Kul-24.4230
Safety and Risks of Marine Traffic P
L3 - A framework for risk assessment of maritime systems

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In this lecture

• Adopted risk perspective

• Overview of risk assessment framework

• Examples
Risk Concept and Perspective

- **Risk concept**: Risk is uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value.

- **Risk perspective**: 
  - "Moderately" constructivist (events/consequences can become real).
  - Risk is not an ontological category.
  - Risk is rather of epistemic nature (*somebody’s* construct).
  - Hence: *risk description* is **not** a reflection of some real, mind-independent, true risk.
  - Risk assessment better understood as a tool for argumentation.

Note! This is not the only possible way to look at risk assessment. Aim is to provide one coherent framework.
In the uncertainty perspective risk is looked at as follows: 
\[ R \sim C \& U \]

- This means that **risk assessment is an expression of an assessor’s uncertainty** (U) about the occurrence of events and the associated consequences (C).
- Following this perspective, risk assessment can always be performed, as it is seen as a tool to describe and convey uncertainties through a model rather than a tool to uncover the truth.
- The risk model encompasses the events and the consequences of the events when they become true.
- To propagate the background knowledge and in order to ease the process of uncertainty assessment, the risk model can be developed with the use of Bayesian Networks (however there are other tools as well).
Risk Description

• Translation of risk concept to a set of conceptual elements which describe risk
• These elements are concepts, not measurements
• \( R \sim (A, C, OU, EU, EB, J \mid BK) \)
  – Events A and consequences C
  – Outcome uncertainty OU
  – Evidence uncertainty EU
  – Evidence bias EB
  – Justification J
  – Background knowledge BK
Risk Description

• Translation of risk concept to a set of elements which describe risk
• These conceptual elements are translated into measurements
• \( R \sim (A, C, P_s, EU_q, EB_q, J_t \mid BK) \)
  – Events A and consequences C
  – Subjective degrees of belief \( P_s \) (uncertainty standard, based on BK)
  – Qualitative assessment of evidence uncertainty \( EU_q \)
  – Qualitative assessment of evidence bias \( EB_q \)
  – Textual description of justification \( J_t \)
  – Background knowledge BK: references, models, data, theories, …
Risk Description

Notes

• Evidential bias may not always be present, depends on what kind of background knowledge there is (engineering models often have some sort of bias, data may also have biases) – see example

• There is no guarantee that all evidence uncertainty / evidence bias is actually found

• Level of required detail for EU / EB are matters of ongoing research

• When a model is applied, very often it is useful to perform a sensitivity assessment (how much the results change depending on given assumptions or parameter values)

• Sensitivity – uncertainty – bias can be put in relation (see examples)
General outline of the framework

- Measure of uncertainty: \( P(X \leq x) \)
- Model input: \( X, d, U, B \)
- Model: \( G(X,d) \)
- Quantities of interest: \( Z \)
- Uncertainty expressed by: \( P(Z \leq z) \), \( EZ, VarZ \), etc.
- Decision: Managerial judgment
- Stakeholder review: Decision criteria, uncertainty and bias evaluation
- Qualitative uncertainty (U) and bias (B) assessment
- Sensitivity analysis

Background knowledge BK
General outline of the framework

Background knowledge

- Measure of uncertainty $P(X \leq x)$
- Model input $X, d$, $U, B$
- Model $G(X,d)$, $U, B$
- Quantities of interest $Z$
- Uncertainty expressed by $P$: $P(Z \leq z)$, EZ, VarZ, etc.

