of the IEEE	136
IEEE Transactions on Intelligent Transportation Systems	8	Applied Ergonomics	132
2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)	7	2004 IEEE International Conference on Systems, Man & Cybernetics, Vols. 1-7	107
2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)	7	IEEE Transactions on Systems Man and Cybernetics Part A – Systems and Humans	84

Notes: NP = Number of publications; TC = Total number of citations.

TABLE 5. Overview of the most cited documents and their WoS characteristics.

#	Title	Reference	Journal	PY	TC	CpY	Behavioral Sciences	Industrial Engineering	Ergonomics	Applied Psychology	Psychology	Transportation Science & Technology	Public, Env. & Occupational Health	Social Sciences, Interdisciplinary	Transportation	Robotics	Automation & Control Systems	Computer Science: Artificial Intelligence	Computer Science: Cybernetics	Computer Science: Software Engineering	Electrical & Electronic Eng.
1	Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control	[52]	Human Factors	2007	156	12.0	x	x	x	x	x										
2	Highly Automated Driving, Secondary Task Performance, and Driver State	[53]	Human Factors	2012	136	17.0	x	x	x	x	x										
3	Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions	[54]	Transportation Research Part C	2013	125	17.9						x									
4	What determines the take-over time? An integrated model approach of driver take-over after automated driving	[55]	Accident Analysis and Prevention	2015	119	23.8			x				x	x	x						
5	Cooperative use of unmanned sea surface and micro aerial vehicles at Hurricane Wilma	[56]	Journal of Field Robotics	2008	109	9.1										x					
6	"Where am I?" Acquiring situation awareness using a remote robot platform	[57]	2004 IEEE Int. Conf. on Systems, Man & Cybernetics	2004	105	6.6										x	x	x	x		
7	Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles.	[58]	Presence-teleoperators and Virtual Environments	2002	84	4.7													x	x	
8	From Here to Autonomy: Lessons Learned From Human-Automation Research	[59]	Human Factors	2017	79	26.3	x	x	x	x											
9	Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving	[60]	Accident Analysis and Prevention	2016	78	19.5			x				x	x	x						
10	Message Passing Algorithms for Scalable Multitarget Tracking	[61]	Proceedings of the IEEE	2018	73	36.5															x
	Total						3	3	5	3	2	1	2	2	2	2	1	1	2	1	1

Notes: PY: publication year; TC: total citations as of early January 2021; CpY: citations per year

Note that only institutions contributing at least 2 papers are listed. Each institution has its country of affiliation added in the second column. Out of those, the highest contributor was the Norwegian University of Science & Technology with eight papers, followed by the United States Department of Defense contributing five documents in total, and Heriot-Watt

FIGURE 6. Dual-map overlay of SA-related research for autonomous transport systems.

University in the United Kingdom with four. It is noteworthy that this differs from the USA being ranked #1 as a whole. Thus, it indicates that the maritime SA-related research is distributed across multiple institutions in the USA, whereas in Norway, as in most other countries, the research is more concentrated in specific institutions.

Figure 7 depicts the country-level collaborations. The order of the countries is based on the ranking presented in Table 7. The numbers on the main diagonal state how many times the papers originated from an institution or institutions related solely to a certain country. As can be seen, institutions based in the USA tended to work either by themselves or cooperate with other US-based ones (22 times out of 27). The Norwegian-based institutions followed the same trend (8 documents out of 11). The country with the highest diversity in terms of cooperating institutions was Germany, having links with institutions from 8 different countries. It is of note that countries with relatively few papers assigned to their institutions published only in collaboration with institutions from other countries, for instance, France, Brazil, Bulgaria, Malaysia, Singapore, and Spain. Moreover, the most productive countries seldom cooperate with each other but rather involve less active ones in the cooperation network.

IV. DISCUSSION
A. REFLECTIONS ON FINDINGS OF THE SCIENTOMETRIC ANALYSES

The performed research indicates that the studies on situation awareness of autonomous vehicles are gaining popularity likely due to the ongoing development of the technology. These developments occur in all modes of transportation, but some are advancing faster. In particular in road and air transportation, with the maritime domain seeing a recent surge in activity as well.

On the other hand, situational awareness of autonomous trains does not develop as fast. This might be caused by the relative simplicity of this mode where it can be designed in complete spatial isolation from other uses of the land, just as is the case of subway systems. Therein, the need for gaining and maintaining situational awareness is likely regarded as limited. A similar tendency may be observed in the space category. Despite this type of transportation being much more advanced than rail, as the environment in which a vehicle operates, not all researchers consider space as a branch of transportation. For instance, the US Bureau of Transportation Statistics does not provide any data on extraterrestrial transportation, likely because of its marginal role [62]. Therefore,

TABLE 6. Country-level affiliations of authors of maritime transportation papers on SA and autonomy.

Country or region	No. of papers
USA	27
UK	12
Norway	11
Australia	7
Portugal	7
Germany	6
Netherlands	5
Italy	4
China	3
Estonia	3
South Korea	3
Sweden	3

TABLE 7. Country-level affiliations of authors of maritime transportation-focused papers on SA and autonomy.

