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Review

Relationship between human factors and a safe performance of vessel traffic service operators: A systematic qualitative-based review in maritime safety

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ABSTRACT

The growth of the world merchant fleet in recent decades has caused an increase in congestion and complexity in maritime traffic, especially in coastal areas, straits and nearby channels.

This fact, which acts negatively upon maritime safety, however, has meant a decrease in the number of accidents, rather, they have even been reduced by half in the last decade.

This anomaly is explained by the implementation of Vessel Traffic Services (VTS) in these conflict areas and for this reason, in this review we will study, through the analysis of different relevant studies on the subject, the relationship between the human element and maritime safety, focusing on the figure of the vessel traffic service operator (VTSO) as a link between safety and efficiency, exploring their staffing, training, functions and factors affecting them within the maritime system.

This review was conducted following the reporting guidelines for systematic reviews based on the PRISMA 2020 model (Preferred Reporting Items for Systematic Reviews and meta-Analyses).

Also, a bibliometric analysis of the extensive academic literature pertaining to maritime safety in relation to the human factor was carried out, focusing especially on VTS and the operators that act in them, with a special focus on the period from 2000 to 2020. Based on 371 articles, the bibliometric analyses yield to us the information on the publication patterns related to the year of publication and the keywords by identifying the main thematic groups, finally extracting 11 representative articles that have been investigated in detail focusing on the influence of the human factor in maritime safety in the VTS environment.

1. Introduction

Recent maritime accidents such as the collision in February 2015 in Jebel Ali, or collision in November 2018 in Norway, highlight the importance of VTSOs in maritime safety became evident by the official reports. Most maritime incidents are related to human errors, so the understanding of human factors to reduce this issue of paramount importance.

Since its appearance in the naval sector at the end of World War II (Grech et al., 2019), human factors have been the object of study so as to improve the effectiveness and efficiency of maritime transport. It must be accepted that in the maritime domain it is a term often identified with human error, but obviously it is not limited to this last concept.

For this reason, the International Maritime Organization (IMO) encourage his partners to make an in-depth analysis about "human element", and defines this as:

> *"…a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection. It involves the entire spectrum of human activities performed by ships crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively"* (IMO A.947(23), 2003).

In addition to the above resolution on the human element, this subject is currently attached in the general principles of IMO within the Strategic Plan for the six-year period 2018 to 2023 (IMO A.1110(30),

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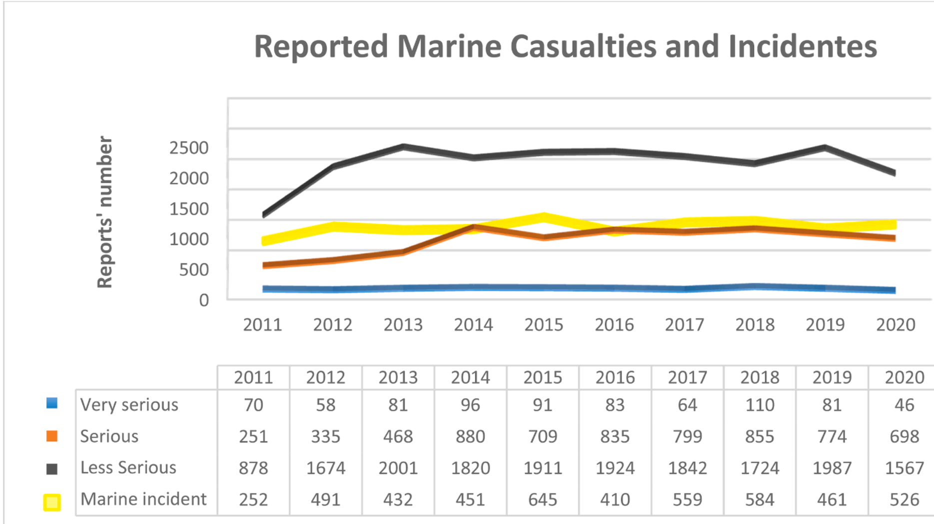

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Very serious	70	58	81	96	91	83	64	110	81	46
Serious	251	335	468	880	709	835	799	855	774	698
Less Serious	878	1674	2001	1820	1911	1924	1842	1724	1987	1567
Marine incident	252	491	432	451	645	410	559	584	461	526

Fig. 1. Marine Casualties and Incidents in last decade. (Source: Annual Overview of Marine Casualties and Incidents, EMSA, 2021).

2017), thus stating the importance of this factor and establishing through this resolution, that the human element must be taken into account in the reviews, development and implementation of both new and existing requirements, including skills, education and training, and human capabilities, limitations and needs.

The Growth of the global merchant fleet over the last decades has increased considerably, not only in ships numbers but in tonnage as well, affecting maritime traffic, especially in nearby coastal areas, straits, and channels, causing congestion and traffic complexity, therefore, ports are a crucial in the maritime transport chain and, in turn, navigation in ports has become increasingly complex the last decades due to this raise in maritime transport of goods and the size of the ships that leads to a greater flow of ships in ports (Bellsolà Olba et al., 2019).

Examples of this traffic complexity and its relationship with Vessel Traffic Services Operators in terms of safety, are the aforementioned collisions within VTS area of Jebel Ali (United Arab Emirates) between Oil Tanker "Alexander I" and the container ship "Ever Smart" on February 2015 or the recent collision between Norwegian frigate "HNoMS Helge Ingstad" and the oil tanker "Sola TS" in November 2018 within Fedje VTS area, in Hordaland County (Norway), consequently, both official reports (MAIB, 2015; AIBN, 2018) remarks the lack of monitoring, loss of the situational awareness and an inadequate overview of the VTS area by the VTS operators, therefore, this human factor was one of the triggers of the accident.

Nowadays sea transport deals with 90 % of the total merchandise that moves around the world (OECD, 2021), and although international

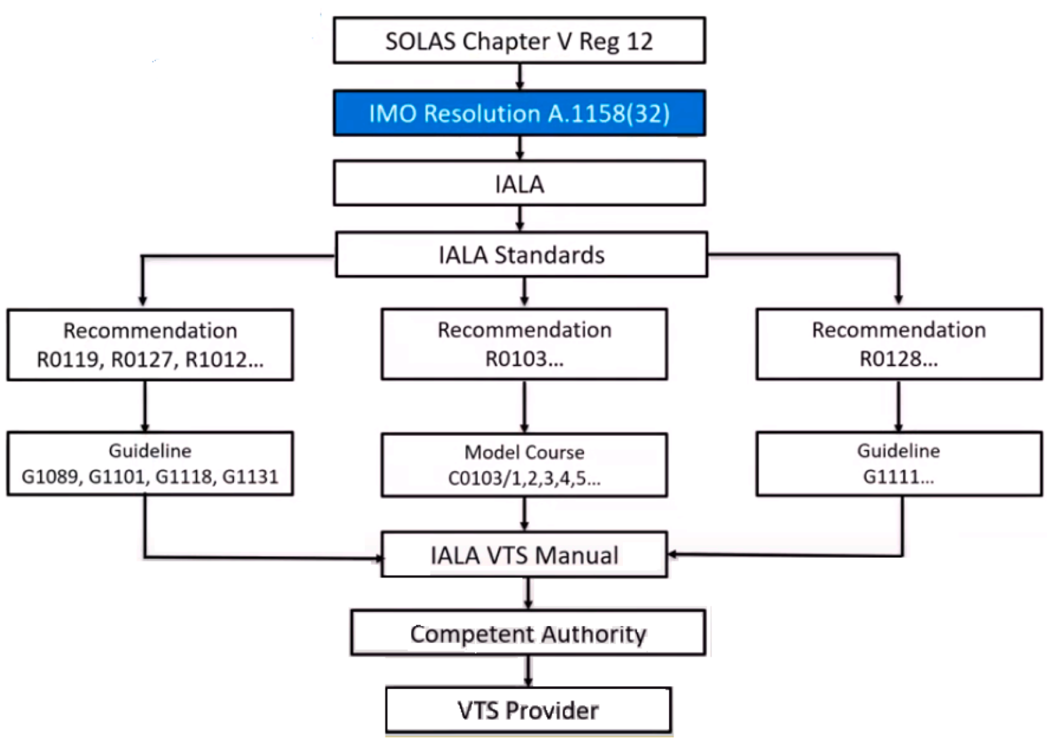

Fig. 2. Framework of Regulations related to VTS ().
Source: IALA, 2022

seaborne trade in 2020 slipped to −3,8% due to COVID's pandemic, growth in maritime trade volumes are expected to moderate and expand at an annual rate of +2.4 % between 2022 and 2026 (UNCTAD, 2021), therefore, maritime transportation can be defined as a fundamental activity for our society. Further increasing maritime traffic and maritime accidents revealed the idea of regulation and monitoring of maritime traffic from land.

Aware of this reality, IMO, establishes various strategies to improve the safety of this activity, which seem to be giving good results, as reflected in the statistics of sectoral accidents. Thus, according to the European Maritime Safety Agency (EMSA), the number of total losses during the 2010–2020 decade has been reduced in general by almost 50 %, with a reduction in the number of accidents in the last 5 years (2015–2020) of 39.4 % and highlighting that the number of very serious maritime accidents was only 46 in 2020, showing a 43.3 %, that means a reduction of 466 casualties in comparison with the year 2019 (Fig. 1), taking into account that these calculations were limited to ships flying the EU flag, and with an IMO number when referring to cargo ships, passenger ships and service ships.

Finally, the analysis, conducted during safety investigations, in which it was determined that, from 2014 to 2020, 89.5 % of all occurrences were related to human action, should be highlighted.

One of the strategies that have been developed with the increase in the number of vessels engaged in maritime transport is the need to, not only regulate, but also to monitor compliance with the standards, therefore.

Within this surveillance strategy, we must look at one of the tools that have been most widely spread lately: The Vessel Traffic Service, that is, elements intended to regulate maritime traffic in areas of special risk for navigation.

IMO recognizes the ultimate value of VTS in the management of potentially high-risk geographic areas and protection of the environment with his legislative efforts present since 1950 s to nowadays, with legislative milestones such as the "*Recommendation on Port Advisory Systems*" (IMO A.158(ES.IV), 1968), or the "*Code for the Investigation of Marine Casualties and Incidents*" (IMO A.849(20), 1997).

On the other hand, technological advances led to a necessary adaptation of the regulations, highlighting the "*Guidelines for Vessel Traffic Services*" (IMO A.578(14), 1985), currently revoked by a new version (IMO A.857(20), 1997). In turn in December 2020, chapter V on Safety of Navigation of the International Convention for the Safety of Life at Sea (SOLAS) 1974 was revised, and came into force on 1 July 2002. It is in this Convention published by the IMO, where we find a declaration of intent on the use of these services as a tool to guarantee maritime safety: "*contribute to safety of life at sea, safety and efficiency of navigation and protection of the marine environment, adjacent shore areas, work sites and offshore installations from possible adverse effects of maritime traffic*"(SOLAS - Chapter V, Rule 12, 2002).

The recently approved Resolution A.1158 (32) "Guidelines for Vessel Traffic Services" in December 2021 by the 32nd IMO Assembly, will replace the previous resolution (IMO A.857(20), 1997).

Resolution A.1158 (32) will work as a bridge between SOLAS and IALA guidance, so it is important to understand the hierarchy of all these resolutions and therefore, the following scheme is presented (Fig. 2):

In short, a Vessel Traffic Services (VTS) could be understood as a fundamental element to guarantee safety and enhance a safety culture within the Maritime Traffic System (MTS).