Uncertainty propagation

- Sensitivity analysis

Decision

- Managerial judgment
- Stakeholder review: Decision criteria, uncertainty and bias evaluation
- Qualitative uncertainty (U) and bias (B) assessment
General outline of the framework

1. Measure of uncertainty
   - Model input: X, d, U, B
2. Model: G(X,d), U, B
3. Quantities of interest: Z
4. Uncertainty propagation
5. Uncertainty expressed by P: P(Z ≤ z), EZ, Var(z), etc.
6. Sensitivity analysis
7. Decision
   - Managerial judgment
   - Stakeholder review: Decision criteria, uncertainty and bias evaluation
   - Qualitative uncertainty (U) and bias (B) assessment

Background knowledge BK
General outline of the framework

Model:

Input ------- Model ------- Output

Measure of uncertainty $P(X \leq x)$

Model input $X, d$

Model $G(X, d)$

Quantities of interest $Z$

Uncertainty propagation

Uncertainty expressed by $P$: $P(Z \leq z)$

Sensitivity analysis

Decision

Managerial judgment

Stakeholder review

Decision criteria, uncertainty and bias evaluation

Qualitative uncertainty (U) and bias (B) assessment

Background knowledge BK

Aalto University
General outline of the framework

- Measure of uncertainty $P(X \leq x)$
- Model input $X, d, U, B$
- Model $G(X,d), U, B$
- Quantities of interest $Z$

Risk measures $E[Z], \text{Var}[Z], \ldots$

Uncertainty propagation

- Managerial judgment
- Stakeholder review Decision criteria, uncertainty and bias evaluation
- Qualitative uncertainty $(U)$ and bias $(B)$ assessment

Background knowledge BK

Sensitivity analysis
General outline of the framework

Background knowledge BK

Measure of uncertainty \( P(X \leq x) \)

Model input

Model

Quantities of interest

Uncertainty expressed by \( P: P(Z \leq z) \)

Uncertainty propagation

Sensitivity Analysis

Stakeholder review
Decision criteria, uncertainty and bias evaluation

Qualitative uncertainty (U) and bias (B) assessment

Managerial judgment

Decision
General outline of the framework

1. Measure of uncertainty $P(X \leq x)$
2. Model input $X, d, U, B$
3. Model $G(X,d)$ $U, B$
4. Quantities of interest $Z$
5. Uncertainty expressed by $P$: $P(Z \leq z)$, EZ, VarZ, etc.

Uncertainty propagation

Decision

Managerial judgment

Stakeholder review
Decision criteria, uncertainty and bias evaluation

Assess $EU_q$, $EB_q$
General outline of the framework

Decision process
Decision criteria – stakeholder review - decision
Framework outline

Notes

• Alternative frameworks exist, some others are also plausible

• Each of the building blocks of the framework will during next lectures be addressed
  – Decision criteria & ethical basis
  – Tools (and some theory) for building the framework
  – Validation framework

• Rest of the lecture addresses examples:
  – Models are developed within past and ongoing research in AALTO
  – Purpose:
    • Show applicability of framework
    • See what you could (in principle) be doing after the lectures
    • Get some practical feeling
Examples: brief outline

• Example 1:
  Risk assessment for a RoPax vessel in the Gulf of Finland
  – Aim: Model risk of RoPax collisions to get basic understanding of the risk existing in transportation system.
  – Scope: Numerous factors related to ship, environment and rescue services included.
  – Tool: Bayesian network, various engineering models, …

• Example 2:
  Risk assessment for RoPax and tankers
  – Aim: Model influence of Global Design Factors (GDF) on Collision risk for use in early ship design stage
  – Scope: Restricted to only account for GDF, other factors equal
  – Tool: Bayesian network, human performance theory, technique for human error analysis
Main research topics

- Formal Safety Assessment
- Risk-based ship design
- Maritime transportation risk management
- Accident and incident analysis
- e-Navigation
- Safety Management
Example 1

Risk assessment for a RoPax vessel in the Gulf of Finland

Maritime transportation risk management


Example 1: RoPax BBN

- Model structure
- What are inputs (X)
- What sort of engineering models go underneath
- Output (Z)
- Derived metrics
- Sensitivity and EU, EB
- SUB matrix – EB justification table
Risk model

There are several methods to estimate the risk and its components for the maritime traffic systems, just to mention the most two relevant groups:

1. Statistical models based on the historical accidents data, although being very popular this type of models is passive in nature.
2. Synthetic models, where the risk components are modelled from the roots, therefore the dynamic nature of such models is recognized.

