Expert elicitation of Risk Control Options to reduce human error in winter navigation

O.A. Valdez Banda, F. Goerlandt, P. Kujala & J. Montewka

ABSTRACT: Navigation in ice conditions possess a higher degree of complexity than open water navigation. This complexity has a significant influence in the human performance during the execution of operations. In this paper, a detailed expert elicitation to assess Human Error Probabilities (HEPs) and proposed Risk Control Options (RCOs) in the performance of winter navigation is presented. For this purpose, an evaluation of the Common Performance Conditions (CPCs) of winter navigation operations and the influence from proposed RCOs is elaborated. The process includes the estimation of cognitive failure probabilities extracted from the experts' elicitation which are subsequently integrated into a Bayesian network model. The results of this analysis identified the operations with the highest need for new actions which can reduce the HEPs. Moreover, actions such as the improvement of winter navigational training, safety and risk management, and electronic navigation support, are identified as key measures to improve human performance.

1 INTRODUCTION

Severe ice conditions, weather conditions, and winter navigation expertise are marked as the most relevant factors influencing the performance of the operations by ships navigating in ice conditions (Valdez Banda et al., 2015). Ship-to-ship collision is the type of accident mainly occurred during winter navigation operations in the Baltic Sea. The severity of the majority of the reported collisions is low. As in other analysis of maritime accidents (Lu and Tsai, 2008; Macrae, 2009), human error is a representative input in the identification of causes of the collisions between ships navigating in ice (Valdez Banda et al., 2015: Jalonen et al., 2005).

In this study, a detailed expert elicitation process for evaluating proposed Risk Control Options (RCOs) for reducing human error in the performance of maritime winter navigation is presented. The aim is to construct a model which is able to probabilistically assess several key factors influencing the cause of potential human errors. These factors are adopted from the framework: Cognitive Reliability Error Analysis Method (CREAM) proposed by Hollnagel (1998) as simplified in He et al. (2008). In order to build the model structure and probabilistically analyze these components, a Bayesian belief networks is elaborated. Thus, the output of this analysis detected specific safety and risk control areas demanding particular attention and the suggestion of determined actions which attempt to reduce the probability of human error and subsequently improve the performance of winter navigation operations.

The rest of the paper is organized as follows. Section 2 describes the general background analyzed in this study. Section 3 presents the methods and data utilized in the presented analysis. Section 4 presents the results of the analyses performed for the assessment of human error and its influence in the development of winter navigation operations. Sections 5 discusses the research findings, and Section 6 presents the final conclusions and recommendations.

2 BACKGROUND

2.1 Ship navigation operations in ice conditions

Winter navigation operations are divided in two general categories: ship independent navigation and icebreaker assistance operations (Valdez Banda et al., 2015). Ship independent navigation comprehends the navigation of merchant vessel in ice conditions without receiving any operational on-site support from any other ship, including icebreakers. Based on previous risk analyses (Valdez Banda et al., 2015: Jalonen et al., 2005) this operation is identified as the most complex operation due to the circumstances in which the operation is performed: isolation and high dependency on master and crew expertise. In the case of icebreaker operations, these are commonly divided into five subcategories (Rosenblad, 2007):

- Escorting: an icebreaker is escorting when it breaks an ice channel and the assisted ship follows the icebreaker at a recommended distance.
– Breaking a ship loose: an icebreaker is breaking a ship loose (or cutting loose) when it passes a ship that is stuck in ice from a close distance and breaks the ice beside and in front of the assisted ship, thus releasing it from ice pressure.
– Convoy: the operation is similar to escorting but in this case there are several ships following the icebreaker. The distances between the convoy vessels should be long enough to allow the following vessels to stop if the ship in front is stuck.
– Double convoy: two icebreakers are involved in a double convoy operation when a second icebreaker travels ahead or behind and slightly to the side of the first icebreaker in a convoy operation. This occurs when the vessel(s) in the convoy has a larger breadth than the icebreakers.
– Towing: an operation occurring when a ship cannot follow an icebreaker because the ice pressure makes the channel close quickly, the channel has too much slush ice, and/or the assisted ship does not perform appropriately in ice. An icebreaker may be towing one vessel while simultaneously leading a convoy.

