Addressing Seasickness of Technicians on board Working Vessels

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Abstract - As the number and size of offshore wind farms grow, so does the demand for technicians and crew transfer vessels (CTVs) for maintenance. Operations and maintenance account for approximately one-third of a turbine's life-cycle costs, highlighting the critical role of CTVs and technicians. The hazardous conditions demand the well-being and concentration of technicians to prevent catastrophic events, making it essential to address motion sickness to improve their work environment. This paper is a systematic literature review investigating approaches for quantifying motion sickness and their application to CTVs. Additionally, it aims to develop a general understanding of motion sickness and its preventive measures. The review reveals limited literature addressing motion sickness on smaller vessels, indicating a need for more research. Motion sickness is primarily quantified through theoretical or empirical models and questionnaires, with the Motion Sickness Index (MSI) being the most widely applied method. However, MSI's reliance on vomiting as an indicator neglects preceding symptoms that impact work ability. Moreover, it focuses solely on vertical accelerations, which is insufficient when considering the motion of smaller vessels. Overall, a method that considers a broader range of symptoms beyond just vomiting and incorporates the specific motions of smaller vessels is needed.

Keywords: Sea Sickness; Vessels; Offshore Wind Farm; Crew Welfare; Operations and Maintenance

INTRODUCTION

In the efforts of meeting international goals for reducing greenhouse gas emissions while balancing the rising energy demands, the number of installed offshore wind turbines has increased extensively over the past decades and is expected to continue increasing [1]. As the number of wind farms rises, so does the demand for technicians and crew transfer vessels (CTVs) to handle the necessary maintenance activities. Operations and maintenance for offshore wind turbines constitute approximately one-third of their overall life-cycle costs [2], emphasizing the critical role of CTVs and the technicians. The hazardous work environments in the offshore wind industry demand technicians' well-being and high levels of concentration to prevent catastrophic events, with motion sickness posing a significant risk to their work ability. Although seasickness is an age-old issue, it remains a relevant problem that warrants further investigation in the maritime industry. Besides enhancing the work environment for technicians, assessing motion sickness on CTVs would also provide financial advantages for wind site owners.

This paper is a systematic literature review, primarily aiming to investigate approaches for quantifying motion sickness and examine their application to smaller vessels such as CTVs. To better understand these approaches, the study also aims to develop a general understanding of motion sickness and its preventive measures. The paper is structured as follows: First, the methodology of the systematic review is explained. The findings are then presented, followed by a discussion of the results and concluding remarks.

METHODS

The review is conducted as a systematic review, where multiple bibliographic databases are searched using block search syntaxes consisting of Boolean operators. Inspired by the concept of PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) diagrams [3], the flow of the review process is visualized in Fig. 1. The following section elaborates each of the illustrated subphases in the figure.

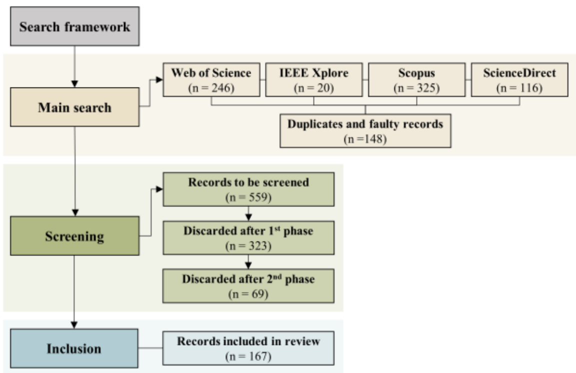

Fig. 1: Overview of review process.

A. Search framework

The search framework defines the boundaries of the main search by performing a scoping search to assess the efficiency of different term combinations. It also outlines the practical aspects of the main search, including search parameters, databases, and bibliographic management software. This section summarizes each of these aspects.

Scoping search

The scoping search is conducted using the open public access catalogue (OPAC) Summon [4] and involves multiple trials with different key terms and search blocks to balance quantity and relevance. The latter is evaluated using Summon's built-in relevance ranking function and the authors' assessment of whether the highest-ranked records effectively address the review's purpose. The scoping search reveals that syntaxes must include terms related to the condition (motion and sea sickness) and the transport object (vessels).