The model presented here fits the concept of synthetic models, being proactive and transferable, suitable for risk estimation of a ship following an open sea collision. Bayesian modelling and continuous variables are applied, which explain - to some degree - aleatory and epistemic uncertainty.

The case study presented focuses on a selected type of RoPax ship navigating in the selected location which is the Gulf of Finland.
Risk model
Risk model

• The aim of the proposed framework is to estimate the risk in MTS, focusing on selected accidental scenarios that, ultimately, lead to the loss of a struck RoPax ship.

• Two scenarios are considered:
  – the inner hull of the RoPax that is struck is breached and consequent flooding is experienced; this can result further in the loss of the ship;
  – the RoPax that is struck has no significant hull damage; however, the ship is disabled and drifts, thus experiencing significant rolling as a result of wave and wind action, which can result further in the ship capsizing.

• The loss of the RoPax is expected if two consecutive limits are exceeded, namely crashworthiness and stability.

• Subsequently the corresponding probabilities of the limits being exceeded given the traffic and environmental conditions are evaluated on the basis of the model presented here.
Risk model

• The following general factors are taken into consideration:
  – the composition of the maritime traffic in the sea area being analysed,
  – the collision dynamics,
  – hydrodynamics of the ship and her loading conditions.

• Ultimately, the cumulative number of fatalities (N) resulting from an accident is modelled utilizing the concept of the rate of fatalities.

• This rate is determined taking into account time for evacuating a ship and time for a ship to capsize. The number of passengers on board is modelled utilizing available data from RoPax operators from the Gulf of Finland. All this, along with the associated probabilities (P) for a given number of fatalities, are finally depicted in a F-N diagram, which can be considered as a risk picture.
Risk model

- Ship loss due to collision
  - Traffic composition
  - Weather conditions
  - Masses of striking and struck ships
  - Struck ship's structure
  - Collision speed and angle
  - Loading and stability conditions
Risk model inputs

Collision relevant parameters:
- Collision parameters
  - Inner hull rupture
  - DSC

Probability of an accident - ship capsizing:
- Time to capsize due to flooding
- Capsize due to flooding
- Capsize due to DSC
- Time to capsize due to DSC

Accident response:
- Weather and time of day
- Response

Results:
- Fatalities
- Fatalities DSC
- Fatalities flooding
Risk model inputs and output

THE PROBABILITY
- Modelling maritime traffic with the use of AIS data;
- Modelling human behaviour, based on literature and expert judgement;
- The probability of an accident where a RoPax ship is being struck;

THE CONSEQUENCES
- Modelling the ship damage based on FEM simulations;
- Modelling the probability of ship flooding and capsizing, based on simulations;
- Estimating the number of casualties;

RISK
- F-N curve;
- Risk acceptance criteria;
- ALARP region;
What is behind the risk model?

Modelling maritime traffic and the meeting scenarios that may lead to a collision if a navigator makes a mistake.

\[ P_{\text{tot, passenger}} = 0.107 \text{ accidents/year} \]
What is behind the risk model?

Modelling the performance of a navigator – probability of a mistake leading to the collision

OOW detects danger in time

By the courtesy of Maria Hänninen
What is behind the risk model?

Critical collision energy = Critical collision speed = Inner hull rupture
What is behind the risk model?
What is behind the risk model?