2.2 Winter navigation experts in the Gulf of Finland

The Gulf of Finland is one of the most ship transited maritime areas in the world (Kujala et al., 2009; Lappalainen et al., 2011). The navigational areas covered by the Gulf of Finland included maritime zones managed and controlled by three countries: Finland, Estonia and Russia. The traffic mainly registered during winter time in these areas accounts for 30% to general cargo vessels, 25% to oil and chemical tankers, 12% to containerships, 8% to ro-ro and passenger ships, 6% to bulk carriers, and the remaining 19% to different type of vessel e.g. LNG vessels, ro-ro cargo, reefers, among others (HELCOM, 2011). Current maritime trends and prognosis of traffic for the Gulf of Finland estimated a continuous increment of the traffic from oil tankers and LNG vessels (Kujala et al., 2009; Wang et al., 2013). This is based on the constant increase in the transportation of oil and gas from Russia.

Winter navigation experts from the three countries connected by the Gulf of Finland have detected these trends since the 1990s and have also evidenced these increments in the last ten years. Therefore, different actions have been implemented to ensure the safety of the operations performed during winter time, including the preparedness of an efficient emergency response capability for accidents produced by oil and chemical tankers (Goerlandt et al., 2012; Goerlandt and Montewka, 2015; Gucma and Przywarty, 2008; Lehikoinen et al., 2015; Montewka, 2009; Montewka et al., 2011; Sormunen et al., 2014).

In this study, the considered experts for the elaboration of the presented analysis included captains, ship officers, and personnel with experience in the operations performed in the bridge of merchant vessels, with capability for ice navigation, and icebreakers. The intention is to focus and limit the operational environment in which the analysis of human error is performed. A complete description of the consulted experts, the analyzed common performance conditions of winter navigation operations, and the implemented methodology of evaluation are presented in the next section.

3 RESEARCH METHODS AND DATA

3.1 Cognitive Reliability Error Analysis Method (CREAM)

CREAM is a method created under the characteristics of the second generation human reliability analysis methods for representing the influence of human performance and the likelihood of errors emerging in a cognitive process (Gao and He, 2004). The method remarks the influence of the context on human performance and provides a cognitive framework for the analysis of this performance (Hollnagel, 1998). The aim of this method is to detect a good indicator for the probability of an interaction rather than a precise failure probability (Fujita and Hollnagel, 2004). The above stated represents the main arguments in the selection of this method for representing the proposed analysis in this study.

The CREAM version utilized for the analysis presented in this study is adopted by the CREAM simplified version proposed in (He et al., 2008). This version adopts the original four types of control modes: scrambled control, opportunistic control, tactical control and strategic control, which attempt to gradually reduce the error.

Based on the 9 Common Performance Conditions (CPCs) proposed in the original version of the model, the analysis presented in this paper has adopted only 6 CPCs which attempt to represent the key elements for analyzing the human error in the performance of the operations in the bridge of merchant vessels and icebreakers during the sea ice season in the Gulf of Finland. The 6 CPCs adopted for the elaborated analysis are:

– Adequacy of the organization: evaluates the aspects represented in the management support provided by organizations in order to effectively develop the winter navigation operations, including aspects such as: responsibility
delegation, safety management support and safety instructions.

- Available procedures and plans: assess the efficiency of the existing procedures and plans to perform the tasks required in the operations. Particularly, the effectiveness of the guidelines provided to avoid potential human errors. Particular aspects such as: the availability of documented guidelines, personnel’s familiarization with the plans and procedures, and the continuous improvement generate from the application of those are analyzed.

- Man-machine interface and operational support: evaluates the efficiency of the bond between the available technology to ensure the correct performance of the operation and the people responsible to execute the commands needed in the operations. This includes aspects such as: the value of the support provided by the utilized devices and technology available on the bridge and the efficiency of the common layout of the bridge.

- Available time: assess the quantity and quality of the time available to plan and perform the operations.

- Training and preparation: evaluates the training and development of skills for ensuring the adequate performance of the operations.

- Collaboration quality: assess the level of quality in the internal and external cooperation, communication and individual satisfaction among the personnel responsible for the performance and control of the operations.

In order to quantify the failure probability, the relations of the scores from adopted CPCs and the control modes are considered as the proposed in the extended method for the calculation of the performance influence index and Cognitive Failure Probability (CFP) in He et al. (2008). The method seeks for a value for the context influence index ($\beta$), which is a number of the reduced CPCs minus number of improved CPCs, formulated as

$$\beta = X - Y = \sum \text{reduced} - \sum \text{improved} \quad (1)$$

where $X$ = the number of the reduced influence indexes, and $Y$ = the number of the improved influence indexes.