On the other hand, it is worth noting the lack of consistency in the use of acronyms related to maritime traffic coordination centers, with terms such as: 'VTS', 'VTIS', 'traffic', 'control', 'coastguard', 'port control', 'port', 'port control' which are used indiscriminately. Hence, emphasis should be place on the importance of IMO Resolution A.857 (20) and the newly Resolution A.1158 (32) which, as we said, will replace the aforementioned, that recommends Vessel Traffic Service (VTS) centres in an area or sector to use a name identifier, and for that reason in all cases, the abbreviation of VTS stands for "Vessel Traffic Services" that is shore-based services catering for vessels as explained later.

The terminology officially applied in this review focused on the staff of VTS Centres is provided to us by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), which are a non-profit, international technical association supported by IMO and whose function it is oriented to developing common best practice standards through publication of Recommendations and Guidelines. This intergovernmental organization, IALA, established the term VTSO and is first defined as follows: "*VTS Operator (VTSO) is an appropriately qualified person performing one or more tasks contributing to the services of the VTS*" (IALA G1083, 2022).

This review, therefore, analyses the human element within the VTS's environment as a complex sociotechnical system, as we will define later, studying the VTSOs and their relation with information technology as a link with the rest of the personnel involved in maritime safety (Captains, pilots, etc.), furthermore, special attention is paid to physical and mental fatigue as one of the most influential factors in the transportation sector based on contributions from different studies related to the impact of human fatigue in all kinds of transport (e.g., road traffic, maritime transport, etc.), which causes between 15 and 20 % of existing transport accidents (Åkerstedt, 2001; Marcus and Rosekind, 2016; Zhao et al., 2021). The different initiative used in the fight against fatigue and the tools employed in diagnosis are identified and discussed.

The purpose of this research is, therefore, to highlight the bilateral relationship between the human element and safety, through the operators' resilience in shift work with high responsibility and cognitive demand, all of these factors responsible to the detriment in performance and efficiency of the operators, with consequences such as impaired attention, delay in decision-making, reduced reaction time, etc., which are triggers of various maritime accidents.

Finally, it should be noted that in this review, several human factors are highlighted, such as: fatigue, workload, teamwork, resilience, performance, trust and communication, all which are related to maritime safety within VTSOs. These factors are analysed in the articles selected for this review; however, the data collection from these studies are mainly subjective data (tests, interviews) which seems insufficient to characterize this issue, so this author, brings up the dilemma throughout the discussion section, about the necessity to obtain not only subjective but objective data as well, understanding by objective data as those physiological data such as temperature, heart rate, encephalograms… etc., obtain by specific sensors.

Another controversy that is observed throughout the review is about the maritime experience as a counterpart to the negative factors, where the authors do not agree on this issue, although the majority support the experience benefit, so more studies are needed on the subject.

In summary, this article is structured as follows: review methods used are explained in Section 2, in turn in Section 3 is introduced the figure of the maritime traffic controller, related to maritime safety, emphasizing the importance of this position and its organization. The issue of fatigue is also pointed out as the core factor of most maritime traffic accidents. What is left of this article is framed into Section 4 describes how the data was collected using both PRISMA framework and a bibliometric analysis, presenting the results obtained from them at the end of this section, then, in Section 5, the most representative compile articles are analysed and discussed. Finally, Section 6 provides final comments.

2. Methods

This review was carried out following the updated guideline for reporting systematic reviews based on the PRISMA 2020 model (Page et al., 2021) to ensure that the relevant literature is adequately covered and the data for this study were retrieved from EBSCO HOST database.

On account of the multidisciplinary nature of the study, both psychosociological and technical, and in order not to miss any important

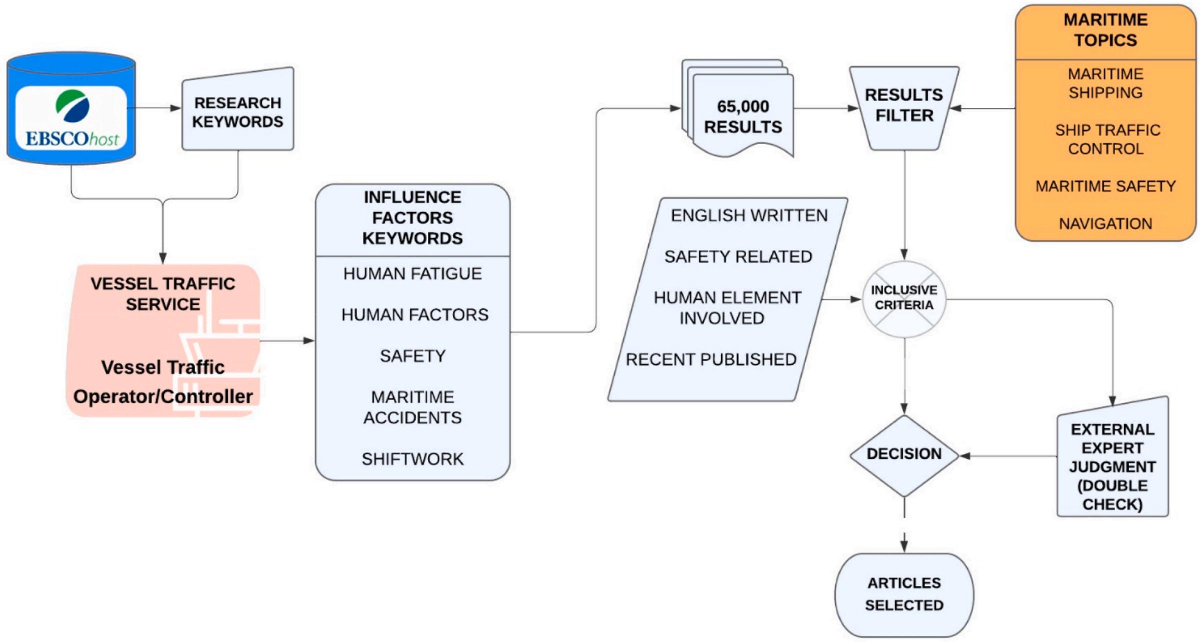

Fig. 3. Review's Methodology Flowchart.

article, initial raw search was carried out, which returned close to 65,000 results, so with a view to reducing results to more specific studies and make an easy to read identification of the related publications, several filters and four topics are used to identify safety-related issues affecting performance of vessel traffic service operators, these topics being:

- topic 1: "Ship" or "Vessel" or "Maritime Shipping", and.
- topic 2: "Ship traffic control", and.
- topic 3: "Maritime Safety", and.
- topic 4: "Navigation".

All these studies were double-checked incorporating into the revision a doctorate in merchant marine and Senior Technician for Work Hazard Prevention in order to avoid bias in article selection.

The qualitative methodology is summarized in the flowchart of Fig. 3.

In addition, a quantitative bibliometric analysis by co-occurrence, was carried out on the dataset containing the identified safety-related publications that affect the performance of Vessel Traffic Services Operators (VTSOs), using the free software "VOSviewer" (Visualizing scientific landscapes), being one of the most used methods in bibliometric analysis (Li et al., 2021).

The final purpose of the methodological framework designed ad hoc for this review, aims to answer the following questions regarding the VTSOs:

(1) What are the human factors involved in VTSOs tasks? and.
(2) What is the relationship between human factors and the safe performance of VTSOs?

We address these questions in the discussion section, finding how fatigue, mental factors, teamwork and communication and trust, are safety key elements.

3. Vessel traffic services: The figure of the maritime traffic operator

This section defines maritime traffic services and introduces the figure of the VTSO, as well as its organization and staffing, outlining the relationship between maritime safety and VTSOs through the human factor, paying special attention to fatigue (see Fig. 4).

3.1. VTS structure

Vessel Traffic Services (VTS) are recognised internationally as a

Fig. 4. Maritime Rescue Coordinator Centre of Cartagena (Spain), (Left Side) VTS Operator on duty; (Right Side) Information Displays. (Own source).

navigational safety measure through the International Convention on the Safety of Life at Sea 74/78 (SOLAS), and on the other hand, the VTSOs are appropriately qualified people as defined above, and as a consequence, these specialised services and operators are directly related to maritime safety in their task to assist the mariner in the safe and efficient use of the waterways, originating a perfect symbiosis between controllers and vessels through the VTS which are implemented by the different nations with responsibilities in their adjacent maritime zones in order to improve safety, maritime traffic efficiency and marine environment protection.[1]

A VTS is a Socio-technical system, this is a term coined by Tavistock Institute research program in the 1950 s, and it can be defined as:

> "…*increasingly common classes of large-scale system that feature a combination of technological systems (where hardware and software technology feature as significant elements within the system), human interfaces, and human-intensive organisational systems*" (Jackson, 2010).

IMO has adopted guidelines on VTS (IMO A.1158(32), 2022) which should be used when planning and implementing a VTS, but these guidelines only address VTS present in coastal or harbour areas or a combination of both coastal and port/harbour areas. Furthermore, SOLAS, specifically states that "*The use of VTS may only be made mandatory in sea areas within the territorial seas of a coastal State*" (SOLAS - Chapter V, Rule 12, 2002).

However, the EU has more than 35,000 km of canals and rivers linking hundreds of key cities and areas of industrial concentration and in this context, several countries in the late 1990 s, started to work on information systems for inland shipping; these services would eventually be known in Europe as River Information Services (RIS). To that end, RIS were implemented with the aim of a safe and efficient transport process and thus contribute to an intensive use of inland waterways.

Subsequently, RIS are the harmonized information services to support traffic and transport management in inland navigation (where present, an Inland VTS is part of RIS, but a RIS does not necessarily have to include a VTS) including interfaces to other transport modes (PIANC, 2011).

IALA Guideline (IALA G1166, 2022) on VTS in Inland Waters, Chapter 4.3.2., in reference to the considerations on continental waters establish:

> "*The close confines of many inland waterways and the ability to maintain a comprehensive traffic image may result in a more limited ability to respond to developing situations*".
>
> Stressing in the same chapter:
>
> "*While decision support tools may differ, they are likely to be of similar value to an inland VTS as it is to a VTS in coastal waters and port/harbour areas and the IALA guidance of equal relevance*".

In these statements, IALA hints that although the purpose and functions may be similar, they are not the same. For this reason, in this review we focus mainly on coastal VTS and their operators, who are staffing (IALA G1045, 2022), operational procedures (IALA G1141, 2022) and training (IALA G1156, 2022) are clearly defined by IALA through its Standards, Recommendations, Guidelines and Model courses, which are applicable worldwide.

In addition, IALA has a guideline, (IALA G1166, 2022), to assist authorities establish inland VTS in inland waters effectively and in a manner that reflects the international regulatory regime for VTS while RIS Guidelines should be complemented by detailed guidelines and standards for applications in specific parts of the world.

These implementation RIS peculiarities, are defined in the guidelines and recommendations prepared by the World Association for Waterborne Transport Infrastructure (PIANC):

> "*The implementation of RIS based on these RIS Guidelines requires the use of RIS key technologies as standardised by the European Commission and/or the Central Commission for the Navigation of the Rhine. These standards are a pre-condition for the implementation of RIS in the CCNR and EU member States*" (PIANC, 2011).