Organization	Country	Papers
Norwegian University of Science & Technology	Norway	8
US Department of Defense	USA	5
Heriot-Watt University	UK	4
Tallinn University of Technology	Estonia	3
Delft University of Technology	Netherlands	3
Portuguese Army	Portugal	3
Universidade do Porto	Portugal	3
Rolls-Royce	UK	3
SeeByte	UK	3
University of Washington	USA	3
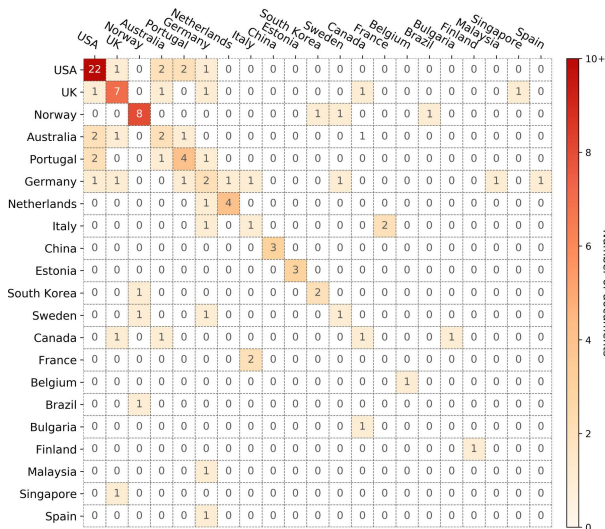
FIGURE 7. Collaborations within the maritime domain between institutions by country active in the research domain on SA. Note that the total cooperation number may be greater than the total number of papers, as some papers are written by authors affiliated with institutions located in more than two countries.

many works about SA in space transportation could be omitted, which probably disrupts the share of paper belonging to a particular transportation mode in time.

The following subsections provide summaries and reflections on the research questions raised in the introduction.

1) GENERAL PUBLICATION TRENDS

The research on situational awareness for autonomous transport systems is dominated by research focusing on road transport. It has seen a great increase in the number of papers published since 2016. It is noteworthy that Tesla Autopilot, the most famous driverless control system, was first introduced in 2014, although with limited capabilities [63]. This industrial development, which may make the prospects

for autonomous cars a feasible reality in the foreseeable future, may explain this sudden marked increase. The disproportionate number of articles on SA for road vehicle autonomy may also be explained by the fact that it is the most common transport mode, where large profits may be expected if high levels of autonomy are safely achieved [64].

Only a fraction (7.6%) of scientific documents published considered more than one mode of autonomous transportation. This shows that there is much room for the exchange of ideas and research findings between the associated scientific communities. The scholarly work focusing on the maritime domain has seen a marked increase since 2016, but overall represents a relatively small body of work compared to road and air transportation.

2) RESEARCH TOPICS ANALYSIS

The research of situation awareness of autonomous vehicles in general developed from investigating very general terms to more domain-specific and human-oriented. This may indicate a developing specialization of the research and a growing interest in investigating human's role in autonomous transportation. The former is supported by the finding that a relatively low number of research papers address more than one mode of transportation with regard to its autonomy and SA. Situation awareness, which is in itself a generic term, is studied separately for the particular modes of transportation which can reflect the fact that those that perform the research are focused on their respective domains.

It is of note that the very purpose of implementing autonomy in transportation was to limit human involvement [65]. Paradoxically, the more developed autonomous (sometimes referred to as unmanned, driverless, or crewless) vehicles are and the less they need humans to operate, the more research is devoted to analysing the role humans play in the system. This can indicate the importance of the concepts known

as ironies of automation [66], [67] or the widely discussed lumberjack effect [68], [69]. These underline the potential negative effects that increased automation (or autonomy) can have on the safety performance of the system. In this context, it is noteworthy that only very recently, the focus has been explicitly directed to safety in relation to automation, situational awareness, and transport.

3) RESEARCH GAPS IN THE MARITIME DOMAIN
SA-oriented research in the maritime domain is focused on technical rather than psychological or cognitive processes. Some other issues have not yet been investigated in maritime, or at least results of such elaborations have not been published in WoS-indexable documents.

As can be seen through the comparison of Tables 2 and 3, issues investigated within the maritime domain and in other transportation modes are quite different. It is sometimes raised that the maritime domain lags behind other modes in terms of research on autonomy and that it therefore can learn from these more developed domains [21]. However, the results indicate that this has not yet been put into practice. This may be because the maritime domain is so different that these insights are difficult to implement, or due to more practical reasons such as lack of appropriate funding sources or other incentives to stimulate such knowledge exchange.

As for situation awareness itself, it can be noticed that in the maritime domain it was seldom associated with the keywords related to cognitive processes or human-oriented terms. Rather, the analysis of the keywords suggests that it was studied along with more technical or general issues. Even though humans are often blamed for causing accidents [70], [71] research on their actual performance is rather scarce [72]. Meanwhile, outside the maritime domain, SA was more often studied in relation to issues concerning the human operator, such as human-computer interaction, situation prediction, and scene perception [73], [74], see Tables 2 & 3.