In this extended method, the influences of the different CPCs on the performance reliability are the same, if the number of the reduced CPCs equals the number of the improved CPCs $\beta$ would be zero and the CFP would be the basic CFP(0). Thus $\beta$ would be

$$\beta = \sum_{i=1}^{6} P_i \quad (2)$$

where $Pi$ is the performance index influence of the CPC$i$ which its value is based on the weighting factor provided by this extended method of CREAM and adjusted by expert judgement. Table 1 list the performance index influence values of the CPCs.

In this extended method, the CFP is calculated as

$$\text{CFP} = \text{CFP}_0 (10^{0.25\beta}) \quad (3)$$

where $\beta = \sum Pi$, CFP$_0$ is the nominal value assigned to the cognitive function failures. Thus, the adaptation to the CFP is by the factor $10^{0.25\beta}$. In the case the expected effect is not representative the performance index influence is set to be 0. Finally, for the case of the existence the CFP value is larger than 1, the value is treated as equal to 1. The CFP value varies depend on three included process for the operation execution: CFP due to wrong observation (Detect = 0.005), CFP due to wrong situational assessment (Assess = 0.001) and CFP due to wrong executed action (Act = 0.003).

### 3.2 Incorporation of proposed risk control options to reduce the human error probability

The analysis of the CPCs presented in previous sub-section enable the elaboration of particular Risk Control Options (RCOs). These RCOs attempt to identify and/or proposed general actions to influence the efficiency of CPCs assessed in the

<table>
<thead>
<tr>
<th>CPC name</th>
<th>Level</th>
<th>Performance index influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequacy of the organization</td>
<td>Efficient</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>Inefficient</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Deficient</td>
<td>1</td>
</tr>
<tr>
<td>Available procedures and plans</td>
<td>Appropriate</td>
<td>-1.2</td>
</tr>
<tr>
<td></td>
<td>Acceptable</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Inappropriate</td>
<td>1.4</td>
</tr>
<tr>
<td>Man-machine interface and</td>
<td>Supportive</td>
<td>-1.2</td>
</tr>
<tr>
<td>operational support</td>
<td>Adequate</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Inadequate</td>
<td>1.4</td>
</tr>
<tr>
<td>Available time</td>
<td>Adequate</td>
<td>-1.4</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Inadequate</td>
<td>1</td>
</tr>
<tr>
<td>Training and preparation</td>
<td>Supportive</td>
<td>-1.4</td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Inadequate</td>
<td>1.8</td>
</tr>
<tr>
<td>Collaboration quality</td>
<td>Good</td>
<td>-1.4</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Table 1. Performance index influence for CPCs.
analysis of the operations performed during winter navigation, focusing in ship’s bridge operations. Thus, the RCOs proposed for each CPCs are presented in Table 2.

Due to the general characteristics of the proposed RCOs, in the elicitation the experts have a free field to include any other specific aspect covered by the RCOs.

Figure 1 presents the created BN model structure for assessing the human error influence on the winter navigation operations, this figure includes decision nodes with the function of representing the influence derived from the implementation of the RCOs.

<table>
<thead>
<tr>
<th>CPC name</th>
<th>RCOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequacy of the organization</td>
<td>Improve organizational safety culture</td>
</tr>
<tr>
<td></td>
<td>Improve the safety management</td>
</tr>
<tr>
<td></td>
<td>Improve personnel’s satisfaction</td>
</tr>
<tr>
<td>Available procedures and plans</td>
<td>Improve emergency drills</td>
</tr>
<tr>
<td>Man-machine interface and</td>
<td>Improve operational procedures</td>
</tr>
<tr>
<td>operational support</td>
<td>Improve responsibilities designation</td>
</tr>
<tr>
<td></td>
<td>Improve electronic navigation support</td>
</tr>
<tr>
<td></td>
<td>Improve (modify) ship bridge design</td>
</tr>
<tr>
<td>Available time</td>
<td>Improve time management</td>
</tr>
<tr>
<td>Training and preparation</td>
<td>Improve navigational training</td>
</tr>
<tr>
<td>Collaboration quality</td>
<td>Improve planning skills</td>
</tr>
<tr>
<td></td>
<td>Improve safety and risk management skills</td>
</tr>
</tbody>
</table>

3.3 Bayesian network model for the analysis of human error

Once the CPCs are defined and the method for quantifying the probabilities of the HEPs is introduced, the next step is to incorporate the CPCs and calculation methods into the structure of a Bayesian Network (BN). BNs are modeling technique that can represent relatively complex, potentially but not necessarily causal dependencies and cope with uncertainty while also having a graphical dimension (Pearl, 1998). The produced structure of the BN enable: a graphical representation of the probabilities, an establishment of the current levels of the operations (from the perspective of the 6 CPCs included), and an incorporation of the estimated influence of the proposed RCOs. This create a framework which contains all the mentioned information and which supports the development of the expert elicitations.