Hence, the need to harmonize internal VTS through international guidelines worldwide and these guidelines should therefore follow the IMO guidelines on VTS as closely as possible. This Recommendation should be used whenever the application of the IMO guidelines on VTS is considered inappropriate (IALA VTS MANUAL, 2021).

3.2. Organization and staffing into vessel traffic services

Recently, there has been a fast growth in vessel traffic services, which has led to a relevant increase in the number of VTS operators required world-wide. Nowadays there are over 500 VTS centres around the world (IALA VTS MANUAL, 2021) and in these centre's the VTSO is "responsible for establishing and maintaining a vessel traffic image, which will facilitate interaction with the vessel traffic thus ensuring the safety of navigation" (IALA 1089, 2022).

There are not any definite criteria for being a VTSO; it depends on the maritime authority for each country; however, there are international recommendations and guidelines that describe the training and qualification of VTSOs as the Annexes of IMO Resolution A.857(20) 'Guidelines for Vessel Traffic Services' (VTS) that describe the skill and knowledge qualifications required by VTS Operators (VTSOs) and follows: "…*VTS Personnel are required to interact with other mariners with responsibility for safety… and that they are trained and qualified according to the current international IALA standards*" also remark that "*VTS personnel should be capable of providing information, traffic organisation and/or navigational assistance service in the area specified by the relevant VTS Authority…*".

On the other hand, this guideline is also addressed to Contracting Government(s) urging to.

> "…*ensure that the VTS Authority has sufficient staff, appropriately qualified, suitably trained and capable of performing the tasks required, taking into consideration, the type and level of services to be provided…*" (IALA G1045, 2022).

In accordance with the IALA guideline cited above, the VTS Authority has the right to define who can be a VTSO taking into account the type and level of services to be provided, in addition to other factors such as periods of service, operational procedures, emergencies, workload, etc.; however, there is no obligation that all VTSOs must have nautical experience or even must have a Master Mariner license, although the IMO recommends considering training and qualifications according to current IALA international standards and VTSO roles.

These roles for personnel in each VTS may vary, and generally consist of four kinds: VTS operator, VTS supervisor, VTS manager and On-the-job training (OJT) instructor (IALA G1156, 2022).

In summary, to keep VTS operations safe it is essential to have qualified VTS personnel and these qualifications will be determined through the balance between the factors mentioned above, which must be kept under periodical review.

Regarding the balance, it is necessary to mention the "risk compensation hypothesis", which theorizes that when an activity is modified to be considered safer, people take more risks and the number of accidents remains constant, in other words, making situations seem more dangerous can make it safer, this phenomenon is what in the safety literature is called risk homeostasis.

The risk homeostasis theory also introduces the concept of perceived risk, in which each individual has their own acceptable target level of perceived risk and balance is achieved through constant adjustment to

[1] IMO defines that a 'Competent Authority' should be responsible for the safety and efficiency of vessel traffic (RESOLUTION A.857 (20)).

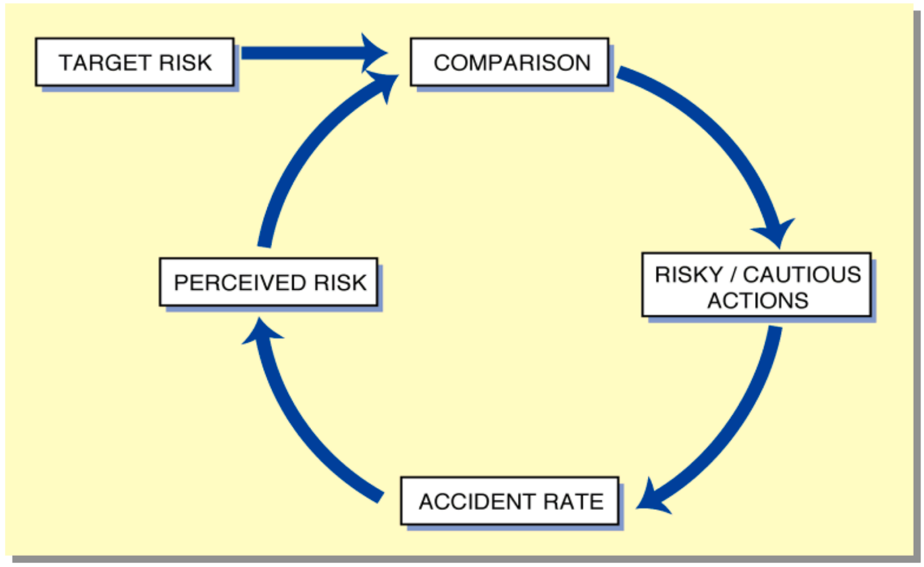

Fig. 5. Homeostatic model relating "circular causality" (source: Gerald J.S. Wilde, 2013).

this (Napier et al., 2007), therefore, homeostasis is the scientific term used to designate systems that tend to maintain a state of balance, in this case a constant sense of security. According to this hypothesis, if we make the environment seem safer, users will engage in riskier behaviour, keeping the actual level of safety constant.

The paradox of this theory is that the greater the operator's workload, the lower the risk of accident because the perceived risk is greater and, conversely, the lower the workload, the lower the perceived risk, since the operator's cognitive load it is lower, resulting into a feeling of less risk. This is a clear example of negative feedback or circular (not linear) causality that links changes in perceived risk to changes in behaviour (Fig. 5):

> *"a change in behaviour produces a change in the accident rate and a change in the accident rate brings about a change in behaviour"* (Gerald J.S. Wilde, 2013).

In the previous figure it is observed that the link between the objective risk and the accident rate is the only element of linear causality, so the accident rate can only be influenced by factors that affect the level of objective risk.

On the other hand, safety innovations are often used as a tool to lower the level of perceived risk. However, the individual may not have the ability to stop that risk after the introduction of a safety innovation and consequently, the operator is giving control to an interface that is not in a position to make decisions, since the sensors of a machine are not only limited but also measure different things from those measured by the senses of the human being. Therefore, as we have previously commented, it is a mere decision support tool.

Special attention should be paid to the workload factor, both due to its negative impact on the performance and motivation of the VTS personnel (Sulastri, 2020; IALA G1045, 2022), and because it is closely linked to one of the main tasks performed by VTSOs compile a traffic image that allows the operator to assess situations and make decisions accordingly.

Thus, in order to make these decisions, data should be collected, and in this respect, IALA recommend the use of decision support tools (DST) in VTS centres to enhance situational awareness (IALA G1045, 2022). Some of these support tools are technological improvements as Automatic Identification System (AIS) or Electronic Chart Displays (ECDIS) (S. J. Chang, 2004; Lützhöft et al., 2011) being an example of integrated devices intended to assist VTSOs and somehow increase safety; however, they have generally been implemented to raise overall productivity, counteracting their initial safety effect.

In the same way, monitoring systems like Long Range Identification and Tracking System (LRIT) and SafeSeaNet (SSN) whose information is used by various users such as Maritime Rescue Coordination Centres (MRCC) or Port Authorities through Vessel Traffic Services (VTS), can be considered, which is the case that concerns this review, as decision-making support tools.

Therefore, SSN is defined as a network for maritime data exchange, linking together maritime authorities from across Europe exchanging information related to maritime safety, port and maritime security, marine environment protection and efficiency of maritime traffic and maritime transport (Directive 2002/59/EC, 2002; Directive 2009/17/EC, 2009).

In turn, on May 19, 2006, four years after the established of the SSN system, LRIT system was set up under the auspices of IMO (MSC.202(81), 2006; MSC.211(81), 2006), for reasons related to national security, making it mandatory for all passenger ships, high speed craft, mobile offshore drilling units and cargo ships of over 300 gross tonnes, and it has been in force since July 2009.

The main purpose of the LRIT ship position reports is, therefore, to enable a Contracting Government to obtain ship identity and location information in time to evaluate the security risk.

Both SSN and LRIT systems are managed and maintained by EMSA.

However, unlike the other decision support tools we have talked about, such as ECDIS, or RADAR, inputs are automatic, even radio communications may or may not be voluntary, while data fetch through the SSN or LRIT systems are always voluntary, the users (Flag States, Port States, Coastal States and Search and Rescue Authorities) must use their authorizations to access the system and obtain the information, so the VTSOs' mental workload with these systems is relative, since they are on demand.

Despite the aid provided by these tools to counteract workload, IALA makes special consideration about the rotation of watchkeeping VTSOs and the need for breaks (IALA G1045, 2022), emphasizing that it's depending on the intensity of work and the overall working environment, and pointing out that due to the unique circumstances in each VTS Centre, it is not appropriate, nor possible, to specify the length or number of breaks necessary to avoid fatigue.

For all of the above, and according to various authors, staffing has been considered the first level of defence in fatigue-risk management (Lerman et al., 2012; Yoo and Kim, 2021) so in order to assessing appropriate staffing levels for a VTS Centre, IALA authorities develop a

Given Input Data:

'a'	= hours per day (normally 24)
'b'	= actual days per week (normally 7)
'c'	= actual days per year (normally 365.25)
'd'	= Individual (contracted) hours per working week
'e'	= normal hours per shift
'f'	= hours leave per year
'g'	= hours sickness per year
'h'	= hours training per year
'i'	= Individual mins lost per shift (meals, handovers, position breaks etc.)
'j'	= number of operational VTS work stations

Calculate (see calculation stages below):

'k'	= Individual hours per year before deductions
'l'	= Individual hours after deductions for leave, sickness and training
'm'	= working shifts per year
'n'	= Individual hours lost per shift (break & handover)
'o'	= total hours lost per year
'p'	= total duty hours per VTSO/Supervisor per workstation per year
'q'	= actual hours per year
'r'	= number of VTSOs/Supervisors required per VTS workstation
'T'	= **Total number of VTSOs/Supervisors required for staffing a VTS Centre**

Calculation:

Stage 1:	k = d * (c / b)	Stage 6	p = l - o
Stage 2:	l = k - (f + g + h)	Stage 7:	q = a * c
Stage 3:	m = l / e	Stage 8:	r = q / p
Stage 4:	n = i /60	Stage 9:	T = r * j
Stage 5	o = m * n		

Input data - Normally fixed for a 24/7/365 VTS
Input data - Variable
Calculated

Fig. 6. VTS Staffing - Calculation guide (Source: IALA G1045-Ed1.1-Annex A, 2018).

staffing calculation (Fig. 6) through a theoretical outcome based on local and cultural issues, predictable traffic levels, etc…(IALA G1045, 2022).

This calculation guide (IALA G1045 ANNEX A, 2018) is applicable to the VTSO and VTS Supervisor staffing levels taking into account the following considerations:

- Individual (contracted) hours per working week ('d') are the terms of employment for an individual VTSO or Supervisor; typically, between 35 and 45 hrs. per week.
- Normal hours per shift ('e') is typically 6 – 12 h.
- Hours leave per year ('f') should be based on the number of days' leave granted multiplied only by the shift hours per day (not the full 24 h).
- Hours sickness per year ('g') is an estimate based on historical records and averages across the VTS department.
- Hours training per year ('h') should include the training hours scheduled for the year.
- Finally, the term ('i') Individual minutes lost per shift for meals, handovers and breaks etc. should be based only on the individual and is necessary to generate the increase in staff required to enable staff rotation.

3.3. The VTS operator

In this section we have seen the short definition of VTS Operator (VTSO); however, it is incomplete and recently updated to the reality of this profession closely linked to safety. According to IALA (IALA G1156, 2022), "*VTS personnel are individuals that are appropriately trained and qualified in VTS operations in accordance with the relevant model course associated with their functions. They actively contribute to the safe and efficient movement of vessel traffic in conjunction with the bridge team and allied services*".