It is of note that autonomy in the maritime domain can take many forms. On one hand, there are small-scale, low endurance industrial or scientific Autonomous Underwater Vehicles (AUV). On the other, concept designs of large-scale, ocean-going Maritime Autonomous Surface Ships (MASS) are being pursued for commercial shipping. Apart from differences in operational and design aspects, the latter are still at a prototype phase at best [75], while the former are used extensively by various stakeholders [76]. The earlier focus on AUV and the more recent attention to MASS may in part explain why there has been less focus on human-in-the-loop experiments compared to the road transport domain, and less attention to issues such as trust in autonomy.

The observed disparity of keywords between the considered transportation modes may arise from at least the following: (1) a different emphasis on the research priorities as determined by stakeholders or (2) intrinsic differences in the operational aspects of particular transportation modes. For instance, it is postulated that a large portion of maritime accidents involves human-centred causal factors [71], [77], but human-oriented aspects of SA are not as commonly investigated as in other transport modes.

The comparative dearth of research on the human element in the context of SA for autonomous maritime systems could also originate from it being easier to examine a large number of human operators for more common modes such as road transport, and the lower costs of simulator test centres for those. Conversely, it may be more difficult to find a representative sample of highly qualified seafarers with whom to perform tests concerning SA and human-oriented concepts or study themes. Perhaps the perceived need to study human perception and situational awareness in road transport is also higher because of the comparatively higher risk to human life this transport mode entails, especially in mixed traffic situations with pedestrians and cyclists. In contrast, operators in the maritime domain are professionals usually navigating vessels in areas with less direct human activity. Another aspect may be related to the operational conditions of maritime transportation. As typical ship speeds are significantly lower than during car driving, the research may be more focused on ensuring the reliability of devices and technical aspects in general than on SA itself, due to the longer operator's response time.

4) CROSS-DOMAIN TRANSFER OF KNOWLEDGE
As can be concluded from Figure 6, the information flow of scientific findings related to situation awareness in autonomous transportation systems is rather unidirectional. The analysis of citation trends indicates that technology-oriented research draws from humanities (i.e., psychology and ergonomics) and is propelled by them. This can indicate two issues: (1) results of generic, human-oriented studies can be applied to at least some of the transportation modes, and more generally that (2) conducting basic research on human psychology has a direct effect on the development of applicable technologies. The latter is of particular importance in terms of shaping the research funding policies on various levels of governance. As it appears, some safety-critical aspects (SA) of technologies that already are or will soon be market-ready (autonomous transport) could not be sufficiently investigated solely by their designers and developers. Building on the foundations laid by those involved in basic research proves crucial yet again. This proves that basic research shall be included in research strategies as it is at least as important for the development of future technologies as applied sciences.

On the other hand, there is little feedback from technology-oriented research to the fundamental one oriented on studying the situation awareness itself. This may suggest that although the psychology-oriented research is being conducted (at least to some extent) in separation from technological advancements, the latter can still benefit from its achievements. However, a stronger interaction between the applied technology development domain and the scientific disciplines concerned with psychology could be beneficial, both to further advance

applications and to gain new insights on situational awareness and to test its associated theories in practical settings.

From Figure 2 and Figure 3, it is seen that several documents deal with multiple modes of transportation as well as very general ones, which indicates that at least some issues can be shared or transferred from one domain to another. However, such cross-domain knowledge exchange remains relatively unexplored, indicating possibilities for future research and technical development. It must be noted however that the transportation modes are intrinsically different due to their operational contexts, so some findings, methods, or test setups may not be easily transferable. Nevertheless, the development of autonomous transport systems (including maritime ones) may benefit if its stakeholders include cross-disciplinary cooperation in their agenda. Herein, certain actions might be taken not only by individual researchers, but also on an institutional level through e.g., cooperation agreements.

5) RESEARCH COLLABORATION IN THE MARITIME DOMAIN

The research cooperation in the SA aspects of maritime autonomous vehicles appears to be very limited. This may be caused by the fact that the scientific literature on autonomous maritime systems is less extensive than for instance for autonomous cars. The research into maritime autonomy has not yet sufficiently developed to study more detailed aspects of situational awareness in relation to various technological developments. One of the reasons may be the scarcity of operational research objects. Once this happens, more cooperation may be needed to solve more complex problems, or to perform empirical tests in simulator settings.

The results of Table 6 unsurprisingly indicate that most of the SA-related studies are performed in countries which are widely regarded as maritime nations. Among these are the United States of America, the United Kingdom, and Norway. Although the former is not a shipping power in terms of the number of merchant ships registered or owned [78], it remains a major naval power with a significant R&D budget. Notably, the US Department of Defense is the second-most productive institution in SA-related research on autonomous transport, see Table 7. This interest is however largely motivated by research on UAVs, rather than on MASS.

Further inspecting Table 7, it is observed that there are quite many industrial organizations listed, as well as several military-affiliated research organizations. Some of these are even more productive than some universities listed in the table, which is different from other scientometric work on transportation [22] and safety [39], which is more strongly academia-focused. This may indicate the relevance of the SA-related research to the practical implementation of autonomous transport technologies. The total contribution of the authors affiliated with these institutions may in fact be larger as companies, due to their nature, work on the development of commercial products. Therefore, the associated authors presumably cannot publish all details of the solutions proposed or raise all issues related to the problem so as

to not expose them to the competitors or negatively affect intellectual property rights. A similar phenomenon may affect the number of papers published by the authors affiliating military institutions. Those also cannot publicly present all of their insights to maintain strategic advantages.