Figure 1 describes the general structure of the BN for assessing the human error based on the CREAM methodology.

3.4 Expert elicitation for assessing human error

3.4.1 Defining the current level of the CPCs

For the expert elicitations of winter navigation operations, different actors involved in winter navigation are interviewed. The consulted groups included two experts from Finland who have more than 15 years of experience in the practical performance of ship operations in ice condition, including operations of merchant vessels and icebreakers. Additionally, four experts from Russia are also consulted, they have over 10 years of practical experience on the performance of ship operations in ice conditions, icebreaker assistance and the provision of winter navigation training. The aim of including these experts in the assessment is to have representative groups from two (out of three) nations involved in the performance, control and monitoring of the operations in the Gulf of Finland and to detect similarities and differences in the values and needs between the two countries.

Thus, the first step of the expert elicitations is to clearly define the scope of the elicitation, starting with a description of the operations to be considered in the assessment (see Section 2.1). Also the experts are informed that the analysis of these operations is limited to the tasks performed in the bridge at the time the described operations are executed.

For defining the current values of the CPCs which assess the winter navigation operations, the experts are provided with a questionnaire which contains:

a. A general description of the CPC under analysis and the aspects covered under the scope of this component (see Section 3.1)
b. Each CPC has a table with several questions analyzing specific aspects of the CPC
c. Each question contains three possible statements (Good, Average and Poor). These statements are provided for the analysis of 5 winter navigation operations (a. independent navigation, b. breaking a ship loose, c. convoy, and d. towing)
d. In empty fields designated to each statement, and each operations, a number based on a scale (1. Strongly agree, 2. Agree, 3. Neither agree nor disagree, 4. Disagree, and 5. Strongly disagree) has to be allocated according to the question under analysis.

Thus, the questions for the analysis of each CPCs are:

**Adequacy of the organization**
- Is the current distribution of the responsibilities and duties on the bridge for the operations \((a,b,c,d,e)\): Good (1–5) Average (1–5) Poor (1–5)
- Is the support provided from the safety management system (for the performance of the operations):
- Are the instructions and guidelines for executing the tasks demanded in the operations:
- Is the installed and adopted safety culture in the operation:

**Available procedures and plans**
- Are the procedures and guidelines available for performing the operation:
- Are the understanding and familiarization of the crew with the plans and procedures:
- Are the periodic reviews and updates of the procedures:
- Is the planning of the operations (on the bridge):
- Is the guidance provided for extraordinary events (e.g. emergency situations):

**Man-machine interface and operational support**
- Are control panels and information provided during the operation:
- Is the bridge equipment (excluding panels):
- Are the constant updates of the equipment:
- Are the ergonomics and layout of the bridge:

**Available time**
- Is the time available to plan the operation:
- Is the time available to perform the operation commonly:

**Training and preparation**
- Is the training provided to the personnel with responsibilities in the bridge:
- Is the training provided to use the technologies adopted in the working context:
- Is the preparation and knowledge of the personnel on the bridge:
- Is the received feedback from the personnel (regarding training and ways of improve the operations) commonly:
- Is the information and notification of new training available:

**Collaboration quality**
- Is the working environment on the bridge:
- Is the fluency of the communication on the bridge:
- Are the responsibilities and working loads among personnel in the bridge delegated:
- Is the personnel’s level of satisfaction regarding the modus operandi in the bridge:

Thus, in order to streamline the process of the defining the current status of the CPCs, the experts are provided with tables containing the presented questions in which experts only need to reply a number representing their level of agreement with the three included statements. Table 3 presents an example of a table designated to the analysis of the CPC Available time.

3.4.2 Defining the possible influence of the RCOs
As a second part of the expert elicitation, the same consulted experts in Finland and Russia have to evaluate the possible impact of proposed RCOs to reduce the HEPs. In this second part the experts are provided with a questionnaire which includes:

a. Several proposed RCOs to each specific CPC (see Table 2).

b. Semi-open questions for each RCO where the expert has to define is the influence generated

<table>
<thead>
<tr>
<th>CPC (Available time)</th>
<th>Good</th>
<th>Average</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the time available to plan the operation:</td>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
</tr>
<tr>
<td>Is the time available to perform the operation:</td>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
</tr>
</tbody>
</table>

To fill in the empty field of the operations (a–e) for each statement: Strongly agree (1) Agree (2) Neither agree nor disagree (3) Disagree (4) Strongly disagree (5).
from the proposed RCO may be positive, negative or neither positive nor negative. And finally, the expert defines the level of this influence: very low, low, medium, high, or very high.

c. A last question included in the analysis of the influence of these RCOs promotes the inclusion and description of any specific aspect relevant for the RCOs.