To carry out these tasks, VTSOs must rely on three key principles (IALA G1131, 2022):

- Overview of Traffic and Maintaining a Traffic Image.
- Interacting with the traffic.
- Responding to traffic situations in progress.

These operators are therefore responsible for establishing and maintaining a vessel traffic image and must interact with vessel traffic to improve the safety and efficiency of navigation within the VTS area responding to developing situations after a meticulous analysis of the information available.

Consequently, such specialized staff, are recommended by IALA, to possess a minimum training requirements (IALA Model Course V-103/1, 2009), such as:

- Prior skills and knowledge within VTS.
- Maritime experience and education.
- Personal suitability characteristics and.
- Medical fitness requirements.

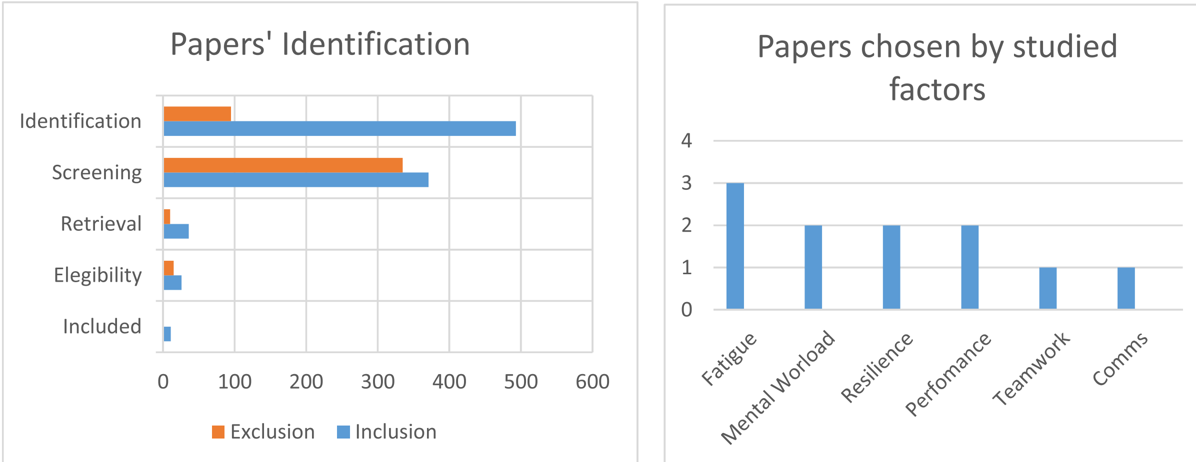

Fig. 7. Graphic Summary of the Data Collection Procedure. (Left side) Identification of studies via databases and registers / (right side) Number of Studies included in review.

VTS personnel should only be considered competent when appropriately trained and qualified for their VTS duties (IALA G1156, 2022) through:

- Satisfactorily completing generic VTS training approved by the competent authority.
- Satisfactorily completing on-the-job training at the VTS where the person is employed.
- Undergoing performance assessment and revalidation training to ensure competence is maintained and.
- Being in possession of appropriate certification.

Also, personal aptitude, attributes and overall suitability requirements emphasizing previous maritime experience should be considered.

The Annexes of IMO Resolution A.857(20) 'Guidelines for Vessel Traffic Services' (VTS) describe the skill and knowledge qualifications required by VTSOs to provide the required services to improve ~~the~~ safety, being Authorities the ones to determine what competencies a VTSO must have.

3.4. *VTSO's human factors: The fatigue paradigm*

Human factors play a fundamental role in process safety management within a system, being designated as a system which includes the following elements: people, tasks, equipment and interfaces, environment, organizations in which they work and location in the world (Randle, 2021).

Related to maritime system, the human factor has always been a constant concern within the sector as can be deduced from early IMO regulations on fatigue factors in manning and safety (IMO A.772(18), 1993), which provides an overview of fatigue and identifies factors in ship operations that may contribute to it.

Fatigue is caused by a range of factors as lack of sleep due to poor quality of sleep and rest (Phillips et al., 2017; Engle-Friedman et al., 2018), also by work/sleep at inappropriate times of the body clock, which implies alterations of the circadian rhythm (MacLean et al., 2003; Moore-Ede et al., 2004), or staying awake for long periods without forgetting stress and excessive workload resulting in prolonged mental and/or physical exertion (Borbély, 1982; Desmond and Hancock, 2000; Dorrian et al., 2011).

Taking this into account, IMO consider fatigue as a hazard that affects safety, health and well-being and it presents a considerable risk to safety of life, property, health, security and protection of the marine environment (MSC.1/Circ.1598, 2019).

At the same time, the increase in maritime accidents between the end of the 20th century and the beginning of the 21st (Ćorović and Djurovic, 2013) involving human factors (Luo and Shin, 2019) and with fatigue as a main trigger, led IMO's Maritime Safety Committee on May 1999 to consider human fatigue as a cornerstone in safety issues and consequently develop a practical guidance to deal with it in the maritime environment.

These first regulatory efforts by the IMO (MSC/Circ.1014, 2001) and subsequent updates (MSC.1/Circ.1598, 2019), provide a regulatory framework on fatigue from which the definition is derived:

> *"A state of physical and/or mental impairment resulting from factors such as inadequate sleep, extended wakefulness, work/rest requirements out of sync with circadian rhythms and physical, mental or emotional exertion that can impair alertness and the ability to safely operate a ship or perform safety-related duties"* (MSC.1/Circ.1598, 2019).

Therefore, fatigue is a key factor in maritime safety related to VTS environment (Li et al., 2020b), that as in many other jobs in the transport sector and elsewhere include a blend of physical and mental tasks that together result in a merged general feeling of fatigue, and mental tiredness.

Human fatigue is often pointed out as the core factor of most traffic accidents (Bye and Aalberg, 2018).

4. Data collection procedure and results

This section, touches upon the process of collected data and the ways to obtain the results for the research.

4.1. *Data collection procedure*

After a careful abstract reading of the dataset obtained, and after applying the methodology discussed above, to ensure the relevance of the articles for the intended coverage of the review, as a result, we collected 493 papers from our keyword search, leaving 371 papers to be screened due to duplicate records mainly.

Additional 335 papers were removed after the title and abstract screening, so 36 were retrieved but 10 were removed because there is no available data, or were conference proceedings.

Consequently, a remaining of 26 papers were assessed for eligibility which resulted from criteria and a full-text screening, was completed on these papers. That produced the exclusion of an additional 17 articles because they were out of scope. A total of 11 papers were eligible for data extraction as representative for this review. Of these 11 papers, 3 articles focused on fatigue, 2 on mental workload, 2 on impact of new

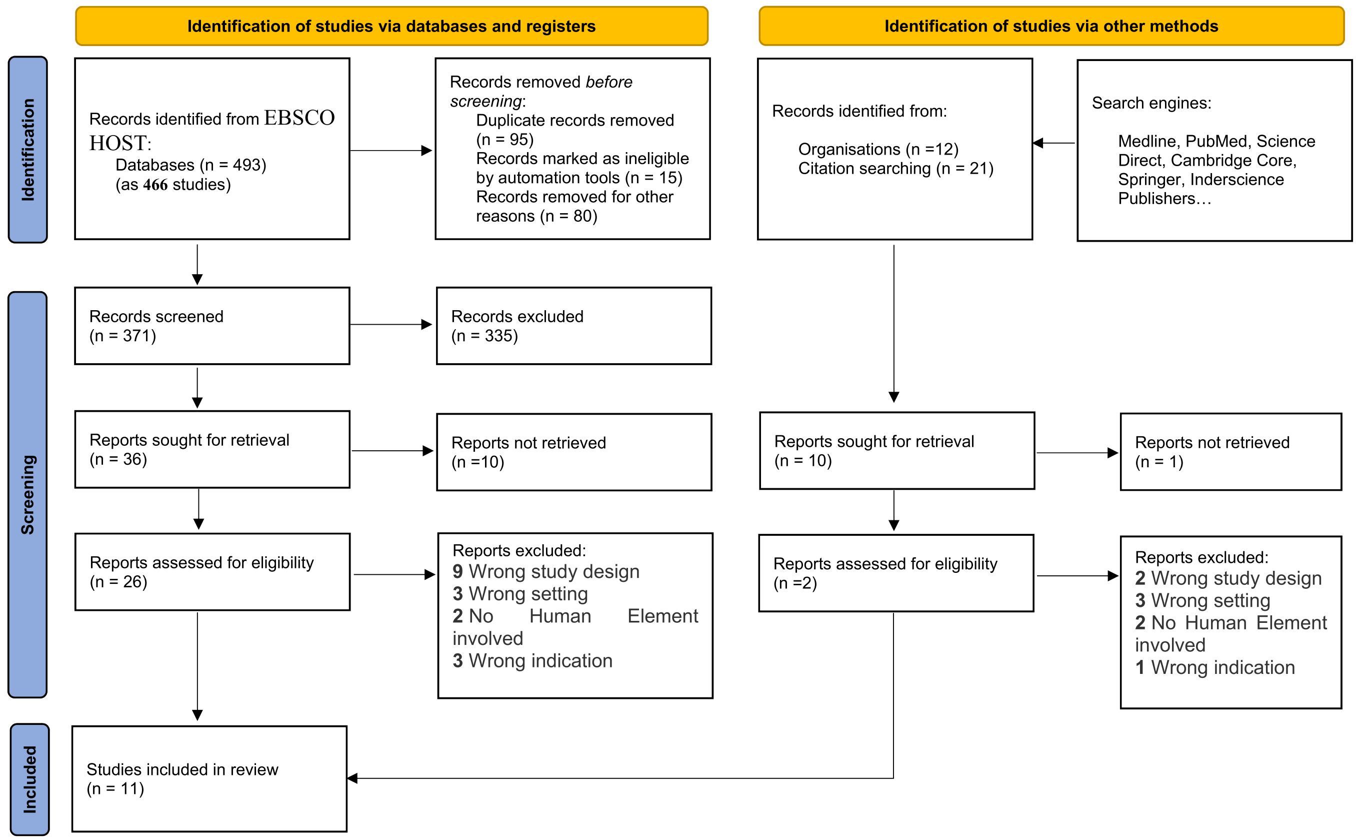

Fig. 8. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources used to identified this review reports.

technologies and resilience, 2 on performance on sociotechnical system, 1 on teamwork and 1 on communications and trust (Fig. 7).

A detailed identification flowchart following PRISMA guidelines is shown in Fig. 8.

4.2. Bibliometric analysis and qualitative systematic review

In this work, in addition to diagrams and flowcharts, the free software "VOSviewer" is applied, which is used to carry out bibliometric analyses by constructing and visualizing bibliometric networks. In this way, co-occurrence analysis was performed, where the publication keywords are shown as items, where the size of each one correlates to the number of occurrences.

As shown in Fig. 9, 45 items are spotted as critical publication keywords addressing human factors related to maritime safety. All the keywords in the figure stand for points with more than five happenings in the chosen 371 publications. The most recurrent items are 'Maritime Shipping' (36 occurrences) and 'Safety' (33 occurrences), followed by 'ships' (27 occurrences), 'risk assessment' (27 occurrences),'navigation', (19 occurrences), 'harbors' (17), 'e-navigation' (12 occurrences) or 'Ship Traffic Control' (10 occurrences), 'Human Factors' and 'VTS' (8 occurrences).

