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A risk model for recreational craft accidents

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The Recreational Craft Platform (RCP, Norwegian: Fritidsbåtplattformen) is being developed to collect and merge available data on recreational craft accidents and thereby enable stakeholders to actively take measures to achieve the vision. The Norwegian Maritime Authority (NMA) will be the owner of the platform, using it to analyse the causes and risks associated with recreational craft, and to identify and evaluate risk reducing measures to reduce the number of accidents significantly. This paper presents the risk model for recreational craft accidents, developed together with the NMA that will support NMA's and their partners work to achieve these goals. The risk model was developed following NMA's existing risk modelling approach, with focus on the accident frequency of motorboats, sailing boats and personal watercraft. The model will be employed to assess effectiveness of measure and visualizing the contributing factors within the RCP.

Keywords: accident modelling, recreational craft, risk influencing factors, risk model, influence diagram

1. Introduction

About 30 recreational craft users die annually in accidents in Norway. During the last five years, 132 people died in 121 accidents (Norwegian Maritime Authority (NMA) 2023). Only the number of accidents with fatalities and severe outcomes are recorded. However, it is estimated that many more accidents occur, leading to injuries of recreational craft users or substantial material damage (Statens Havarikommisjon for Transport 2019). Norway has the vision to reduce the number of fatalities significantly (NMA 2019). The Recreational Craft Platform (RCP, Norwegian: Fritidsbåtplattformen) is being developed to collect and merge available data on recreational craft accidents and thereby enable stakeholders to actively take measures to achieve this vision (Græslie 2021). Contrary to the commercial maritime segment, few risk models exist for recreational craft, and this hampers risk management. Thieme et al. (2022) analysed the scientific literature on leisure craft accidents for identifying risk models and factors that influence the risk level. The findings in Thieme et al. (2022) were used as input to the research presented in this paper.

Risk in this project is seen as the combination of frequency and consequences of a leisure craft accident. Leisure craft are *every floating equipment that is designed for and able to move on water with a maximal length up to 24 m and that is used for non-commercial activities* (Norwegian Ministry for Fisheries and Economy 2015). The NMA has previously developed risk models for commercial shipping and fishing vessels, the Norwegian National Ship Risk Model (Haugen et al. 2016). The method for building the risk model was adopted in this paper, to build the risk model for recreational craft accidents.

The research presented in this paper is aiming to develop a conceptual risk model and a quantitative indicator-based model for recreational craft accidents for assessing the frequency of leisure craft accidents, which has not been available before. The model will be implemented in the RCP, to provide decision support to stakeholders. The paper is limited to leisure (sailing and motor) boats and personal watercraft, which are similar regarding their operation. The next session will introduce the chosen method for building the risk model. Section 3 presents the qualitative risk model and

outlines the further quantitative modelling process. This is followed by the discussion and conclusion sections.

2. Method

The method for developing the Norwegian National Ship risk model (Haugen et al. 2016) was adopted to develop the risk model in this article. As no risk model for recreational craft accidents in Norway exists, the method was followed step by step. The steps are:

(i) Describe scope and context of the risk model;
(ii) Identify risk factors that should be included in the risk model and document relevance;
(iii) Build an influence diagram and document relevance of influences;
(iv) Identify indicators for the nodes in the influence diagram;
(v) Assign weights to each nodes' influences on other connected nodes;
(vi) Assign weights to the indicators' influence on their respective nodes;
(vii) Operationalize indicators.

In the first step (i), the goal and scope of the risk model is defined. This includes the operational context and the limitations with respect to content. The second step (ii) is conducted in a workshop setting to identify relevant factors to be included in the risk model. Workshop participants use their experience, supplemented by data on accidents and statistics. Each risk factor needs to be described and it needs to be documented, why the factor needs to be included in the model. A risk [influencing] factor is "an aspect (event or condition) of a system or an activity that affects the risk level of this system or activity" (Øien 2001). Risk factors can affect the frequency or likelihood, the consequences or both of an accident. There are three major categories of risk factors, technical and operational (1), regulatory activities (controls through governmental and private organizations (2), and rules and requirements (3). Figure 1 summarizes the relationships between the three different types of risk factors and the risk level.

The third step (iii) aims at connecting the different factors in a meaningful way, representing causal relations. The influences need to be documented and justified. The influence diagram serves as visual representation of the risk model, which is built through indicators. The fourth step (iv) establishes possible indicators for each factor that is included in the influence diagram. Indicators are "[…] a measurable representation ("an indication") of a risk [influencing] factor" (Øien 2001).