Just as with cross-disciplinary cooperation and knowledge transfer, similar solutions can be sought within the maritime domain, e.g., through enhanced cooperation between research institutions. In particular, those not being burdened with corporate or defence-related bans on the dissemination of their results.

B. LIMITATIONS

Like every study, the results of the presented work should be seen in light of some limitations associated with the method applied. First, there are uncertainties related to the process of data gathering, explained in Section 2.1. Among these are choices made in the design of the search query, incomplete coverage of all academic work by the WoS database, indexing criteria that exclude some of the potentially relevant papers, as well as indexing delays in the WoS.

Furthermore, uncertainties can be related to the application of data analysis methods. The procedure included manual extraction of certain data related to the papers in the sample and as such involves a certain degree of subjective judgment. This especially concerns the assignment of the papers to the relevant mode of transportation. However, as this analysis was done by transport domain experts, the potential for misjudgment is rather low.

Another limitation can be attributed to the research topics analysis, shown in Section 3.2. Herein, the keywords were used as input as declared by the authors of the original paper. This may cause some topics to be missing from the current analysis as they were touched upon in the original papers but considered marginal by their authors. The latter would rather focus on the main findings and topics of their research and not list others in the list of keywords. Such limitations are typical of scientometric analysis, see e.g. [39]. Hence, the presented scientometric analysis is primarily intended to provide a high-level overview of the research domain. Specific aspects of this domain, such as issues related to specific technologies, methods, or experimental studies can only be investigated through traditional review methods.

C. FUTURE WORK

The potential future works may include identifying ways of enhancing the cross-modal transfer of SA-related research findings. Obviously, it is likely that not all of these can be transferred directly, but it is worth exploring in more depth what concepts, ideas, and methods could be applied in similar domains. From a maritime perspective, the potential for borrowing ideas and findings already explored in other modes could focus on topics such as take-over, trust, supervision, and perhaps surprisingly, safety. Reflecting on the limitations of scientometric analyses to provide in-depth insights into particular topics, it could therefore be beneficial to write

state-of-the-art reviews of these topics in the context of SA and automation across transport modes, to advance these topics based on more detailed findings.

Another general potential for growth of the understanding of situation awareness concept within autonomous transport systems lies within closer cooperation between basic and applicable research scientists. Apparently, the latter uses the results obtained by the former, but the reverse does not seem to be the case. Such research could more closely couple the research in psychology or ergonomics with the advances made in technology by investigating human-oriented aspects of technologies which actually being developed, or which are already operating in real environments. In return, a deeper understanding of the basics of human performance within highly automated systems including SA could foster technological developments and improve the safety performance of autonomous transportation. This could be of particular importance within the maritime transport domain where the technology is still relatively new and requires an increased research effort.

From a bibliometric perspective, the future effort can be directed into identifying the amount of effort dedicated to the situation awareness of (1) autonomous vehicles themselves and (2) humans supervising them and expected to step in in case of an emergency.

V. CONCLUSION

The objective of the presented study was to obtain high-level insights into the developments and trends related to situation awareness as a safety-critical feature of autonomous transportation systems. Special attention was paid to maritime transportation as this industry is rapidly moving towards implementing full-scale, commercially feasible carriers. This objective was achieved by an application of a bibliometric analysis of available scientific literature indexed in the Web of Science Core Collection.

The results indicate that most of the research related to situation awareness is devoted to road transportation. This field has been growing fast in recent years and is responsible for the overall increase in the number of research papers on autonomous situation awareness. Throughout the time, the detailed research interests varied until they became mode-specific and human-oriented. The latter is quite surprising as the purpose of autonomous vehicles was to limit human involvement in the first place. Several topics which have already received scientific attention in other transport modes could be further investigated in the maritime domain, including take-over, trust, supervision, and safety. The findings furthermore suggest that knowledge gained through fundamental research involving psychology has been used to a reasonable degree in technology development and applied research. However, there is much opportunity to use insights from the technical application domains to reflexively inform the basic research domains. This finding also confirms the need for investing in basic research before applications and technology developments can be implemented in practice.

Finally, it was found that the cooperation links between institutions and countries active in maritime-related, human-oriented research are rather weak.

The results can be relevant to research institutions already active in the investigation of situation awareness of autonomous vehicles, as well as scholars willing to join the effort. Several avenues for future scholarship are identified as well, in line with the aim of this article to provide high-level insights into the research domain.

DECLARATIONS OF INTEREST STATEMENT
The authors declare no conflicting interests.

CREDIT
Krzysztof Bogusławski: Conceptualization, Investigation, Resources, Data curation, Writing - Original Draft

Jan Nasur: Conceptualization, Investigation, Resources, Data curation, Writing - Original Draft

Jie Li: Conceptualization, Methodology, Software

Mateusz Gil: Conceptualization, Writing - Original Draft, Visualization

Krzysztof Wróbel: Conceptualization, Writing - Original Draft, Supervision

Floris Goerlandt: Conceptualization, Validation, Writing – Original Draft, Writing - Review & Editing

REFERENCES

[1] T. H. Rashidi, A. Najmi, A. Haider, C. Wang, and F. Hosseinzadeh, "What we know and do not know about connected and autonomous vehicles," *Transportmetrica A, Transp. Sci.*, vol. 16, no. 3, pp. 987–1029, Jan. 2020.