Life loss = Yes, if hazard exposure time > response time,
Blue – variables obtained from the numerical simulations.
Yellow – variables taken from the literature.
Grey – variables based on certain assumptions.
No filling – variables conditional on their parents.
Risk model – BK propagation

Stability conditions $s$ $s_1; s_2; s_3; s_4$
Collision angle $\alpha$ uniform(10,170); triangular(10,90,170)
Collision angle significant $\alpha_{sign}$ uniform(45,135); uniform(20,160)
Damage extent significant $des$ $1.2L_{struct}; 1.4L_{struct}$
Ships stay separated $sss$ $f(des_i, \alpha_{sign}),$ where $i = 1, 2, 3$
Machinery damaged $md$ 0.1; 0.16; 0.25
Time to evacuate a ship $TTE$ T1; T2; T3; T4
Methodological basis for describing risk
Outcome uncertainty: probability concepts

• Probability is a useful tool for measuring/describing risk, but the type/interpretation of probability is important

• “Objective” probabilities
  – Classical probability
  – Frequentist probability

• “Subjective” probabilities
  – Betting probability
  – Reference to uncertainty standard
  – Imprecise (interval) probability
## Risk model – metrics used

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributions – based on data</td>
<td>Frequency</td>
</tr>
<tr>
<td>Ship mass</td>
<td>F-N curve</td>
</tr>
<tr>
<td>Collision angle</td>
<td></td>
</tr>
<tr>
<td>Wave height</td>
<td></td>
</tr>
<tr>
<td>Frequencies – based on engineering models</td>
<td></td>
</tr>
<tr>
<td>Ship capsizing</td>
<td></td>
</tr>
<tr>
<td>Ship colliding</td>
<td></td>
</tr>
<tr>
<td>Probabilities based on experts judgement</td>
<td></td>
</tr>
<tr>
<td>Significant collision angle</td>
<td></td>
</tr>
<tr>
<td>Ships are separated after collision</td>
<td></td>
</tr>
<tr>
<td>Probability models based on judgement</td>
<td></td>
</tr>
<tr>
<td>Evacuation time</td>
<td></td>
</tr>
<tr>
<td>Ship capacity</td>
<td></td>
</tr>
<tr>
<td>Time for tugs to arrive</td>
<td></td>
</tr>
<tr>
<td>Judgements</td>
<td></td>
</tr>
<tr>
<td>Stability conditions</td>
<td></td>
</tr>
</tbody>
</table>
Risk model - output

![Graph showing frequency of N or more fatalities per year against number of fatalities (N). The graph includes lines representing limits of 95% band and average for the BBNs model.](image-url)
Results and model validation

1 year of Maritime Traffic System operating in the Gulf of Finland, in ice free season.
Results and model validation

The probability of the loss of a RoPax as a result of an open sea collision $P(\text{Cflood})$ and the probability of serious damage to a ship $P(\text{des})$, comparison of various models.

**$P(\text{Cflood})$**
1. the average value obtained from the framework presented here;
2. the model based on global statistics, see Guarin et al. (2009);
3. the results of analysis for the specific RoPax, see Konovesis, Vassalos (2007);
4. the results for a specific RoPax operating in the Atlantic Ocean, see Otto et al (2002).

**$P(\text{des})$**
1. the average value obtained from this model;
2. the probability of serious damage given open sea collision, according to historical data, compiled by Guarin, Konovessis, Vassalos (2009).
Results and model validation

The rate of fatalities - comparison of results obtained form framework with historical data

\[ N = (1 - (\text{haz/resp})) \times N_{\text{passengers}} \]

- The agreement exists between discrete distributions based on historical data - as compiled by Jasionowski et al (2007) - and continuous one obtained from the framework.
- The above statement holds for the rates between 0.3 and 0.5 and for the rates 0.85-0.9.
- Otherwise, the model presented here tends to slightly overestimate this parameter for rates lower than 0.95.
- The probability of the rate of fatalities falling in the range (0.95-1), given accidental flooding, is 0.15 – Jasionowski et al (2007).
- The model presented here delivers a number of 0.16 for the same range.

A. Jasionowski, D. Vassalos, A. Scott. 2007 Ship vulnerability to flooding, in: 3rd international maritime conference on design for safety. Berkeley, California
Results against risk acceptance criteria
1 year of Maritime Traffic System operating in the Gulf of Finland, in ice free season.
Sensitivity-Uncertainty-Bias analysis

To assess the strength of knowledge and the influence of choices based on which the assessment is made we propose high-level assessment of the uncertainties, biases and sensitivities.