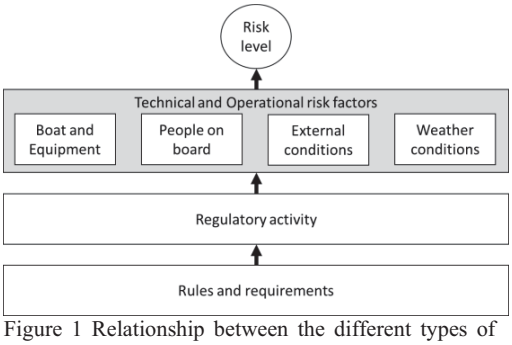

Figure 1 Relationship between the different types of risk factors considered in the risk model. Figure adapted from Thieme et al. (2022).

Step (v) starts the quantitative development of the risk model. Each risk factor that is influenced by a parent risk factor is evaluated for the influence of all the factors. In addition, it is determined the self-weight of the risk factors. The self-weight can be interpreted as the portion of the risk factor that is explained by factors not included in the parent risk factors. This self-weight also describes also how much of the risk node is explained through its associated indicators. In step (vi), similarly to step (v) the indicators are weighted against each other regarding their influence on the risk factor under evaluation.

Figure 2 visualizes the quantitative development process and the weighting process. In the last step (vi), the risk indicators are operationalized, i.e., the measurements are normalized to a scale. This scale should be the same for all risk factors in the risk model, in order to facilitate calculations and interpretations. Then the risk model is ready for use, being able to indicate the current risk level based on the current indicator measurements or predicting the risk level, making assumptions on the status of (some of) the indicators.

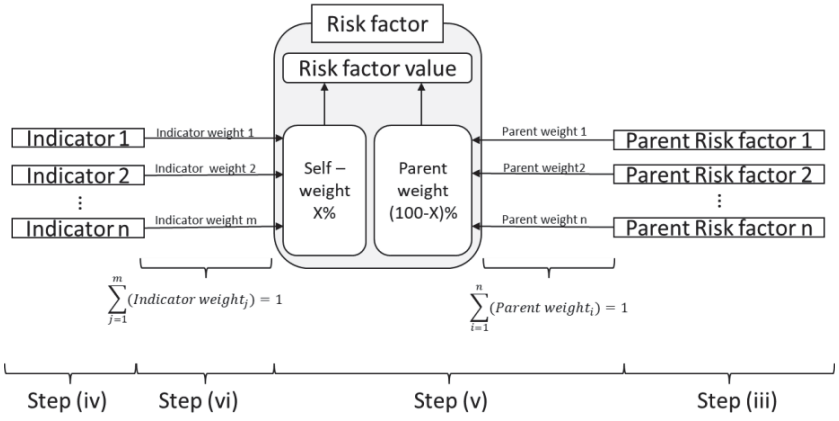

Figure 2 Explanation of the quantitative steps of the risk model development.

The steps (ii) through (vii) are carried out iteratively, where information and insights gained in the later steps is used to update the information in the earlier steps. This may relate, for example, to the contents of risk factors, the self-weight, or the identification of indicators.

3. Resulting risk model

This section presents the qualitatively developed risk model for leisure craft accidents and outlines the further approach to quantifying it.

3.1. *Scope and context*

The risk model presented in this paper was developed together with the NMA for use in their operational work to determine the risk level of leisure craft in Norway. The risk model will be used to assess the impact of campaigns, changes in the regulations, etc. Thereby it will provide decisions support when allocating resources and campaign effort. The risk model will be normalized to the annual activity level of the selected recreational craft types. In this case, sailing and motorboats, and personal watercraft are considered, excluding other types of recreational craft, such as, kayaks, canoes, rafts, and sailing and surf boards. Based on the NMA's recreational craft accident database the following accident types were considered:

- Person over bord
- Fall from pier/quay into the sea
- Personal accident
- Engine breakdown
- Capsizing
- Grounding
- Collision
- Water ingress
- Fire

3.2. *Identification of risk factors*

Risk factors were initially identified in several workshops in autumn 2021. Through several iterations they were used to build the influence diagram, and for identifying indicators and self-weights. The description of risk factors was refined and some factors were determined to be *not relevant*, *could be used as indicators*, or are a *part of another risk factor*. The findings in Thieme et al. (2022) were used as part of the refinement process and to validate the relevance of factors. Table 1, Table 2, Table 3, Table 4, and Table 5 provide the definitions and justifications for the risk factors included in the influence diagram.

3.2. *Influence diagram*

Figure 3 presents the developed risk model. The influence diagram was organized from left to right. The risk factors are arranged by timely proximity to the accident. Meaning that the risk factors to the right of the influence diagram are more varying with time and have a more direct influence on the risk level.