[2] P. A. Hancock, "Some pitfalls in the promises of automated and autonomous vehicles," *Ergonomics*, vol. 62, no. 4, pp. 479–495, Apr. 2019.

[3] F. Goerlandt, "Maritime autonomous surface ships from a risk governance perspective: Interpretation and implications," *Saf. Sci.*, vol. 128, Aug. 2020, Art. no. 104758.

[4] F. Favarò, S. Eurich, and N. Nader, "Autonomous vehicles' disengagements: Trends, triggers, and regulatory limitations," *Accident Anal. Prevention*, vol. 110, pp. 136–148, Jan. 2018.

[5] C. A. Thieme and I. B. Utne, "Safety performance monitoring of autonomous marine systems," *Rel. Eng. Syst. Saf.*, vol. 159, pp. 264–275, Mar. 2017.

[6] P. Singh, M. A. Dulebenets, J. Pasha, E. D. R. S. Gonzalez, Y.-Y. Lau, and R. Kampmann, "Deployment of autonomous trains in rail transportation: Current trends and existing challenges," *IEEE Access*, vol. 9, pp. 91427–91461, 2021.

[7] L. E. van Cappelle, L. Chen, and R. R. Negenborn, "Survey on short-term technology developments and readiness levels for autonomous shipping," in *Proc. Int. Conf. Comput. Logistics*, 2018, pp. 106–123.

[8] K. Wróbel, M. Gil, P. Krata, K. Olszewski, and J. Montewka, "On the use of leading safety indicators in maritime and their feasibility for maritime autonomous surface ships," *Proc. Inst. Mech. Eng. O, J. Risk Reliab.*, Jul. 2021, Art. no. 1748006X2110276.

[9] R. McCall, F. McGee, A. Mirnig, A. Meschtscherjakov, N. Louveton, T. Engel, and M. Tscheligi, "A taxonomy of autonomous vehicle handover situations," *Transp. Res. A, Policy Pract.*, vol. 124, pp. 507–522, Jun. 2019.

[10] P. Koopman and M. Wagner, "Autonomous vehicle safety: An interdisciplinary challenge," *IEEE Intell. Transp. Syst. Mag.*, vol. 9, pp. 90–96, 2017, doi: 10.1109/MITS.2016.2583491.

[11] H. Ghaderi, "Autonomous technologies in short sea shipping: Trends, feasibility and implications," *Transp. Rev.*, vol. 39, no. 1, pp. 152–173, Jan. 2019.

[12] M. R. Endsley, "Toward a theory of situation awareness in dynamic systems," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 37, pp. 32–64, Sep. 1995.

[13] N. A. Stanton, P. R. G. Chambers, and J. Piggott, "Situational awareness and safety," *Saf. Sci.*, vol. 39, no. 3, pp. 189–204, Dec. 2001.

[14] E. M. Lappalainen, O. Seppänen, A. Peltokorpi, and V. Singh, "Transformation of construction project management toward situational awareness," *Eng., Construct. Archit. Manage.*, vol. 28, no. 8, pp. 2199–2221, Jul. 2021.

[15] S. Yan, K. Yao, and C. C. Tran, "Using artificial neural network for predicting and evaluating situation awareness of operator," *IEEE Access*, vol. 9, pp. 20143–20155, 2021.

[16] M. R. Endsley, "Situation awareness misconceptions and misunderstandings," *J. Cogn. Eng. Decis. Making*, vol. 9, no. 1, pp. 4–32, Mar. 2015.

[17] X. Demeulenaere, "How challenges of human reliability will hinder the deployment of semi-autonomous vehicles," *Technol. Forecasting Social Change*, vol. 157, Aug. 2020, Art. no. 120093.

[18] M. R. Endsley, "The limits of highly autonomous vehicles: An uncertain future: Commentary on Hancock (2019) some pitfalls in the promises of automated and autonomous vehicles," *Ergonomics*, vol. 62, no. 4, pp. 496–499, Apr. 2019.

[19] C. Kooij, A. P. Colling, and C. L. Benson, "When will autonomous ships arrive? A technological forecasting perspective," in *Proc. Int. Nav. Eng. Conf. Exhib. (INEC)*, vol. 14, Oct. 2018, pp. 1–11.

[20] I. Y. Noy, D. Shinar, and W. J. Horrey, "Automated driving: Safety blind spots," *Saf. Sci.*, vol. 102, pp. 68–78, Feb. 2018.

[21] M. Wahlström, J. Hakulinen, H. Karvonen, and I. Lindborg, "Human factors challenges in unmanned ship operations—Insights from other domains," in *Proc. 6th Int. Conf. Appl. Hum. Factors Ergonom.*, vol. 3, 2015, pp. 1038–1045.

[22] N. M. Modak, J. M. Merigó, R. Weber, F. Manzor, and J. D. D. Ortúzar, "Fifty years of transportation research journals: A bibliometric overview," *Transp. Res. A, Policy Pract.*, vol. 120, pp. 188–223, Feb. 2019.