3.5 Quantification of the information collected in the expert elicitations

This section describes the process for incorporating the probabilities describing the current levels of the 6 components which are based on the information collected from the expert elicitations.

3.5.1 Quantification of the base-line probabilities describing the current levels of the CPCs

Each value has a designated percentage (1. Strongly agree 100%, 2. Agree 75%, 3. Neither agree nor disagree 50%, 4. Disagree 25%, 5. Strongly disagree 0%). The total value in each statement comes from the sum of these percentages designated to each analyzed question in the CPC. The probability of the statement for each operation is obtained by dividing the total value of each statement into the sum of the total values given to the three statements (good, average and poor) in one winter navigation operation.

\[
P(\text{CPC"Good"}) = \left( \sum Q_1 \ldots n \right)/TVS 
\]

(4)

\[
P(\text{CPC"Average"}) = \left( \sum Q_1 \ldots n \right)/TVS 
\]

(5)

\[
P(\text{CPC"Poor"}) = \left( \sum Q_1 \ldots n \right)/TVS 
\]

(6)

where \( \sum Q_1 \ldots n \) = the sum of the percentages in each statement based on the assigned number by the expert; \( TVS \) = the total value obtained by the sum of the total percentages assigned to the three statements in the same operation.

3.5.2 Quantification of the influence of the RCOs in the base-line probabilities of the CPCs

Table 4 present the scales representing the influence of the implementation of the RCOs.

Thus, the calculation of the potential influence is obtained by representing the numerical improvement/worsen in the probability obtained for the base-line of the CPC. For example:

- If the type of influence is marked as positive with a high impact, the probability for the statement “Good” increases 70%. Thus, if the \( P(\text{CPC"Good"}) = 0.33(33%) \), the improvement generated by the RCO increases the probability to 0.56 (56%). The other two statements (average and poor) have to equally share the decrease of their base-line probability.

### Table 4. The numerical influence of the proposed RCOs.

<table>
<thead>
<tr>
<th>Type of influence</th>
<th>Impact</th>
<th>Numerical improvement/worsen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Very high</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Very low</td>
<td>0.05</td>
</tr>
<tr>
<td>Neither positive nor negative</td>
<td>Very high</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Very low</td>
<td>0</td>
</tr>
<tr>
<td>Negative</td>
<td>Very high</td>
<td>-0.95</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>-0.70</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>-0.50</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>-0.25</td>
</tr>
<tr>
<td></td>
<td>Very low</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

4 RESULTS

4.1 Current levels of the CPCs

Based on the elicitations performed to the experts, the current situation of the 6 analyzed CPCs present the following intervals describing the probability of the statements (good, average and poor) in the assessment of each winter navigation operation (from the perspective of the task performed in the bridge) (Figs. 2–7):

Thus, defining the probabilities for each CPC and the incorporation of the CREAM formulas to quantify the HEPs, identify the actual HEP designated to each analyzed operation. Table 5 presents the HEPs of each operation extracted from the model, the HEPs are categorized by the country represented by each consulted expert group.

4.2 Influence of the RCOs

Based on the experts, the represented influence from the implementation of the RCOs has detected the RCOs whit a higher impact for reducing the HEP in each winter navigation operation. Thus, the RCOs which may lead to a more significant benefit for the development of the operations are:

- Improve navigational training
- Improve safety and risk management training
- Improve the electronic navigation support in the bridge

Table 6 presents the effect of the complete assessed RCOs and the percentage of reduction
in HEPs for the winter navigation operation: ship independent navigation. According to the experts, there are not RCOs which can increase the HEPs. Table 6 differentiates the effect estimated by the group of experts in Finland and Russia.

Table 5. HEPs categorized by winter navigation operations.