Rules and regulations influence corresponding regulatory activities. These

regulatory activities influence the condition of the recreational craft operator, the recreational craft passengers and the recreational craft itself. These conditions will consequently have an influence on the behaviour of the boat operator and passengers on board. The behaviour together with the local circumstances, such as weather and fairway condition, may lead to an accident.

Table 1. Risk factors in the category *Rules and regulations* included in the risk model.

Risk factor	Definition	Justification of risk factor
Legal alcohol limit	The legal alcohol limit that currently is valid at sea.	The legal alcohol limit gives the police the legal basis for alcohol checks. The alcohol level of boat operators also is an important factor in many accidents. Therefore, many awareness campaigns aim at limiting alcohol consumption at sea.
Rental requirements	Requirements to boat rental services, which includes that rentals need to assure competency of boat renters and ensure their safety during the rental period.	Through the duty of boat rentals to assure safety of renters, this directly influence the risk management of boat rentals and gives authorities the legal basis for assessing boat rental services.
Requirements for certificates	Requirements for boat operators to have the right certificates for operating boats of certain sizes and speed.	The requirement for having certificates shall ensure that boat operators have an understanding for what constitutes safe navigation and safe behaviour at sea.
Speed-, harbour, and fairway regulations and laws	Includes restrictions and regulations at sea that are generally valid on the Norwegian coast and the special regulations for specially assigned areas.	The rules and regulations are developed to reduce the risk along the Norwegian coast. These laws and regulations affect education, efforts to communicate safe behaviour at sea and the improvement of fairways.
Technical and maintenance requirements	Requirements for the design, performance and maintenance of recreational craft, engine and propulsion systems, and equipment on board.	The regulatory requirements provide the basis for what is considered a safe recreational craft. Therefor it affects the risk level of recreational craft, where craft that do not fulfil the requirements are considered less safe.

Table 2. Risk factors in the category *Regulatory activity* included in the risk model.

Risk factor	Definition	Justification of risk factor
Education, courses, activities to increase competency	Quality and number of educational courses and competency lifting activities for boat operators, boat users and employees of organisations working with recreational craft.	Education and knowledge communication is an important element for increasing boat operator's competency and safe behaviour at sea.
Effort to shape attitude and communication of regulations	The risk factor relates to efforts of non-formal education, i.e., advertisement campaigns in relevant journals, fora, and social media platforms. These campaigns aim at creating awareness of hazardous behaviour and what the boat operators can do to reduce the risk.	The effort affects people on board by creating awareness of hazardous situations and how to counteract these. These can be behavioural advice (no drinking at sea) or the use of navigational support systems or smartphone apps.
Improvements of harbours and fairways	Effort related to improve the safety in fairways, harbours, marinas, etc. This relates to evaluation and prioritization of areas and planning and executing improvement measures.	These activities are directly related to reduce the risk of maritime accidents, including recreational craft accidents. Improvements can aim at Aids to navigation, Speed limits, and Pier and quay condition.
Inspections and audits	This includes inspections and audits within the recreational craft segment which are carried out by or in the name of the NMA, the Norwegian Directorate for Civil Protection (DSB), and the Royal Norwegian Boating Association (KNBF).	Inspections and audits are carried out to ensure that regulatory requirements are met by boats, equipment and organisations. This affects boat rentals, design, navigational support, engine and propulsion systems, and maintenance, as these are regulated to some degree.
Police checks and local presence	Checks and presence of authorities (Police, coast guard) and other actors (volunteer rescue association (Norw.: Redningsselskapet (RS))).	Presence is a corner stone of the police and other actors, to demonstrate authority and create awareness to adhere to regulations and laws. This influences the condition of the people on board.

Table 3. Risk factors in the category *Activity and behaviour of people on board* included in the risk model.

Risk factor	Definition	Justification of risk factor
Area of use	Activity on board or aim for the use of the boat	The area of use will influence the behaviour of the people on board and may be associated with certain hazards.
Loading	The distribution of cargo, passengers, and equipment on board.	The distribution of weight influences the stability and manoeuvrability of the boat, incorrect positioning may lead to loss of stability, personal damages, fall overboard, or insufficient control over the vessel.
Navigation and boat handling	Describes the boat operator's actions and handling with respect to controlling the boat and adapting speed and course to the given circumstances the boats characteristics. The actions also include the general boat operator's behaviour on board of the boat.	The boat operator has direct influence with their action on the safety of the boat trip.
Passengers' behaviour	The passenger's behaviour when boarding, being on board and disembarking the recreational boat. This includes following commands by the boat operator and moving safely around the boat, adequate for the current activities on board.	The behaviour of passengers (if they are present) influences the safety on board through their actions that may distract the boat operator. Also, passengers through their own behaviour may damage themselves or other passengers or fall into the sea.
Recreational craft accident	Type of accidents that are considered in the risk model, these are listed in Section 3.1.	