[23] L. Sun and Y. Yin, "Discovering themes and trends in transportation research using topic modeling," *Transp. Res. C, Emerg. Technol.*, vol. 77, pp. 49–66, Apr. 2017.

[24] R. M. Gandia, F. Antonialli, B. H. Cavazza, A. M. Neto, D. A. D. Lima, J. Y. Sugano, I. Nicolai, and A. L. Zambalde, "Autonomous vehicles: Scientometric and bibliometric review," *Transp. Rev.*, vol. 39, no. 1, pp. 9–28, Jan. 2019.

[25] R. L.-T. Cho, J. S. Liu, and M. H.-C. Ho, "The development of autonomous driving technology: Perspectives from patent citation analysis," *Transp. Rev.*, vol. 41, no. 5, pp. 685–711, Jan. 2021.

[26] S. Fu, F. Goerlandt, and Y. Xi, "Arctic shipping risk management: A bibliometric analysis and a systematic review of risk influencing factors of navigational accidents," *Saf. Sci.*, vol. 139, Jul. 2021, Art. no. 105254.

[27] M. Luo and S.-H. Shin, "Half-century research developments in maritime accidents: Future directions," *Accident Anal. Prevention*, vol. 123, pp. 448–460, Feb. 2019.

[28] X. Zou and H. L. Vu, "Mapping the knowledge domain of road safety studies: A scientometric analysis," *Accident Anal. Prevention*, vol. 132, Nov. 2019, Art. no. 105243.

[29] X. Tian, Y. Geng, S. Zhong, J. Wilson, C. Gao, W. Chen, Z. Yu, and H. Hao, "A bibliometric analysis on trends and characters of carbon emissions from transport sector," *Transp. Res. D, Transp. Environ.*, vol. 59, pp. 1–10, Mar. 2018.

[30] L. Wu, W. Wang, P. Jing, Y. Chen, F. Zhan, Y. Shi, and T. Li, "Travel mode choice and their impacts on environment—A literature review based on bibliometric and content analysis, 2000–2018," *J. Cleaner Prod.*, vol. 249, Mar. 2020, Art. no. 119391.

[31] J. D. Ampah, A. A. Yusuf, S. Afrane, C. Jin, and H. Liu, "Reviewing two decades of cleaner alternative marine fuels: Towards IMO's decarbonization of the maritime transport sector," *J. Cleaner Prod.*, vol. 320, Oct. 2021, Art. no. 128871.

[32] P. Kołakowski, M. Gil, K. Wróbel, and Y. Ho, "State of play in technology and legal framework of alternative marine fuels and renewable energy systems: A bibliometric analysis," *Maritime Policy Manag.*, vol. 49, no. 2, pp. 236–260, Sep. 2021.

[33] A. Faisal, T. Yigitcanlar, M. Kamruzzaman, and A. Paz, "Mapping two decades of autonomous vehicle research: A systematic scientometric analysis," *J. Urban Technol.*, vol. 28, nos. 3–4, pp. 45–74, Aug. 2020.

[34] M. Gil, K. Wróbel, J. Montewka, and F. Goerlandt, "A bibliometric analysis and systematic review of shipboard decision support systems for accident prevention," *Saf. Sci.*, vol. 128, Aug. 2020, Art. no. 104717.

[35] K. Kulkarni, F. Goerlandt, J. Li, O. V. Banda, and P. Kujala, "Preventing shipping accidents: Past, present, and future of waterway risk management with Baltic Sea focus," *Saf. Sci.*, vol. 129, Sep. 2020, Art. no. 104798.

[36] L. Chen, X. Xu, P. Zhang, and X. Zhang, "Analysis on port and maritime transport system researches," *J. Adv. Transp.*, vol. 2018, pp. 1–20, Nov. 2018.

[37] C. Ducruet, R. Panahi, A. K. Y. Ng, C. Jiang, and M. Afenyo, "Between geography and transport: A scientometric analysis of port studies in journal of transport geography," *J. Transp. Geogr.*, vol. 81, Dec. 2019, Art. no. 102527.

[38] Y. He, J. Mou, L. Chen, Q. Zeng, P. Chen, and S. Zhang, "Survey on hydrodynamic effects on cooperative control of maritime autonomous surface ships," *Ocean Eng.*, vol. 235, Sep. 2021, Art. no. 109300.

[39] J. Li, F. Goerlandt, and G. Reniers, "An overview of scientometric mapping for the safety science community: Methods, tools, and framework," *Saf. Sci.*, vol. 134, Feb. 2021, Art. no. 105093.

[40] J. Li and A. Hale, "Output distributions and topic maps of safety related journals," *Saf. Sci.*, vol. 82, pp. 236–244, Feb. 2016.

[41] J. Li, G. Reniers, V. Cozzani, and F. Khan, "A bibliometric analysis of peer-reviewed publications on domino effects in the process industry," *J. Loss Prevention Process Ind.*, vol. 49, pp. 103–110, Sep. 2017.

[42] L. Sun and I. Rahwan, "Coauthorship network in transportation research," *Transp. Res. A, Policy Pract.*, vol. 100, pp. 135–151, Jun. 2017.