Search parameters

The parameters for the main search include language (restricted to English), content type (encompassing everything from conference papers to chapters of books), data fields (title, abstract, and keywords), and date of publication (all times). Fig. 1 shows that four bibliographic databases are utilized for comprehensive coverage. Due to the health scientific and technical nature of motion sickness, the chosen databases have cross-disciplinary properties. Records from the main search are managed using the bibliographic management software EndNote [5].

B. Main search

Once the general search syntax and parameters are defined, specific search syntaxes are tailored for each database and applied accordingly, see Fig. 2. The main search was conducted on 6 June 2024. Duplicates and records with faulty information are removed as a preliminary step before the screening phases, as illustrated in Fig. 1.

C. Screening

The screening process consists of two phases. The first phase involves reviewing titles, abstracts, and keywords to exclude irrelevant records. The following exclusion criteria are defined:

- Highly irrelevant
- Motion sickness related to animals

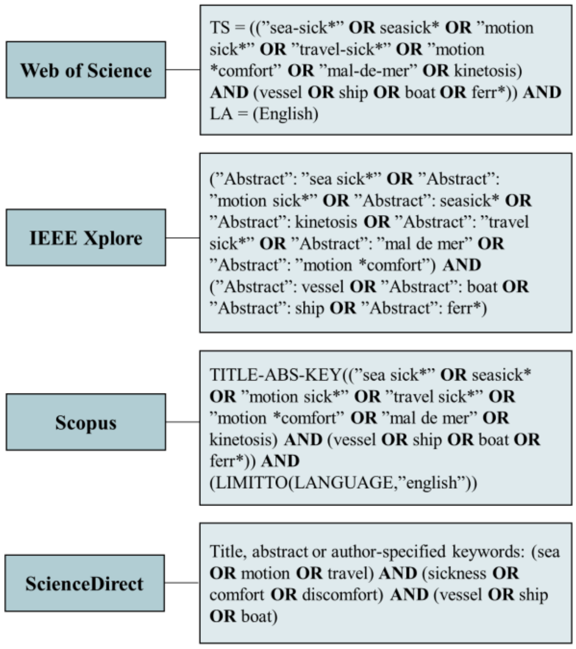

Fig. 2: Search syntax applied in each database.

- Motion sickness related to specific transport objects other than vessels
- Focus on pure discomfort rather than motion sickness

The second screening phase assesses the availability of full text for the remaining records. The numbers of discarded records are shown in Fig. 1.

D. Inclusion

Based on the work conducted in the phases illustrated in Fig. 1, a total of n=167 records are included in the review.

RESULTS OF REVIEW

In the following section, the processing of the included records is presented. Based on the objectives defined in the introduction, findings can be categorized into two main purposes:

- Understanding motion sickness
- Quantifying motion sickness

The following sections will summarize the findings obtained from the records for each objective.

A. Understanding motion sickness

Motion sickness is a complex matter. While the review's focus is quantification of motion sickness, a basic understanding of the phenomenon is required. The following section outlines general findings on the condition and preventative measures.

Motion sickness in general
Motion sickness refers to the sickening discomfort experienced in various motion environments. Common symptoms include dizziness, drowsiness, and reduced alertness [6]. Experiments have also demonstrated an increase in skin pallor [7] and sensitivity to smells [8]. More severe symptoms range from sweating, salivation, and headache to nausea and vomiting [6, 9].

Motion as provocator
According to [10], factors governing susceptibility to motion sickness can broadly be categorized into two groups. The first category involves physical stimuli related to motion and movement, while the second group includes individual characteristics such as experience, age, gender, pathology, and ethnic origin [11]. This section focuses on how physical stimuli provoke motion sickness.

One proposed explanation for motion sickness is the postural instability theory. The theory suggests that individuals who struggle to maintain this postural stability in motion environments are more susceptible to motion sickness [12]. Another widely recognized theory is the sensory conflict theory. This theory claims that motion sickness arises from a mismatch between actual and expected signals from the vestibular, proprioceptive, and visual systems, referred to as intersensory conflict [13]. Motion sickness can also be induced by intrasensory conflicts [10, 14].

Prevention
Efforts to prevent motion sickness are ongoing. These efforts include pharmacological approaches, alternative medicinal plants, behavioural strategies, and movement reduction, all summarised in the following.