The connections between the keywords in the publications are shown by the links between the items whose terms are commonly found together represented by thicker lines.

Consequently, extra clustering of such terms allows expert interpretation of forthcoming narrative patterns in the research area.

Hence, in this study the items were gathered in seven clusters, so as to represent terms which are strongly linked to one another than other terms in other clusters resulting as follows:

- cluster 1 (RED): "AIS", "collision avoidance", "collisions at sea", "computer simulation", "collisions at sea", "e-Navigation", "human factors", "safety", "ship traffic control", and "VTS";
- cluster 2 (YELLOW): "focus group", "human error", "international law", "marine accidents", "maritime safety" and "rescue work";
- cluster 3 (BLUE): "accidents", "automatic identification", "container ships", "forecasting", "risk assessment", "ships" and "system identification";
- cluster 4 (GREEN): "case studies", "cognition" or "communication", "decision making", "emergency management", "harbors", "maritime" and "waterway";
- cluster 5 (PURPLE): "big data", "information storage & retrieval systems", "marine vehicles", "navigation", "navigation in shipping" and "situational awareness";
- cluster 6 (LIGHT BLUE): "electronic navigation", "probability theory", "traffic engineering", "traffic flow" and "traffic safety";
- cluster 7 (ORANGE): "maritime shipping", "simulation", "simulation methods and models" and "transportation".

As a result, the high number of clusters obtained from this analysis, is an example of the multidisciplinary nature of the subject studied, human factor (VTSO) related to maritime safety within VTS area.

Although all the clusters obtained are related to safety, the publications bounded by the red cluster are the most representative of a plausible narrative centred on traffic control and human factor meanwhile the yellow cluster can be understood to stand for a narrative pattern addressing accidents and human error.

On the other hand, there are some conflicting terms in the network and its clusters, for example, AIS (red group) and automatic identification (blue group), indicating that the identified narrative patterns are mainly intended as a basis for discussion.

In contrast to the figure previously cited related to the co-occurrence

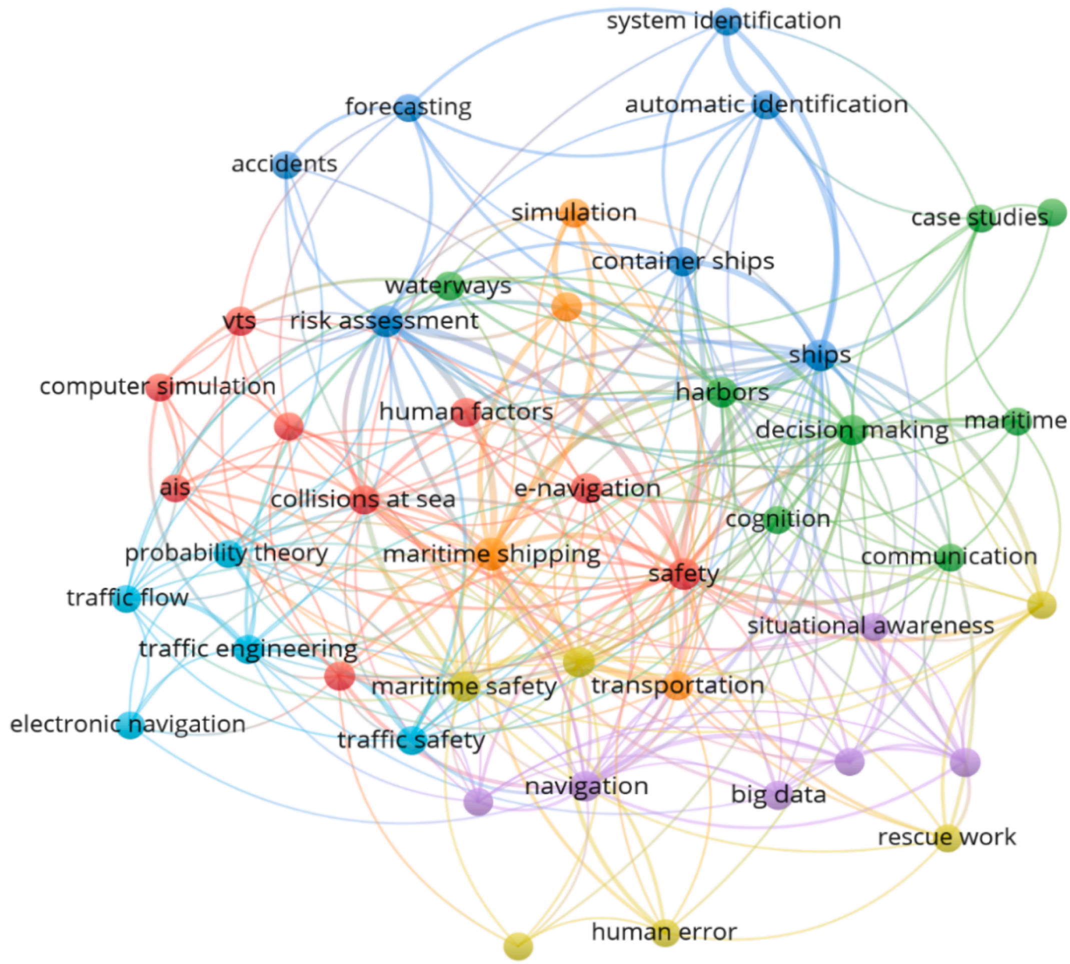

Fig. 9. Network visualization of co-occurrence analysis by keyword in the 371 publications related to safety affecting performance of VTSO from 2000 to 2020, created by VOSviewer.

of keywords, the following image (Fig. 10) shows the transient trend of the focus items in the narrative patterns about safety in the maritime sector, related to the human factor. It is remarkable how at the beginning of 2012, the publications were more focused on the analyses related to risk assessment, and how this trend change from 2016 until nowadays, focusing on issues more related to safety, ships, ports and navigation in all its aspects (e-navigation, maritime shipping, etc…).

Recently, researchers have paid more attention to other issues intrinsically related to safety, such as VTS systems, human error, big data, AIS, and situational awareness, among other topics.

5. Discussion and analysis

There are several studies aimed at the implementation of the technological aspect of VTS, mostly related to various aspects of monitoring and vessel tracking (S. A. Midwood et al., 1998; Harre, 2000; S. J. Chang, 2004; Ming-Cheng Tsou et al., 2010; Xie et al., 2011); however, few studies are aimed to report the working conditions and cognitive demands of the VTSO, that's why this review aims to classify the main initiatives and methods of the last decade used by researchers to identify human factors related to safety in the framework of VTS domain.

VTS is frequently compared to Air Traffic Control (ATC) however, although the systems share common goals, there are huge differences between them; ATC is rather stiff in its design with clear procedures to cope with several situations. VTS, on the contrary, is a very flexible system that leaves the details of execution to the actors in a situation (Praetorius et al., 2012).

The VTS system is considered a complex sociotechnical system (Praetorius et al., 2015; Relling et al., 2019) and requires highly specialized personnel prepared to deal with situations that often go beyond protocols and procedures.

The studies' structuration was designed applying the principle of the "Five Ws" first established by Aristotle in his work "Nicomachean Ethics" (Aristotle, 2000) based in Hermagoras of Temnos's method of dividing a topic in seven elements of circumstance or Septem Circumstantiae. Some authorities add a sixth question, "how", to this list, but "how to" information generally fits under what, where, or when, depending on the nature of the information (Table 1).

Studies in recent years related to VTSOs have been tabulated and synthesized in six key epigraphs (Table 2), following the structure mentioned above, gathering essential information about the different investigations about the influence of human factors on safety within the VTSOs' environment.

5.1. Studies (Who, When)

Studies by prolific authors with ascendancy on maritime safety and human factors have been chosen. The authors are therefore related to the maritime environment, either directly having served as merchant marine officers or with a more academic profile, but always related to the maritime domain.

Either way, recent publications were selected for this review since the technological advance in this area affects the performance of the operator positively or negatively, as we will see later.

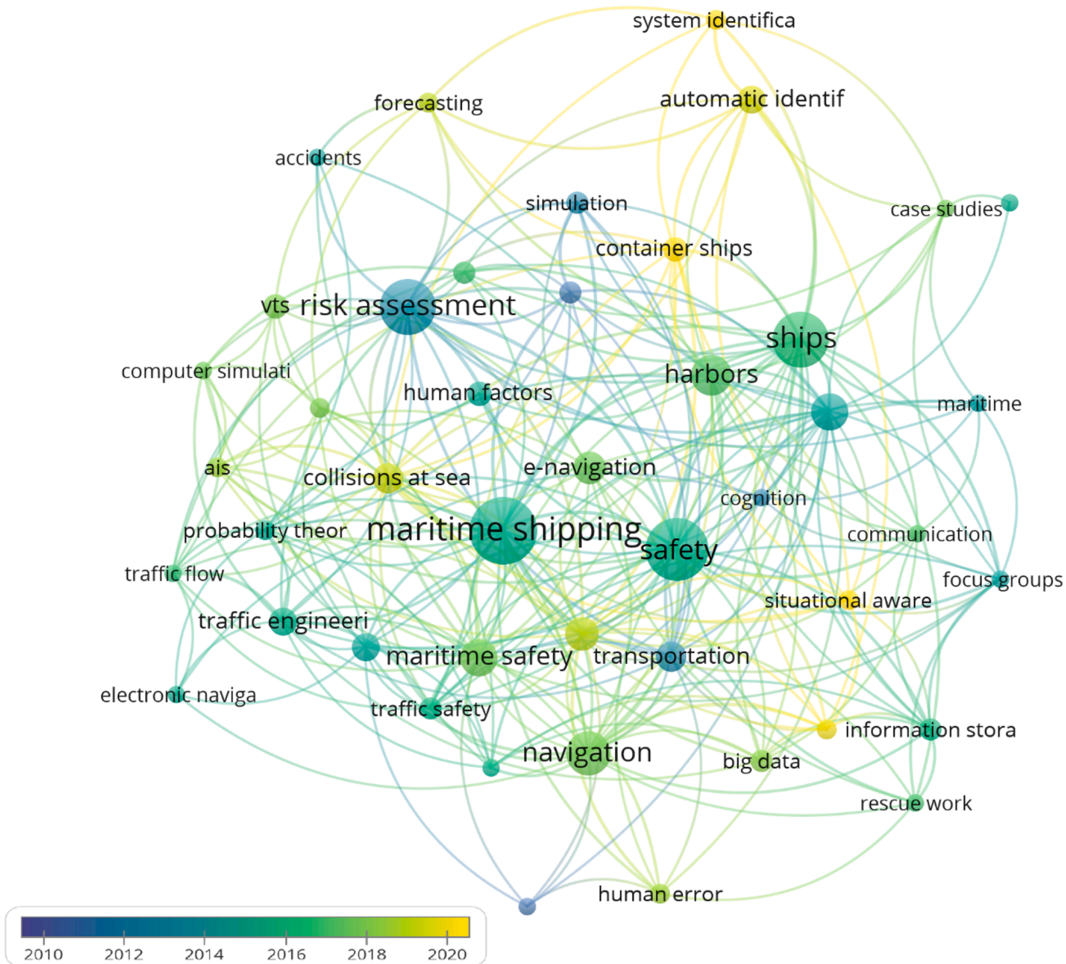

Fig. 10. Temporal evolution of keyword co-occurrence analysis in the 371publications related to safety affecting performance of VTSO from 2000 to 2020, created by VOSviewer.