[43] Clarivate Analytics. (2020). *Search Operators*. Accessed: Jul. 19, 2021. [Online]. Available: https://images.webofknowledge.com/images/help/WOS/hs_search_operators.html

[44] M. Aria and C. Cuccurullo, "Bibliometrix: An R-tool for comprehensive science mapping analysis," *J. Informetrics*, vol. 11, no. 4, pp. 959–975, Nov. 2017.

[45] N. J. van Eck and L. Waltman, "VOS: A new method for visualizing similarities between objects," in *Proc. 30th Annu. Conf. Gesellschaft Für Klassif. e.V.*, Berlin, Germany, 2007, pp. 299–306, doi: 10.1007/978-3-540-70981-7_34.

[46] N. J. van Eck and L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping," *Scientometrics*, vol. 84, no. 2, pp. 523–538, Aug. 2010.

[47] C. Chen and L. Leydesdorff, "Patterns of connections and movements in dual-map overlays: A new method of publication portfolio analysis," *J. Assoc. Inf. Sci. Technol.*, vol. 65, no. 2, pp. 334–351, Feb. 2014.

[48] C. Chen, "CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature," *J. Amer. Soc. Inf. Sci. Technol.*, vol. 57, no. 3, pp. 359–377, Feb. 2006.

[49] S. Carley, A. L. Porter, I. Rafols, and L. Leydesdorff, "Visualization of disciplinary profiles: Enhanced science overlay maps," *J. Data Inf. Sci.*, vol. 2, no. 3, pp. 68–111, Aug. 2017.

[50] R. G. Wright, "Intelligent autonomous ship navigation using multi-sensor modalities," *TransNav, Int. J. Mar. Navigat. Saf. Sea Transp.*, vol. 13, no. 3, pp. 503–510, 2019.

[51] S. van den Hove, "A rationale for science–policy interfaces," *Futures*, vol. 39, no. 7, pp. 807–826, Sep. 2007.

[52] C. A. Miller and R. Parasuraman, "Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 49, no. 1, pp. 57–75, Feb. 2007.

[53] N. Merat, A. H. Jamson, F. C. H. Lai, and O. Carsten, "Highly automated driving, secondary task performance, and driver state," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 54, no. 5, pp. 762–771, Oct. 2012.

[54] A. H. Jamson, N. Merat, O. M. J. Carsten, and F. C. H. Lai, "Behavioural changes in drivers experiencing highly-automated vehicle control in varying traffic conditions," *Transp. Res. C, Emerg. Technol.*, vol. 30, pp. 116–125, May 2013.

[55] K. Zeeb, A. Buchner, and M. Schrauf, "What determines the take-over time? An integrated model approach of driver take-over after automated driving," *Accident Anal. Prevention*, vol. 78, pp. 212–221, May 2015.

[56] R. R. Murphy, E. Steimle, C. Griffin, C. Cullins, M. Hall, and K. Pratt, "Cooperative use of unmanned sea surface and micro aerial vehicles at Hurricane Wilma," *J. Field Robot.*, vol. 25, no. 3, pp. 164–180, Mar. 2008.

[57] H. A. Yanco and J. Drury, "'Where am I?' Acquiring situation awareness using a remote robot platform," in *Proc. IEEE Int. Conf. Syst., Man Cybern.*, vol. 3, Oct. 2004, pp. 2835–2840.

[58] H. A. Ruff, S. Narayanan, and M. H. Draper, "Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles," *Presence, Teleoperators Virtual Environ.*, vol. 11, no. 4, pp. 335–351, Aug. 2002.

[59] M. R. Endsley, "From here to autonomy: Lessons learned from human–automation research," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 59, no. 1, pp. 5–27, Feb. 2017.

[60] K. Zeeb, A. Buchner, and M. Schrauf, "Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving," *Accident Anal. Prevention*, vol. 92, pp. 230–239, Jul. 2016.

[61] F. Meyer, T. Kropfreiter, J. L. Williams, R. Lau, F. Hlawatsch, P. Braca, and M. Z. Win, "Message passing algorithms for scalable multitarget tracking," *Proc. IEEE*, vol. 106, no. 2, pp. 221–259, Feb. 2018.

[62] *Transportation Statistics Annual Report 2020*, BTS, Washington, DC, USA, 2021.

[63] B. Petrovan. (2021). *Tesla Autopilot: Everything You Need to Know*. Accessed: Jul. 8, 2021. [Online]. Available: https://greenauthority. com/tesla-autopilot-564/#Tesla_Autopilot_History

[64] D. J. Fagnant and K. Kockelman, "Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations," *Transp. Res. A, Policy Pract.*, vol. 77, pp. 167–181, Jul. 2015.

[65] Z. Tian, T. Feng, H. J. P. Timmermans, and B. Yao, "Using autonomous vehicles or shared cars? Results of a stated choice experiment," *Transp. Res. C, Emerg. Technol.*, vol. 128, Jul. 2021, Art. no. 103117.

[66] L. Bainbridge, "Ironies of automation," *Automatica*, vol. 19, no. 6, pp. 775–779, Nov. 1983.

[67] B. Strauch, "Ironies of automation: Still unresolved after all these years," *IEEE Trans. Human-Mach. Syst.*, vol. 48, no. 5, pp. 419–433, Oct. 2018.