There are various pharmacological approaches to treat motion sickness, many of which are listed in [9, 15]. However, the side-effects such as drowsiness may limit their use in some settings, as they can impact working performance [11, 16, 17].

In addition to pharmacological drugs, alternative medicinal plants like ginger, peppermint, lemon, and oral vitamin C have proven effective in suppressing symptoms [9, 16, 18].

Non-drug behavioural strategies are also recommended to supress symptoms. Such strategies include focusing on the horizon or a distant point, practicing active deep diaphragmatic breathing, and using mental distraction techniques [16].

While no single countermeasure can eliminate all symptoms, combining remedies can reduce the risk of motion sickness [16]. Despite individual differences in susceptibility, most humans can develop habitation to motion patterns over time with spaced exposure [9].

An evident prevention involves minimizing movements of the motion environment. Among the included records, n=19 records do not provide any theoretical nor experimental justification for reducing specific motions to mitigate motion sickness. The detailed list of records can be found in [19].

B. Quantifying motion sickness
Quantification of motion sickness is based on models and questionnaires in the reviewed literature. Fig. 3 provides an overview of the most applied models for assessing motion sickness, along with the number of records employing each model. A corresponding figure, Fig. 5, lists employed questionnaires. Some records use both models and questionnaires, resulting in multiple counts for the same records. For details on methods not elaborated in the following, see [19].

Models
As depicted in Fig. 3, the reviewed models are predominantly based on either empirical approaches or theoretical frameworks.

Despite the sensory conflict hypothesis often being qualitatively formulated, efforts have been made to develop physiological models based on mathematical formulations. One such example is the subjective vertical conflict motion sickness model (SV-conflict model) [13]. The model is a simplification of Oman's theoretical model [20], which suggests that motion sickness relates to the vector difference between afferent and expected sensory information, with higher differences indicating an increased risk of seasickness. The SV-conflict model challenges the conventional conflict sensory theory by only focusing on the conflict between the sensed and subjective vertical.

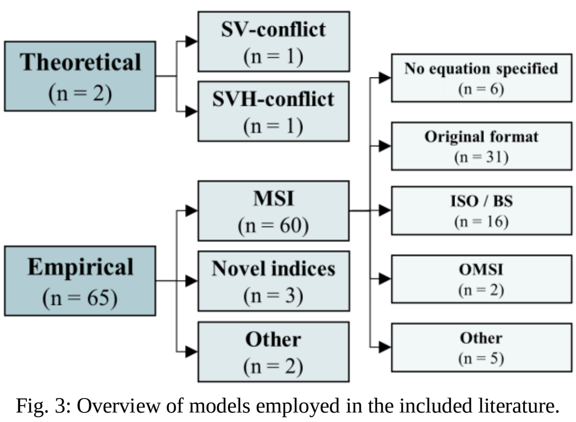

Fig. 3: Overview of models employed in the included literature.

The theory has been experimentally verified using all six degrees of freedom, finding that lateral accelerations on high-speed crafts contribute to motion sickness more than initially believed [21]. Another theoretical model is the subjective vertical-horizontal-conflict (SVH-conflict) [22], which explicitly incorporates a horizontal dimension to the SV-conflict model. The model has been validated through 68 field trials of 10 different vessels, statistically outperforming the SV-conflict model [23]. Among the included literature, n=1 record employs the SV- and SVH-conflict theory, respectively.

Being an empirical model, the Motion Sickness Incidence (MSI) is the most supported quantification of motion sickness in the reviewed literature. The model is an empirical model based on a series of simulator experiments conducted in the 1970’s [24, 25]. It predicts the percentage of subjects likely to vomit after 2 hours of exposure to vertical oscillations with specific acceleration and frequency, focusing exclusively on heave motions. Pitch and roll were not included in the model, as the experiments indicated that combining heave with either pitch or roll induced similar levels of motion sickness as heave alone, a finding that also surprised the authors [25]. The MSI has undergone many later iterations, but the experimental basis remains the same. From Fig. 3 it appears that a total of n=60 records employ the MSI in one formulation or another.

One widely employed MSI formulation is the one standardised in the International Standard ISO-2631/1 and in British Standards BS-6841 as the Vomiting Incidence (VI) [26, 27]. Under continuous motion exposure of constant magnitude, the percentage of individuals likely to vomit is determined by the Motion Sickness Dose Value (MSDV), depending on the frequency weighted vertical acceleration, and a constant accounting for population characteristics.