Table 1
Five Ws principle (and 1H) structure.

Five Ws	**Who**	are the authors of the studies?
	When	was this research published?
	Why	were these factors chosen?
	Where	has this research been developed?
	What	did this research show? (conclusion)
	How	was the data acquisition performed?

The collected studies have been carried out in the workplace during VTSOs' shifts that is to say in real work situations.

5.2. *Safety key point studied (Why)*

In this section, leitmotiv of collected studies is pointed out, all of them based on human factor and inherently related to safety. Most of the authors opted for the analysis of both physical and mental fatigue (Kum and Furusho, 2014; Murai et al., 2015; Yen et al., 2016; Li et al., 2020a, 2020b) or for the organizational structuring of the staff in a complex sociotechnical system depending of teamwork (Praetorius et al., 2015; Mansson et al., 2017; Relling et al., 2019), only one of the studies compiled (Bruno and Lützhöft, 2010) deviates from this trend and analyses communications and trust as a key factor in maritime safety issue.

Therefore, objectives are widely ranged depending on the factor analysed, in the case of studies focused on operators' fatigue as a safety factor, range from fatigue prediction by detecting causal factors to analysing the relationship of fatigue onset with shift work.

On the other hand, the other collected studies for this review that are addressed to the performance and organization of the human factor in a complex VTS system, and along the same lines based on maritime safety, the goal is a greater understanding of the operators' tasks, how they affect communications and in general how activities are carried out in a VTS environment.

However, all these investigations have a common target: to study how the human factor (VTSOs) affects safety of the maritime environment within the VTS area.

Summing up, methodology used to evaluate the influence of human factor in sociotechnical systems were based on task analysis (Praetorius et al., 2015; Relling et al., 2019) or in a categorization and qualitative analysis of data collected (Bruno and Lützhöft, 2010; Mansson et al., 2017) while studies that worked with objective measurements (Kum and Furusho, 2014; Murai et al., 2015) used computerized software analyses methods oriented to the treatment of physiological data obtained through sensors such as heart rate monitor, thermal imaging temperature detector, eye tracking sensor… etc.

5.3. *Sample (Where)*

The studies were conducted at VTS centres where volunteers perform their duties. Operators working on these centres have different tasks depending on geographic situation and providing services (information, traffic organization, navigational assistance), they can also be responsible for issuing berth clearances, and clearances to leave anchorage, and they can besides work closely together with other services, such as pilot

Table 2
Summary of articles related to the influence of human factors on safety within the VTSOs' environment in the last decade.

Year	Author	Safety Point Studied	Data Collection	Analysis Method	Sample
2020	Aylward et al	Impact of new technologies (Sea Traffic Management (STM)) in VTSOs performance	Observational methods and questionnaires (online survey software Qualtrics) using the European Maritime Simulator Network (EMSN)	Analysis by experienced VTS instructor throughout the simulations carried out.	16 VTSOs from 7 EU countries
2020	Li et al. (1)	Fatigue	Interviews & Questionnaires	Hierarchy Task Analysis (based on SHELL model)	68 Singapore VTSOs
2020	Li et al. (2)	Fatigue Prediction	Questionnaire survey	Algorithm (XGBoost)	132 Singapore VTSOs
2019	Relling et al.	VTSOs performance in a complex Sociotechnical System (VTS)	Interviews & Observations	Applied Cognitive Task Analysis (ACTA) and a Critical Decision Method (CDM)	7 Kvitsøy (Norway) VTSOs
2017	Mansson et al.	Teamwork in the Maritime Traffic System (MTS)	Interviews and interactive polling tool	Qualitative Analysis	54 subjects (18 Australian's VTSOs & 31 maritime professionals from different countries)
2017	de Vries	Navigational assistance performed by pilots and VTSOs in a Sociotechnical System	Interviews & Observations	Functional Resonance Analysis Method (FRAM)	7 VTSOs & 9 Pilots, from 5 nationalities
2016	Yen et al.	Mental and Physical Fatigue	Questionnaires	Mathematical model	98 Taiwan VTSOs
2015	Praetorius et al.	VTSOs resilience in a complex Sociotechnical System (VTS)	Interviews & Observations/Workshops	Functional Resonance Analysis Method (FRAM)	8 informants who worked as VTSO in VTS studied from North Europe
2015	Murai et al.	Mental Workload	Thermography (Nasal Temperature)	Timing analysis of temperatures variation in a defined nasal point related to the port coordinator's tasks	7 Hataka (Japan) Port Coordinator
2014	Kum and Furusho	Mental workload factors	Measure of Heart rates Eye movements & Nasa-TLX Questionnaires	Heart rates analysed by Polar software (model S 810i) Eye mark recorder data analysed by Frame-by-Frame method Questionnaires analysed by software SPSS 13.0	8 Istanbul VTSOs (heart rate) 3 Istanbul VTSOs (eye movements) 172 Japan & Turkish VTSOs (questionnaires)
2010	Bruno and Lützhöft	Communication and trust	Literature studies, field research, observations, focus group and interviews	Qualitative analysis	VTSOs from 3 centres: Sweden, Netherland, and Swedish/Danish

service, lock service and tug service.

On the other hand, these studies are concerned about the level of confidence of the sample as they do not express the population size of the studied sector. There isn't information about VTSOs in the world, however, VTS are well established all over the globe, according to IALA (IALA VTS MANUAL, 2021), it is assumed that there are 500 VTS areas that have been monitored with 3 operators per console (on average) and operated in 3 shifts which means 9 operators a day, plus 9 operators' backup for replacement. Examining (Kum and Furusho, 2014) calculations it might be assumed that there are 10,000 VTSOs all over the World and supposing a confidence level of 1 % with a tolerance of $\pm$ 10 %, the sample size should be 164 operators, with these figures only one study meets the minimum, so the interpretation could not be generalized for all VTSOs in the World.

Even more, volunteers in these studies vary widely both in age, gender and VTSOs' experience (Table 3), therefore it is necessary to analyse these factors individually in relation to the key factor studied, having more effect, for example, age factor in the fatigue onset, than in mental workload or teamwork.

It should be noted that in the gender aspect there is still a majority of male volunteers, it is due to the fact that nautical profession continues to have a long male tradition and nowadays there is still a gender imbalance in maritime professions.

5.4. Chosen factors (Why)

Human factors examine the relationship between human beings and the systems with which they interact by focusing on improving efficiency, creativity, productivity and job satisfaction, with the goal of minimizing errors. (Kohn et al., 2000).

Human factors are therefore a key factor in maritime safety and specifically those related to the VTS environment, which is why the collected publications focus on investigating the influence of the human factor on maritime safety, having the VTSOs as a cornerstone.

With this objective in mind, safety, each author has focused on investigating a specific influencing factor that affects operators thus presenting their different conclusions.

Fatigue, teamwork, workload, performance-related resilience, trust, and communication are some of the factors studied and analysed below.

5.4.1. Fatigue studies

VTSOs undergo multidimensional fatigue, and physical fatigue seems to be more serious than cognitive fatigue in VTS (Li et al., 2020a), from this claim, the author analyses the prediction and occurrence of fatigue, emphasizing that there is no clear and widely recognized definition of human fatigue, thus developing a new definition of fatigue based on aspects both physical and psychological: "*Task-related human fatigue is a suboptimal physical, emotional, motivational, cognitive condition caused by a prolonged period of exposure to task-related stimuli*". Following this trend, authors also explore causal of fatigue and identify twelve key causal factors and ten symptoms (five physical, two emotional, one motivational and two cognitive symptoms) of human fatigue in VTS, determining that the 'Language barrier', workload, monitoring problems such as information overlap, unnecessary ship alarms, lack of standardization of markers, etc., are elements that contribute to fatigue onset and can be corrected. The physical fatigue issue is highlighted due to the high probability of suffering this kind of distress, with effects such as tired eyes and stiff neck, so training courses to cope with this fatigue are recommended. These same authors develop a novel fatigue prediction algorithm that considers contextual factors (Li et al., 2020b) and invalidates traditional biomathematical models of fatigue because they are not suitable for VTS due to dynamic working conditions (e.g., traffic density, weather conditions, etc…). However, sleep disorder in operators were not considered in this study so this limitation affects the usability of this model in practice.

Delving into key causal factors (Fig. 11), some authors (Yen et al.,

Table 3
Age, gender, and VTSOs' experience extracted from the analysed studies.

Study	Sample Gender	VTSOs Experience Average	Age Average
Aylward et al, 2020	16 VTSOs (13 men and 3 women). Eight VTSOs were from Sweden, 6 from the UK, and 2 from Norway	ranged from < 1 year to 11–20 years	between 20 and 69 years
Li et al., 2020a	68 Singapore VTSOs (47 males; 9 females) Rest of volunteers no response (response rate 80 %)	11 years	41 years
Li et al., 2020b	132 Singapore VTSOs (119 males; 13 females)	11 years	N/A
Relling et al., 2019	7 Kvitsøy (Norway) VTSOs (all males)	5.3 years	42.4 years
Mansson et al., 2017	54 subjects (18 Australian's VTSOs gender Not Available)	N/A	N/A
de Vries, 2017	7 VTSOs & 9 Pilots (gender Not Available)	Over 20 years	N/A
Yen et al., 2016	98 Taiwan VTSOs (96 males; 2 females)	≈ 15 years	50 years
Praetorius et al., 2015	8 North Europe VTSO (gender Not Available)	6 to 26 years	N/A
Murai et al, 2015.	7 Hataka (Japan) Port Coordinator (5 males; 2 females)	5.39 years	N/A
Kum and Furusho, 2014	8 Istanbul VTSOs (heart rate) (all males) 3 Istanbul VTSOs (eye movements) (all males) 112 Japan (JP) & 60 Turkish (TR) VTSOs (questionnaires) (Turkish are all males but no gender info from Japan)	2.5 years 2 years 5.04 (JP); 2,75 (TR) years	41.1 years 37 years 49.1 (JP); 39.1 (TR) years
Bruno and Lützhöft, 2010	VTSOs from 3 centres: Sweden, Netherland, and Swedish/Danish (gender Not Available)	N/A	N/A

2016) went further and investigated how shift work affected the fatigue onset using for this purpose fatigue questionnaires and mathematical models.

It was concluded that shift work affects sleeping quality, one of the most important factors along with workload, that affects fatigue levels and therefore would be detrimental to the outcome of the controllers work and even cause health consequences due to lack of rest and circadian disorders.

5.4.2. *Teamwork studies*

Teamwork in the maritime traffic system has been identified as an area of concern (Mansson et al., 2017), being the VTSOs, one of the most important pieces of the system by serving as a link between pilots and vessels and monitoring designated waters, ensuring safety into them.

The research target was understanding how everyday activities are performed through qualitative research interviews in which eighteen Australian VTSOs were involved.

A lack of common ground was found in terms of the role of different team members with variable level of involvement by VTSOs, being unclear about what they had to do or should do, further prioritizing administrative tasks or commercial interests over monitoring and interacting with ship traffic (primary task for VTS operators according to international recommendations and guidelines). Concluding that to facilitate coordination and therefore improve security, a further implementation of VTS is suggested.

5.4.3. *Workload studies*

Nowadays, mental workload is an important factor in human error, especially so, when human resources (safe manning) on board have been reduced, it is for that reason that many authors research VTSOs workload as a key factor in maritime safety (Kum and Furusho, 2014; Murai et al., 2015; Yen et al., 2016).