[68] G. A. Jamieson and G. Skraaning, "The absence of degree of automation trade-offs in complex work settings," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 62, no. 4, pp. 516–529, Jun. 2020.

[69] C. D. Wickens, L. Onnasch, A. Sebok, and D. Manzey, "Absence of DOA effect but, no., proper test of the lumberjack effect: A reply to Jamieson and Skraaning (2019)," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 62, no. 4, pp. 530–534, Jun. 2020.

[70] J. Sánchez-Beaskoetxea, I. Basterretxea-Iribar, I. Sotés, and M. D. L. M. M. Machado, "Human error in marine accidents: Is the crew normally to blame?" *Maritime Transp. Res.*, vol. 2, Jan. 2021, Art. no. 100016.

[71] K. Wróbel, "Searching for the origins of the myth: 80% human error impact on maritime safety," *Rel. Eng. Syst. Saf.*, vol. 216, Dec. 2021, Art. no. 107942.

[72] J.-U. Schröder-Hinrichs, E. Hollnagel, M. Baldauf, S. Hofmann, and A. Kataria, "Maritime human factors and IMO policy," *Maritime Policy Manage.*, vol. 40, no. 3, pp. 243–260, May 2013.

[73] Z. Lu, X. Coster, and J. de Winter, "How much time do drivers need to obtain situation awareness? A laboratory-based study of automated driving," *Appl. Ergonom.*, vol. 60, pp. 293–304, Apr. 2017.

[74] C. D. Mole, O. Lappi, O. Giles, G. Markkula, F. Mars, and R. M. Wilkie, "Getting back into the loop: The perceptual-motor determinants of successful transitions out of automated driving," *Hum. Factors, J. Hum. Factors Ergonom. Soc.*, vol. 61, no. 7, pp. 1037–1065, Nov. 2019.

[75] K. V. Størkersen, "Safety management in remotely controlled vessel operations," *Mar. Policy*, vol. 130, Aug. 2021, Art. no. 104349.

[76] R. Miętkiewicz, "LNG supplies' security with autonomous maritime systems at terminals' areas," *Saf. Sci.*, vol. 142, Oct. 2021, Art. no. 105397.

[77] Z. Wan and J. Chen, "Human errors are behind most oil-tanker spills," *Nature*, vol. 560, no. 7717, pp. 161–163, Aug. 2018.

[78] *Review of Maritime Transport 2020*, United Nations Publications, UNCTAD, Geneva, Switzerland, 2020.

JIE LI is currently an Associate Research Fellow at the National Science Library, Chinese Academy of Sciences, Beijing, China. His research interests include mapping safety science, quantitative science studies, and science of science.

MATEUSZ GIL received the B.Sc. and M.Sc. degrees in navigation with a particular focus on maritime transportation and offshore technologies, in 2015 and 2017, respectively. He studied at the Gdynia Maritime University (GMU) where he obtained the Officer of the Watch License. After graduation, he started working at sea on board merchant ships. At the end of 2018, he has been employed as a Research Assistant with the Department of Navigation, GMU. His main research interests include maritime transportation risk and safety issues, introducing autonomous ships to the maritime industry, as well as maritime education and training.

KRZYSZTOF WRÓBEL received the B.Sc. degree in marine transportation from Gdynia Maritime University, Poland, in 2011, the M.Sc. degree in ocean engineering from the Gdańsk University of Technology, Poland, and the Ph.D. degree in civil engineering and transport from Gdynia Maritime University.

He worked at ocean-going merchant vessels up to the position of Third Officer (Deck), mostly on board LPG carriers owned by various companies, most notably Navigator Gas LLC. He is currently an Assistant Professor at Gdynia Maritime University. He is the author of several peer-reviewed publications on the safety of maritime transportation, including the performance of prospective maritime autonomous surface ships. His research interests include the safety of transportation and the human role in autonomous transportation systems.

KRZYSZTOF BOGUSŁAWSKI is currently pursuing the bachelor's degree with Gdynia Maritime University.

His research interests include navigation, autonomous shipping, and sailing. He is a member of the Gdynia Maritime University Student Council.

JAN NASUR is currently pursuing the bachelor's degree with Gdynia Maritime University, Poland.

His major field of study is navigation, autonomous shipping, and collision avoidance. He is a member of the Gdynia Maritime University Student Council.

FLORIS GOERLANDT received the Master of Science in Engineering degree in marine technology from Ghent University, Belgium, the Master of Science in the Maritime Sciences degree from Antwerp University, Belgium, and the Doctor of Science (Tech.) degree in marine technology, with a focus on risk and safety, from Aalto University, Finland.

He worked with the shipping service industry, with technical and operational assignments in Belgium, Norway, Singapore, China, and Finland. He took up the position of an Assistant Professor with the Industrial Engineering Department, Dalhousie University, where he currently holds the Canada Research Chair (Tier 2) in risk management and resource optimization for marine industries. In this context, he is the Co-Lead of the Maritime Risk and Safety (MARS) Group, working together with Dr. Ron Pelot. His research interests include several aspects of applied risk management for marine industries, authorities, and associated stakeholders. He also contributes to foundational issues in risk research and safety science, with topics focusing on mapping safety science, uncertainty assessment, and validation.

• • •