This is performed on the level of the whole BBN model, using a set of pairwise matrices showing combinations of sensitivity, uncertainty and bias (SUB) for various model elements.

Both the uncertainty (U) and the bias (B) of the model elements can be systematically assessed and put in relation to the sensitivity of the model outcome to changes in the individual nodes of the BBN (S).

Systematic assessment provides an overall picture of how uncertain the resulting probability assignment in terms of the F-N curve is expected to be. Moreover, it provides some insight as to whether the F-N curve is expected to be optimistic or conservative.
Sensitivity-Uncertainty-Bias analysis an example

- The sensitivity score is a purely mathematical result from BBN analysis.

- Qualitative evaluation of uncertainty and bias depends on a subjective interpretation.

- We propose a SUB-score justification table with a ranked scoring system of individual simplifications and assumptions underpinning a given engineering model.
Sensitivity-Uncertainty-Bias analysis an example

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Score</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>L</td>
<td>- The assumptions made are seen as very reasonable&lt;br&gt;- Much reliable data are available&lt;br&gt;- There is broad agreement/consensus among experts&lt;br&gt;- The phenomena involved are well understood; models used are known to give predictions with the required accuracy</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Conditions between those characterizing low and high uncertainty</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>Conditions opposite to low uncertainty</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>Adopted values lead to a characterization of consequences severity / risk which is believed to strongly underestimate the ‘true’ consequence severity / risk</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Adopted values lead to a characterization of consequences severity / risk which is believed to accurately reflecting the ‘true’ value</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Adopted values lead to a characterization of consequences severity / risk which is believed to strongly overestimate the ‘true’ consequence severity / risk</td>
</tr>
<tr>
<td>S</td>
<td>L</td>
<td>Large changes in base values needed to bring about altered conclusions</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Relatively large changes in base values needed to bring about altered conclusions</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>Relatively small changes in base values needed to bring about altered conclusions</td>
</tr>
</tbody>
</table>
Sensitivity-Uncertainty-Bias analysis
an example

• The UB-score justification table lists all simplifications underpinning an engineering model and provides a score to each of these as to how significant this simplification is in terms of uncertainty or bias.

• Subsequently, a relative rank is assigned to each of these model simplifications in terms of how important the effect of these simplifications is expected to be for the overall model output.

• Assessing the score of the highest ranked simplifications allows an overall uncertainty and bias score to be derived.
Sensitivity-Uncertainty-Bias analysis
an example

<table>
<thead>
<tr>
<th>Uncertainties due to model simplifications</th>
<th>Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1 Striking ship bulbous bow is assumed rigid, leading to uncertainty in the force-penetration curve: the bulb will deform and absorb some impact energy.</td>
<td>L</td>
<td>2</td>
</tr>
<tr>
<td>U2 Omission of forecastle structure of striking ship leads to uncertainty in force-penetration curves and required energy for inner hull rupture.</td>
<td>H</td>
<td>1</td>
</tr>
<tr>
<td>U3 One material failure criterion is applied in the rupture analysis. Important differences in the application of different criteria are known to exist.</td>
<td>M</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biases due to model simplifications</th>
<th>Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 The inner hull rupture analysis is based on the midsection frame, i.e. the structurally weakest. This is a conservative assumption.</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>B2 Omission of forecastle structure is a very severe but conservative simplification: the forecastle structure will absorb some impact energy.</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>B5 The hull scantlings are based on newbuilding conditions, yet in real vessels the plates may be partly corroded leading to lower plate and stiffener thicknesses. This is an optimistic assumption in light of the required energy for hull breach.</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Overall uncertainty score M-H

Overall bias score 7-9
Sensitivity-Uncertainty-Bias analysis an example

Qualitative SUB-assessment for the RoPax BBN model
Conclusions - example 1

In the proposed risk framework uncertainty and bias are given a more important role than is the common practice in many risk assessments.