<table>
<thead>
<tr>
<th>Winter navigation operation</th>
<th>HEPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td></td>
</tr>
<tr>
<td>Independent navigation</td>
<td>0.005</td>
</tr>
<tr>
<td>Convoy</td>
<td>0.003</td>
</tr>
<tr>
<td>Towing</td>
<td>0.003</td>
</tr>
<tr>
<td>Cutting loose</td>
<td>0.003</td>
</tr>
<tr>
<td>Russia</td>
<td></td>
</tr>
<tr>
<td>Independent navigation</td>
<td>0.006</td>
</tr>
<tr>
<td>Convoy</td>
<td>0.013</td>
</tr>
<tr>
<td>Towing</td>
<td>0.003</td>
</tr>
<tr>
<td>Cutting loose</td>
<td>0.005</td>
</tr>
</tbody>
</table>

5 DISCUSSION

The CREAM provides a structured framework and quantification process which enable the assessment of particular factors relevant for the analysis of human error in different types of activities. In this study, the method has been implemented to assess specific CPCs which are marked as essential in the development of winter navigation operations from the perspective of the tasks and particular operations performed in the bridge of merchant vessels and icebreakers.
Bayesian networks represent a tool which supports the graphical description of the CREAM’s function. Moreover, the constructed BN supports the incorporation of the estimated probabilities by the experts while it is able to represent the effect of particular actions (RCOs) for the reduction of human error.

Thus, a combination between CREAM and BNs enabled the elaboration of a structured expert elicitation process which is able to initially set the current HEPs of each CPC included for the analysis of the five winter navigation operations (see 2.1). The process continues with the evaluations of a set of proposed RCOs for determining their possible effect on supporting the reduction of the HEPs initially estimated.

The elicitation process and the functioning of the BN enable a probabilistically and graphically representation of the possible impact from the proposed RCOs. Thereby, identifying the RCOs which seem to be the most representative and subsequently identifying a possible pattern to follow-up in order to improve the operations.

Based on the two group of experts, independent navigation and convoy are the operations with the higher HEPs. This represents the identification of the two operations which are more in need of further safety engineering and safety or risk management development for preventing human error in their performance.

This study proposes 13 RCOs for the 6 CPCs included in the analysis. The general characteristics of these RCOs contain advantages and also limitations for the moment in which the experts need to evaluate them. The main represented advantage is the identification, descriptions and assessment of particular key areas (CPCs) in the development of the operations, and the evaluations of possible actions (RCOs) which may support the improvement of the operations. The proposed RCOs do not limit their execution to a specific measure, they attempt to promote a guided action which leads to an assessment of possible measures with clear intended purpose. The main disadvantage of this general RCOs is that if an organization do not have actually commitment to invest efforts, time and resources for the improvement of the operations, the RCOs have the effect of only pointing a particular area of opportunity without obtaining any concrete result (improvement).

The expert elicitations and HEPs represented in the model have detected that investing in more navigational training, more safety and risk management training and more e-navigation support are the possible actions which can lead to a more significant improvement of the winter navigation operations. Other proposed RCOs presented significant effects but only to one particular group of experts, this the case of e.g. the RCO improve ship bridge design, experts from Finland see this option as interesting approach for elaborating updates in the layout of the ships which can lead to an improvement of the operations of the existing fleet. However, experts from Russia consider this option is only relevant for the design of new ships and it is quite complex to apply in the existing ones. Another evident difference is represented in the available procedures and plans for performing the operations, while Finns described this aspect as already good enough, Russians still see the need for developing new actions for the improvement of this CPC.

### 6 CONCLUSIONS

Evaluating the influence of human error in the performance of winter navigation operations is a task which requires of structured methods for integrating several needed components for elaborating such analysis. This paper has combined the structure of the CREAM, Bayesian networks and a structured
process for consulting experts in maritime winter navigation in order to represent the current efficiency levels of the winter navigation operations and possible actions to reduce the HEP.

The elaboration of expert elicitations and the incorporation of the data produced from these elicitation into the created BN model structure enable a simpler representation of the HEPs for each winter navigation operation. This has detected ship independent navigation and convoy as the operations with the higher HEPs. Based on the analysis of the CPCs and proposed RCOs, Man-machine interface, operational support, and training and preparations are the areas where actions of improvement may have a more significant effect on the development of winter navigation operations. Furthermore, particular RCOs such as the improvement of navigational training, risk and safety management training, and electronic navigation support seem to be the actions which can potentially lead to a reduction of the HEPs in each assessed operation.

Thus, the presented analysis has elaborated an assessment of the performance of winter navigation operations based on the input from the human factor. It can be concluded that the information produced from this assessment is useful for pointing the possible directions to support and improve the human performance during the development of winter navigation operations. Further research can be focused in e.g. defining the identified HEPs for each CPC based on its relation to particular ice conditions.

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