Ref. [28] proposes a modified version of the MSI known as the Overall Motion Sickness Incidence (OMSI). It calculates a mean MSI across the deck, considering variations in vertical motion across the ship's breadth and length for specific sea-states and heading angles. The OMSI has been utilized in modelling wave-piercing high-speed catamaran vessels [29].

When considering the remaining empirical formulations, Fig. 3 shows that n=3 records propose novel indices. For instance, [14] modifies the ISO/BS MSI to include passenger behaviour and adaption effects, introducing the Sickness Portion Ratio (SPR%). The MSDV is modified such that vertical accelerations are calculated based on heave, pitch, and roll motions, rather than just heave motions. Another novel index is proposed in [30], where a seasickness ratio is derived based on experiments conducted aboard a training ship. Unlike the MSI and related formulations, this index is based on questionnaires with three levels of seasickness (alright, unwell, vomited), providing a more nuanced assessment. The model incorporates both vertical and lateral accelerations, as well as exposure duration. A third novel index in the reviewed literature is based on data conducted aboard a CTV [31], where seasickness is predicted based on subjective symptoms and accelerations in three degrees-of-freedom.

Vessels

A number of n=3 records specifically address motion sickness aboard CTVs, with n=2 records employing the MSI as motion sickness model. A wide range of records do not specify the purpose of the considered vessel, such as a CTV, but instead solely mention vessel type like catamaran, monohull, or high-speed craft. Given the diverse shapes and designs of CTVs, examining their properties such as length can be valuable, as these characteristics may be similar to those of CTVs. Fig. 4 depicts the motion sickness model applied to each vessel, including their respective lengths where available. The authors define a small vessel as one that is 50 meters or less in length. From the figure, it is evident that motion sickness models are primarily evaluated on larger vessels, with the exception of the novel indices.

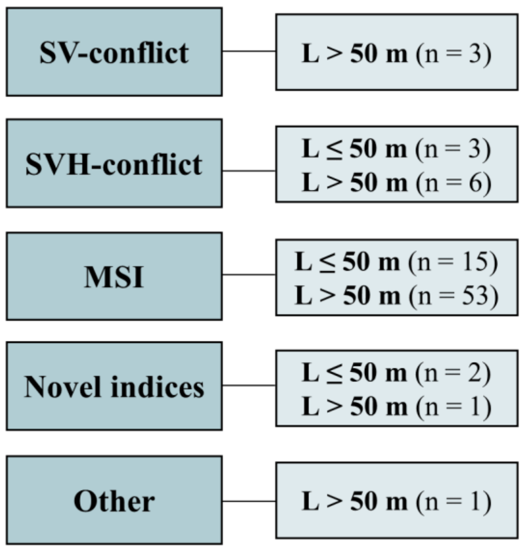

Fig. 4: Interval of lengths and corresponding number of vessels. Note: n=18 records do not provide details on dimensions and are therefore not included.

Questionnaires

Fig. 5 provides an overview of the questionnaires used in the reviewed records, categorized into two main types. The first assesses motion sickness susceptibility, while the second measures motion sickness severity, either integrated into empirical models or through symptom factor analysis without direct model incorporation. It is seen that n=19 records quantify susceptibility, while n=51 quantify motion sickness severity.

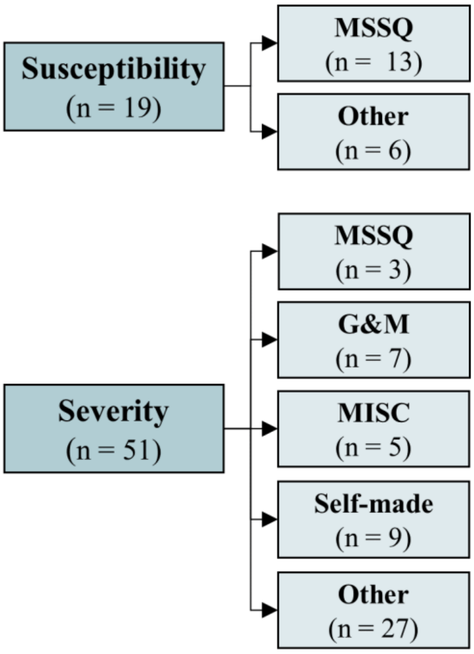

Fig. 5: Overview of questionnaires employed in the included literature.