The extended assessment in terms of the SUB-matrices and the UB-justification table places the numbers in a wider context of the strength of the knowledge base and the value judgments which may underpin simplifications and assumptions in the applied engineering models.

This provides a wider risk picture which may support decision makers in making judgments on risk acceptability or in how to manage the risk.
Example 2

Risk assessment for RoPax and tankers

Risk-based ship design


Agenda

• Aim of the risk models presented here

• General structure of risk model

• Human performance modelling

• Collision and grounding risk models
  • Adopted risk perspective
  • Risk metric
  • Uncertainty assessment
  • Results benchmarking

• Conclusions
Aim of the presented risk models

In the maritime domain there has been an increased focus on the development of Risk-Based Ship Design (RBSD) methodology and inclusion of human element therein.

In the RBSD the assessment of the risk level of a new ship is conducted in the early design stage, where a design modification is easy and cost-effective. Risk is thus treated as a design objective rather than a constraint imposed by prescriptive safety rules.

Therefore, the quantification of the effect of design-related factors (modifiable in the course of ship design) that shape human performance, on risk is of high interest.

This paper presents two models that quantify the effect of performance-shaping factors (PSFs) pertaining to ship design, a.k.a. as global design factors (GDFs) on human performance and ultimately on ship collision and grounding risk.

The GDFs that can be modified at the stage of ship design are as follows:
• ship noise,
• ship vibration,
• ship motions.
Aim of the presented risk models

Exclusions

The Performance Shaping Factors - PSFs - are an aspect of the human’s individual characteristics, environment, organisation, or task that specifically decrements or improves human performance, thus increasing or decreasing the likelihood of human error respectively.

While there are many other PSFs that can affect human behaviour – for instance training, experience, competence, time available, workload, job design, manning, ergonomics of the equipment and procedures - these are excluded from the collision and grounding risk models as they are not affected by exposure to GDFs.

All the excluded PSFs are implicitly assumed to remain constant within the model.
General structure of the risk models

The effect of GDF-affected human performance on the possible occurrence of collision and grounding in combination with the safety critical task being performed are considered.

Two paths of GDFs influence on human behavior were defined here.

Path I
Exposure to Global Design Factors (GDFs) act as a stressor and can affect the capabilities of an individual (attention management), subsequently impairing the performance of the individual.

Path II
Exposure to GDFs can have specific and direct effect on the behavior produced.
It was found that the data on the specific GDF effects of ship motion, noise, WBV on human performance are sparse and in many cases generated under very specific, often non-marine, conditions.

Data shows that there is certainly evidence for GDFs having some effect on human performance.
- Impact of GDFs on specific human capabilities.
- Impact of GDFs on specific human behaviours.
- Impact of errors on task performance.

However, there is very little data about the link between the following components:
- Degraded human capabilities and collision or grounding related human performance.
- Degraded task performance and exposure to the collision / grounding hazard.

*Key:*  
- ↓ No quantitative data  
- ↓ Some quantitative data
Human performance modelling

The approach taken here to describe a mechanism that accounts for the impact of stressors on human performance, has been based on the principles of **attention management**.

**Attention management** is the supervisory human capability that directs, allocates and regulates the attentional resources required to perform various tasks.

This high-level supervisory capability manages lower-level tasks such as perception, cognition, decision-making, memory, fine motor control and locomotion.
Human performance modelling

The principles from three theoretical models were combined in the proposed approach:
• Dynamic Adaptability Model (DAM).
• Cognitive Control Model (CMM).
• Malleable Attentional Resources Theory (MART)

Adoption of attention management concept allows us representation of the effect of GDF exposure as a stressor that sits either above or below the threshold of attentional capacity for any given task.

If the stressor exceeds the attentional capacity then a negative effect is expected.

The thresholds are estimated based on the available literature.

Key:
- No quantitative data
- Some quantitative data
Due to the limitations in data on the effects of GDF exposure on human performance, one cannot find precise values in the scientific literature. A solution was found in Human Reliability Analysis (HRA) techniques.