Diverse methods have been used by these authors to characterize operators' workload, (Kum and Furusho, 2014) by data analysis obtained from sensors and questionnaires combination, they found that VTSOs have the greatest mental workload at the beginning of the watch meanwhile they become aware of the traffic conditions in their VTS sector and decrease during the middle of the watch but in contrast performance starts to decline due to tiredness. Furthermore (Yen et al., 2016) they identify workload as an important fatigue factor.

It is also highlighted in this study that the information processed by the operator is delayed due to excessive mental work (the information

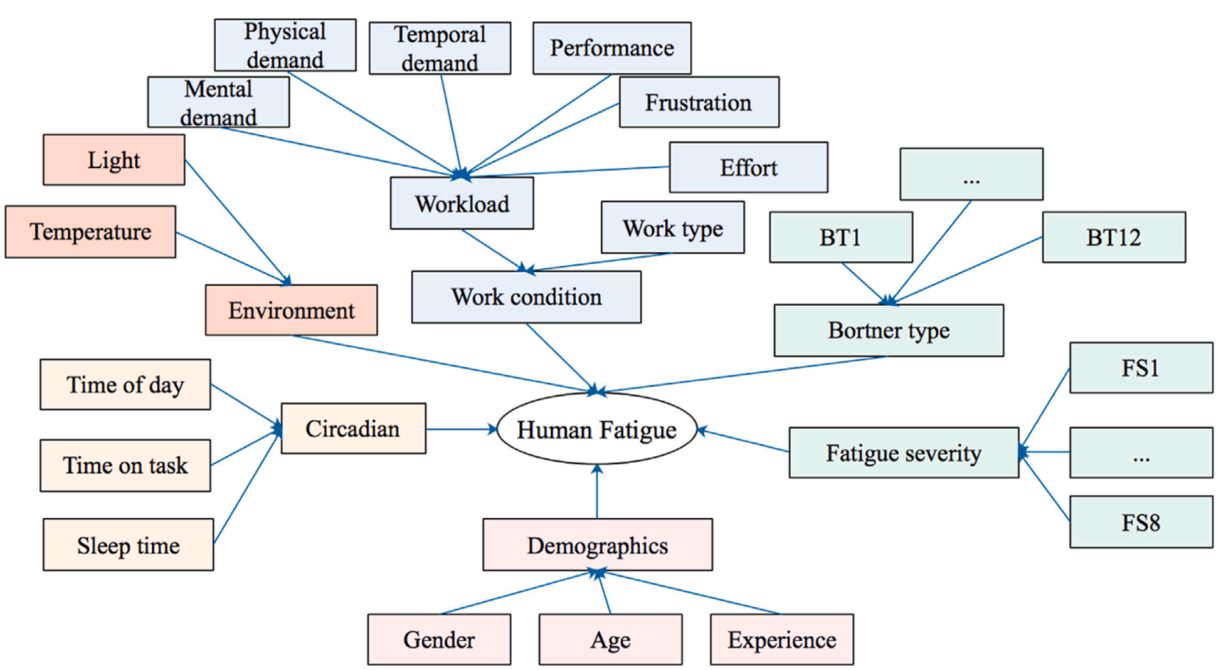

Fig. 11. VTSOs' fatigue causal network (Li et al., 2018).

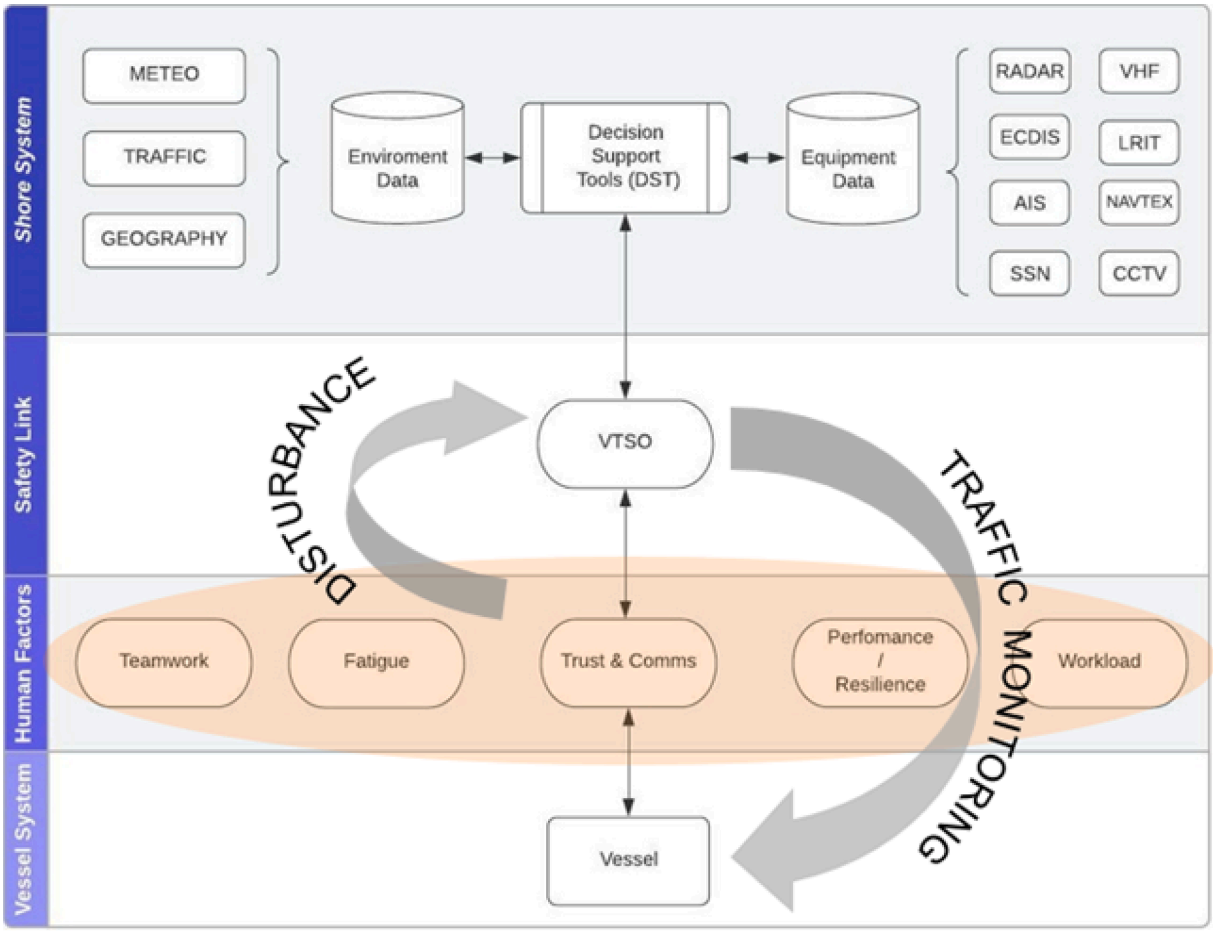

Fig. 12. Cyclic control model adapted to VTSOs' everyday operations related to maritime safety.

exceeds their capacity) on the other hand when the operators have little mental workload, they lose their attention and tend to make mistakes easily.

The study ends by concluding that the mental workload depends entirely on the individual elements and is related to the nature of the task, however, the experience (experience at sea and experience as operator) had a partial effect (beneficial) on mental workload.

On the other hand, (Murai et al., 2015) they used thermography to characterize the workload because the facial temperature is easy to measure with a thermal camera and is able to obtain the data without stress for the subjects since there are no sensors that affect motion. The only limitation is to frame the subject.

This study focused on the temperatures of the facial area, specifically in the nasal tip where the effect of temperatures related to workload is more prominent. The analysis of these nasal temperatures resulted in fluctuations in events with a high concentration of VHF communications, while in periods of relaxation without communications these temperatures increased dramatically, pointing out low workload.

However, previous studies highlight and confirm the importance of the VTSOs' experience; it was shown that in a highly trained veteran coordinator, the nasal temperature remained stable even with periods of high communication, so the mental workload was suppressed by experience.

The bottom line from these results, the nasal temperature decreased when the port coordinator needs the decision-making for supplying useful information to vessels and on the other hand increased when the subject is in relax time or workload were counterbalanced by experience.

5.4.4. *Performance-related resilience studies*

A sociotechnical system in the broad sense, it is refer to how a development of technology involves decisions upon how to distribute competences and functions between humans and technology (Herrmann et al., 2018). At present, the socio-technical theory is accepted as a joint optimisation between social and technical factors (Mumford, 2006; Walker et al., 2008).

On the other hand, FRAM is an analysis tool that reflects resilience engineering close related to safety and provides a method to describe a sociotechnical system as maritime domain (Perrow, 2011).

In this context, VTS are recognized as a sociotechnical systems (Praetorius et al., 2015; de Vries, 2017; Relling et al., 2019) in which VTSOs have to face every day complex interactions caused by area characteristics, organization and services offer, in order to provide an increased ability to anticipate upcoming events. However, complex systems are less flexible and a disruption in one or two functions can spread to a system breakdown that can be counteracted by knowledge and experience, variations in nautical and VTS-experience create variations in the VTSOs (Relling et al., 2019).

Once again experience is pointed out as an important factor to countermeasure negative effects in everyday activities performance.

Finally, both authors propose recommendations to improve the performance of operators' tasks through the implementation of standards that reduce the variety (Relling et al., 2019) and by adoption of a new concept of resilience markers that identify the needs and training requirements based on the models of everyday operations (Praetorius et al., 2015).

5.4.5. Communication and trust studies

New technologies transform the way people interact and can easily be applied to new forms of interaction in general. (Bruno and Lützhöft, 2010) they found that communications are closely related to trust, and state that adapting these means of communication to the context can be used as tool to trust creation based on rather small communicative details, such as tone of voice, clarity of communication or the speed of a read back.

Communication and information exchange have been identified by several studies as a key factors for safe and effective traffic management and navigation assistance (Chang, 2004; Costa et al., 2018; Aylward et al., 2020). Therefore, working in a VTS the main form of direct communication between vessels and shore when underway is VHF radio, and in this way the interviewed VTSOs states sentences about communications like "*It's 90 % of my work", "As a VTS operator, communication is everything, it's all about the communication…*" (de Vries, 2017).

On the other hand, "trust" was defined as an output, or emerging property, of communication functions, some VTS operators describe their "gut feeling" on whether they trust a vessel based on the first radio contact (de Vries, 2017).

Another important result found is that the ability of the shore-based operator to see the situation from the viewpoint of the crew is crucial for the creation and maintenance of trust, somehow a nautical background can be important to reach a situational normality that is a prerequisite for the establishment of role-based trust, hence the importance of a maritime baggage with experience at sea, as opposed to results found by other authors (Kum and Furusho, 2014).

However, there is a maritime simulator study that indicates that the reliance on VHF radio may change with the implementation of additional information exchange services (Aylward et al., 2020).

As a result, trust requires some kind of personal relationship between trusting individuals, but if in temporal systems, built by strangers interacting to achieve a common goal, people with deal each other more as roles than individuals, expectations should be more stable, less whimsical and more standardized hence the importance of standard phraseology used for communication at sea: Standard Marine Communication Phrases (SMCP), that according to VTSOs' interviews is an excellent tool, but due to the maritime environment is a dynamic system, SMCP needs deviations to normal languages in some situations.