Fig. 5 shows that the Motion Sickness Susceptibility Questionnaire (MSSQ) is widely used [32], with n=13 records employing it to assess susceptibility and n=3 records using it to assess motion sickness severity. The MSSQ exists in short and long versions [33-35].

The most employed questionnaire for quantifying motion sickness severity during and after exposure is the Graybiel and Miller (G&M) scale, where nausea symptoms are reported through a scoring system [36]. A total of n=7 records utilize this scale for quantifying motion sickness.

Another frequently employed questionnaire to quantify motion sickness is the Misery Scale (MISC), which assigns scores based on experienced symptoms [37]. A total of n=5 records employ the MISC.

Fig. 5 shows that n=9 records employ self-made questionnaires that, like official ones, focus on quantifying symptom severity or assessing susceptibility.

DISCUSSION

Several key points emerge from the conducted analyses. A general observation is that a range of the included records lack explicit and detailed argumentation for reducing vertical motions. This suggests a presumption that vertical accelerations are the primary cause of motion sickness regardless of vessel types, despite multiple studies demonstrating certain effects from lateral motion on motion sickness [21, 31]. One reason for this presumption could be the widespread popularity of the MSI, which focuses on vertical heave accelerations. From this review, it is seen that n=60 records apply a form of MSI. The experimental basis of the MSI has been questioned, as the rationale for excluding pitch and roll effects stemmed from simulator experiments that included conditions of heave only, pitch only, roll only, and combinations of heave with pitch or roll [25]. Ref. [38] suggests that strong heave motions may mask the effects of pitch and roll in smaller vessels. This was experimentally verified, showing that the combination of pitch and roll with small heave motions induces more motion sickness than predicted by the original models [38]. Another critique of the study setting the basis for MSI, is that the influence of infrasonic sound pressure level present in cyclic motion was not considered as a nausea influencing factor [39]. Despite limited correlation between the model's assumptions and smaller vessels' motion conditions, the MSI and its subsequent formulations remain highly trusted cornerstones of motion sickness research. This can lead to improper application of MSI to vessel types for which it is unsuitable. The review suggests a certain bias towards the MSI, likely due to its long history and widespread use in research settings. One of the conducted analyses reveals that n=15 records employ the MSI on smaller vessels, which significantly differ from large ones, such as passenger ferries and naval vessels.

Another point to address regarding the MSI is its straightforward application, favored in the industry for its simplicity and objectivity. However, relying solely on vomiting as an indicator of motion sickness neglects preceding symptoms. Technicians must perform work tasks under hazardous circumstances upon arriving at the wind farm, highlighting the importance of considering the impact that preceding symptoms such as dizziness, drowsiness, and reduced alertness have on their work ability. Thus, a more sensitive model that includes a broader range of symptoms would be advantageous, especially for a limited population aboard. However, a great drawback of measuring symptoms rather than just occurrences of vomiting is the subjectivity inherent in self-reporting.

Another point to be made is the range of records focusing on reducing sickness in passenger ferries due to the high number of daily passengers and potential financial losses from poor travel experiences. Despite fewer people aboard CTVs, the financial motivation for developing a motion sickness model specifically for working vessels should not be underestimated. The offshore wind market is expected to grow significantly in the coming years, resulting in an increased demand for technicians. The conducted review reveals that habituation to motion patterns can be developed, emphasizing the importance of addressing seasickness to retain new technicians in particular.

CONCLUDING REMARKS

Analyses of the included literature reveal that current motion sickness assessment primarily focuses on larger vessels, whose purposes and properties differ from those of CTVs. The most employed method to quantify motion sickness is the MSI. Although roll and pitch motions are more pronounced in smaller vessels, the MSI remains foundational in motion sickness assessment across vessel types. Moreover, the analyses suggest that motion sickness should be understood as a spectrum of preceding symptoms, rather than solely vomiting as done in the MSI. Overall, a method that considers a broader range of symptoms beyond just vomiting and incorporates the specific motions of smaller vessels is needed.

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