While HRA techniques do not typically cover the specific GDFs or the maritime environment, the human error probabilities (HEPs) generated by HRA allow sensible bounds to be determined.

The HRA method Nuclear Action Reliability Assessment (NARA) was selected to provide the HEPs associated within collision and grounding model.
Human performance modelling

Nuclear Action Reliability Assessment (NARA) was selected to provide the HEPs associated within collision and grounding model.

\[
\text{HEP} = \text{GTT} \times [(\text{EPC}-1) \times (\text{APOA} + 1)]
\]

Two GTTs considered:
- **Task C1** – Simple response to alarms/indications providing clear indication of situation (Simple diagnosis required) Response might be direct execution of simple actions or initiating other actions separately assessed - nominal HEP = 0.0005.
- **Task D1** - Verbal communication of safety critical data - nominal HEP=0.006.

EPC No 15, poor environment

APOA=0.1
In this paper we adopted an uncertainty-based perspective of risk:

\[ R \sim C & U \]

This means that risk assessment is an expression of an assessor’s uncertainty (U) about the occurrence of events and the associated consequences (C).

Following this perspective, risk assessment can always be performed, as the risk model is seen as a tool to describe and convey uncertainties rather than a tool to uncover the truth.

For this purpose, the risk description encompasses:
- the events
- the consequences of the events
- the assessment of associated uncertainties

Collision and grounding risk models

Translation of general structure into a workable model using **Bayesian Belief Network (BBN)**.

**BBN allows for:**
- probabilistic and causal representation of the background knowledge on the analysed domain,
- reasoning in the presence of uncertainty,
- assessment of the effect of the uncertainties on the outcome of the model.
Collision and grounding risk models
Risk metric
Collision and grounding risk models

Risk metric

For practical purposes the risk metric this needs to be estimated on a yearly basis.

The risk metric is \textbf{the probability of human error given the safety critical tasks when a ship is exposed to a hazard.}

The hazard is defined as a collision or grounding course.

Two step procedure has been established to estimate the annual probability of an accident for a ship:

1) \textbf{Estimate the human error probability per exposure}

2) \textbf{Estimate the number of exposures per year}

The latter has been elicited from experts for two predefined specific ship types and routes.
Collision and grounding risk models
Uncertainty assessment

Table 3: The qualitative assessment of model parameters importance for models assessing the probability of an accident.

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Evidential uncertainty score</th>
<th>Sensitivity score</th>
<th>Importance score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Task Performance</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>C1 - Detection, Assessment and execution of simple actions</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>D1 - verbal communication of safety critical data</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Evasive action of another ship</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Helmsman present</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Collision risk model for RoPax
- The collision risk model for RoPax ships delivered mainly acceptable results when compared to historical averages.
- More specifically, the risk results are of the same order of magnitude as the historical averages.
- This study does not give rise to corrections to the risk model for RoPax.

Grounding risk model for RoPax
- The grounding risk model did not deliver acceptable results when compared to historical averages.
- More specifically, the risk results are of up to three orders of magnitude higher than the corresponding historical averages.
- Corrections are necessary so the cost benefit analysis, when such performed, delivers reasonable results.
Conclusions

• The causal mechanism represented within the model that describes occurrence of an accident as the result of insufficient performance of an individual when exposed to hazardous situation offers a flexible modelling framework.

• Modelling improper performance in critical situations is compatible with the general conceptualisation of human error within the Human Factors (HF) domain and its relationship to task performance.

• As expected, the paucity of data on GDF effects presented a particular challenge. However, attention management theory successfully provided a means to represent the mechanism by which ship motion, noise and WBV affect cognitive performance.

• The application of BBNs as a modelling tools, allows for clear representation of the modelled problem and comprehensive distribution of all the recognised uncertainties.

• Finally, comparative assessment of vessel designs based on manipulation of the GDF input nodes is possible in principle.
Collision and grounding risk models for RoPax and tankers

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Next lecture

• Introduction to Bayesian Networks, as a modelling tool suitable for risk assessment.