In the Fig. 12 we find depicted the relationship between shore system and vessel system through the role of VTSOs (maritime safety link); therefore, their goal, is to promote traffic fluency and safety within the VTS area.

The environment data in the picture refers to meteorological conditions, ship's traffic, geographical limitations (canals, rivers, straits… etc.), while equipment data, are all the inputs from sensors such as Radar, AIS, ECDIS, SNN, LRIT, VHF, CCTV, and whatever other sensor the VTS is equipped with.

The VTSOs in their duties have to deal with the complexity of daily operations and must cope with disturbances or deviations (fatigue, workload, teamwork, communications, resilience) and prepare for it, so that adequate measures can be taken to satisfy future operating demands (traffic monitoring) which means to continuously employ feedback from decision support tools (DST) so that the VTSOs can adapt its actions to the current context and possible future demands.

The operator can choose to interact with a certain vessel or the traffic as a whole, based on the anticipated change in the process or environment to be controlled, namely the traffic within the VTS area. The data, both environment and equipment data, provide sensor input to the DST and the information is displayed on the interface, which is in turn the feedback for the operator.

6. Conclusions

There are several resolutions and guidelines related to the implementation and requirements for the competent authorities and VTS authorities to use to establish VTS services and the subsequent auditing and assessment of those services being the most important the Convention SOLAS Chapter V (Safety of Navigation) Regulation 12 that states that governments may establish VTS when, in their opinion, the volume of traffic or the degree of risk justifies such services apostilling that Contracting Governments planning and implementing VTS shall, wherever possible, follow the guidelines developed by the Organization, specifying that the use of VTS may only be made mandatory in sea areas within the territorial seas of a coastal State.

Nonetheless, in terms of governance related to VTS, there is lack of standardization, despite IMO Resolution A.857 (20) that provides guidelines and criteria for VTS operations that are associated with SOLAS Regulation V / 1/7/02, so for that reason, sovereign States establish varying levels of authority and service provisions to traffic control services and consequently, different models of VTS implementation emerge (public or private).

Thus, the studies compiled in this review show different types of VTS as Port Radios, Coastal VTS, Information Service (INS), Traffic Organization Service (TOS), Navigational Assistance Service (NAS), even a few countries (Spain, Italy, France, South Korea… etc.) have adopted more complex models of joint integration of traffic services and rescue and search operations, resulting in Maritime Rescue Coordination Centres (MRCC) or in Joint Rescue Coordination Centres (JRCC) if it encompasses the aeronautical and maritime environment.

However, IMO, being aware of this problem, in January of 2020, through the IMO's Sub-Committee on Navigation, Communication and Search and Rescue (MSCR 7) met and discussed the IMO-VTS guidelines in order to revise the IMO Resolution A.857 (20), sanctioned this revision in the 102nd session of Maritime Safety Committee with several important changes as show in Appendix A, and which clarify the obligations of contracting governments about VTS and developing a regulatory framework for their establishment.

Currently, the operational requirements depend on several conceptual and technical requirements (IALA G1111, 2022) such as:

- Delineated of VTS area and, if appropriate, VTS sub-areas or sectors.
- Type of services to be provided (INS, TOS, NAS).
- Types and sizes of vessels which are required or expected to participate in the VTS.
- Navigational hazards and traffic patterns.
- Human factors including health and safety issues.
- Operational procedures, staffing level and operating hours of the VTS; etc.….

Therefore, in these studies, data collection is subordinate to the functions assigned to the operators, which depend on the operational requirements mentioned above being the most important aspect both geographical location (Coastal, Port) and type of service offered (INS, NAS, TOS), (IALA S1040, 2018; IMO A.857(20), 1997) which will affect the results obtained, being difficult to extrapolate to other centres that do not have the same workload, traffic density or communications.

Most of these studies found experience (both nautical and as operator) together with standardization (organization, communications, services, etc.…), to be essential to counteract the negative effects of the rest of the factors studied, related to the maritime safety: fatigue, workload, teamwork, resilience, performance, trust, and communication.

Consequently, in all studies experience stands out as one of the most influential factors in each of the objectives pursued:

(Bruno and Lützhöft, 2010); Communication and Trust: *"It was also generally understood that more experience with the use of a particular service led to more trust in that service…"*.

(Kum and Furusho, 2014); Mental workload factors: *"It was obtained that the experience (experience at sea and experience at VTS) had partial effect on the mental workload. Operators had less experience to feel higher mental workload than those who had more experience"*.

Types of Service (INS, TOS and NAS)

A.857(20)	A.1158(32)
• Was subjective and open to broad interpretation and debate. • Caused confusion to stakeholders, particularly masters of vessels navigating in different VTS areas. • Concern that services are not being declared or delivered globally in a consistent manner.	• All reference to "Types of Service" have been removed. • Emphasises the purpose of a VTS in mitigating the development of unsafe situations through: ✓ providing timely and relevant information ✓ monitoring and managing ship traffic ✓ responding to developing unsafe navigational situations. (*Section 3*)

Changing traditional boundaries

A.857(20)	A.1158(32)
• Silent on the ways that a VTS may contribute to the safety of vessel traffic and the protection of the environment beyond territorial waters.	• Recognises VTS may be established beyond the territorial sea: - In association with an IMO adopted ships' routeing system or mandatory ship reporting system, in accordance with regulations V/10 and V/11 of the Convention. - To provide information and advice on the basis of voluntary participation. (*Sections 4.4 and 4.5*)

Recognition of IALA Standards

A.857(20)	A.1158(32)
• Did not recognise IALA Standards and associated Recommendations, Guidelines and Model Courses. • The guidance and terminology was limiting and complicated the development and modernisation of IALA guidance in a range of areas.	• Recognises: o IALA as an important contributor to IMO's role and responsibilities relating to VTS (*Section 1.3*) o IALA Standards and associated recommendations, guidelines and model courses specifically related to the establishment and operation of VTS (*Section 9*)

VTS and Future Developments

A.857(20)	A.1158(32)
• Did not provide a framework to accommodate new trends o e.g. Maritime Services, e-navigation, Sea Traffic Management, etc.	• Recognises Governments should take account of: o Applicable IMO instruments and refer to the relevant international guidance prepared and published by appropriate international organizations. (*Section 1.4*) o Future technical and other developments recognized by the Organization relating to VTS (*Section 5.1.4*)

VTS Qualifications, Training and Certification

A.857(20)	A.1158(32)
• Annex 2 was: o Overly prescriptive – some 12 pages; o Dated; and o In conflict with, or constraining the necessary continued development of modern IALA training Recommendations, Guidelines and Model.	• Recognises IALA Standards and associated recommendations, guidelines and model courses specifically related to VTS Qualifications, Training and Certification (*Sections 8 and 9*)

Role / Responsibilities of the Competent Authority / VTS provider

A.857(20)	A.1158(32)
• Overly prescriptive on the respective responsibilities. • Did not recognise circumstances may differ due to national law.	• Concisely describes the responsibilities at a high level. ➢ Contracting Government – establish a legal basis for VTS that gives effect to regulation V/12 of the SOLAS Convention ➢ The Competent Authority is seen as the *Regulator* ➢ The VTS Authority as the *Provider* - responsible for management, operation and coordination of the VTS. (*Section 5*)

Fig. 13. Key changes between Regulations A.857 and A.1158 ().
Source: IALA, 2022

(Murai et al., 2015); Mental workload: *"We think that this result depends on the experienced years. …., the mental workload was suppressed by the experience"*.

(Praetorius et al., 2015); Resilience in a complex Sociotechnical System: *"VTSOs are educated according to recommendations and guidelines but previous experience at sea as well as working experience as VTSO can affect the way in which this functions"*.

(Relling et al., 2019); Performance in a complex Sociotechnical System *"The VTS operators' experience, such as their background and years of service, is a major source for coping with complexity. The experience affects how the VTS operator gathers and interprets information from the environment"*.

(Li et al., 2020b) Fatigue prediction: *"…it has been found that personalities, experience, gender, and age would affect the experience of fatigue"*.

Nevertheless there is controversy between authors regarding the experience in its double aspect, both nautical or VTSO, while (Kum and Furusho, 2014) states that there was no significant difference between the operators who have a maritime background and those who have not, (Relling et al., 2019) find that variations in nautical and VTSO experience create variations in the operators' response.

As a final thought, these studies manage to identify the causal factors of the decrease in operability, performance, effectiveness of the human factor on VTSOs and therefore, the decrease of maritime safety, but as we can see from the data obtained, they are difficult to extrapolate due to the unique conditions of each centre.

Furthermore, the characterization of the data should be re-evaluated in most of these studies, since only psychological or physiological measures are collected, where several factors such as fatigue, workload, etc., are affected by both.

As future work, a study on VTSOs and work experience counter effect over fatigue is proposed, as it is the most recognized factor in maritime accidents and therefore strictly related to maritime safety.

For this reason, the characterization of the fatigue onset, through the use of specific tests (NASA TLX, BORG, Stanford Sleepiness Scale,…etc.), by contrasting the results with the data obtained from the analysis of physiological signals through non-invasive sensors, such as thermographic cameras, a sensor with which this author is familiar (Crestelo et al., 2018), appears to be a prerequisite for producing further comparable studies in order to predict fatigue, evaluate the quality of evidence, and thus guide concrete actions in the field of maritime safety.

CRediT authorship contribution statement

F. Crestelo Moreno: Conceptualization, Writing – original draft, Methodology, Investigation. **J. Roca Gonzalez:** Supervision. **J. Suardíaz Muro:** Supervision. **J.A. García Maza:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Introduction to IMO resolution A.1158 (32) guidelines for vessel traffic services

When the 32nd session of IMO assembly approved the revised guidelines for Vessel Traffic Services on the 15th of December 2021 this was the end of a long thorough and determined revision initiated and prepared by the VTS committee.

In fact, this VTS committee in 2003, already had a revision of the IMO Resolution A.857 on the agenda; however, for several years it would not considered an urgent and compelling need for the resolution to be revised as it also had to be brought up on the agenda of the Maritime Safety Committee of IMO.

However, a lot of work and many discussions have been done between the IALA VTS committee and IMO Maritime Safety Committee during these years, and as a result of these meetings several reasons were exposed for carrying out this regulation revision, such as:

- Clarity on the role of the Competent Authority and VTS Authority,
- Accommodating new developments such as the e-Navigation Maritime Services,
- Doubts over the interpretation and application of the types of service,
- Improvements in VTS communications,
- Developments in VTS qualifications, training and certification, and.
- The international recognition of IALA standards.

Finally, in December 2021 the Resolution A.1158 (32) was approved by IMO assembly, updating 27 IALA's recommendations and guidelines to ensure that VTS documents align with the new resolution, with three of them being extensively revised to reflect the new IMO resolution changes:

- G1089 – Provision of a VTS - updated to reflect the change associated with removal of 'types of service' and clarification on the 'purpose of VTS'.
- G1132 – VTS Voice Communications and Phraseology - new section with standardised operational phrases.
- G1141 – Operational Procedures for Delivering VTS - updated to comply with the new resolution and amendments to the above guidelines.

In summary, six important changes are introduced compared to the Resolution A.857 (Fig. 13):

- Types of VTS Services
- Change of traditional boundaries
- Recognition of IALA Standards
- VTS Future Developments
- VTS Qualifications, Training and Certification, and
- Role/Responsibilities of the Competent Authority / VTS provider

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