Table 4. Risk factors in the Condition *of boat and equipment* and *Boat rentals* included in the risk model.

Risk factor	Definition	Justification of risk factor
Boat operator's competency	Formal and informal competency with respect to navigation and boat handling. This also encompasses the experience of the boat operator.	The competency will highly influence the performance of the boat operator navigating and handling the boat and adapting the navigation to the local circumstances. It also influences the performance when preparing for a trip, i.e., loading of people and equipment on the boat in a safe manner.
Boat operator's condition	Boat operator's alertness, risk perception, physical and mental skills with respect to boat operation.	The boat operator's condition determines reaction time, behaviour, and ability to navigate and operate the boat safely.
Boat rentals' safety management and practice	Commercial boat rentals practices regarding mandatory risk management and consequent maintenance of equipment and instruction of renters. Note: Boat rentals constitute only a small part of the overall recreational craft fleet.	Boat rentals must instruct renters and need to have a risk management in place to ensure that renters are safe. This affects the boat operator's competency, navigational support, and maintenance.
Design	The design of the recreational craft, inside and outside, including the hull shape, railings, etc.	The design influences the manoeuvrability through the hull shape and the stability of the vessel.
Engine and propulsion system	The reliability and performance of the engine and propulsion system.	The type of propulsion and engine will strongly influence the boats speed, acceleration and thus influence the manoeuvrability. In addition, the engine may fail and lead to engine breakdown.
Maintenance	All actions and measures taken to keep the recreational craft, the hull, navigation aids, and the engine and propulsion system in operational condition through measures such as adjustments, overhaul, replacement of parts, or repair of parts.	Maintenance is an important measure to ensure that all systems and components work as intended and that they are fit to meet the environmental conditions.
Manoeuv-rability	The recreational boat's limitations and characteristics with respect to controllability and stability during a voyage.	The ship operator will need to consider the boats characteristics when navigating and operating the boat.
Navigational support	Additional systems on board the boat that shall assist with trip planning, navigation and communication with other boats.	Navigational support aids help the boat operator to gain a better situation awareness.
Passengers' condition	The passenger's alertness, risk perception, physical and mental characteristics with respect to boating.	The physical and psychological condition influences the attention, behaviour, and their behaviour.
Technical safety barriers	Equipment and systems on board that shall prevent an accident if something unexpected occurs. This are for example, Deadman's switch, safety lines and alco-locks.	Having additional safety barriers in place can directly prevent the escalation of an unforeseen event to an accident.

Table 5. Risk factors in the category *Weather and external conditions* included in the risk model.

Risk factor	Definition	Justification of risk factor
Aids to navigation	Signals and installations that have been placed in the area to mark areas of danger and to aid in navigation. This risk factor also includes physical changes in the area, for example removal of rocks or reefs.	This is an important part of the work of the coastal administration to reduce the risk of maritime accidents. It directly influences the quality of the fairway.
Fairway	Describes the environment that the recreational craft is operated inn and summarizes the risk level presented from the different environmental components, such as traffic, weather, visibility, etc.	The fairway summarizes the conditions that the boat operator needs to navigate in and adapt boat operation to.
Light and visibility	The combination of weather and light conditions that affect the visibility in the respective area. This includes dusk, dawn, night, fog, precipitation, light pollution from man-made light sources, etc.	The visibility and the visual range are an important part of the local aspects of the fairway and thereby influence the boat operator's ability to navigate safely.
Pier and quay conditions	Condition of piers, quays, and other harbour infrastructure	The condition is important in context with personal injuries and fall into the sea, as quays and piers may be instable or slippery.
Speed limit	Describes the speed limit for recreational craft in the chosen area.	The speed limit and average speed of boats contributes to the complexity of the fairway that the boat operators need to adhere to.
Traffic	Density and composition of the traffic in the local area. The traffic can be made up of commercial vessels, fishing vessels and recreational craft.	The traffic and its complexity influence the fairway and the local conditions there. Other traffic participants may be involved in collisions.
Waves, wind, and currents	Combination of weather and sea state that influences the recreational boat.	The weather and sea state influences conditions in the fairway that the boat operator needs to navigate accordingly. In addition, strong wind, waves, or currents may lead to damages and directly recreational boat accidents.

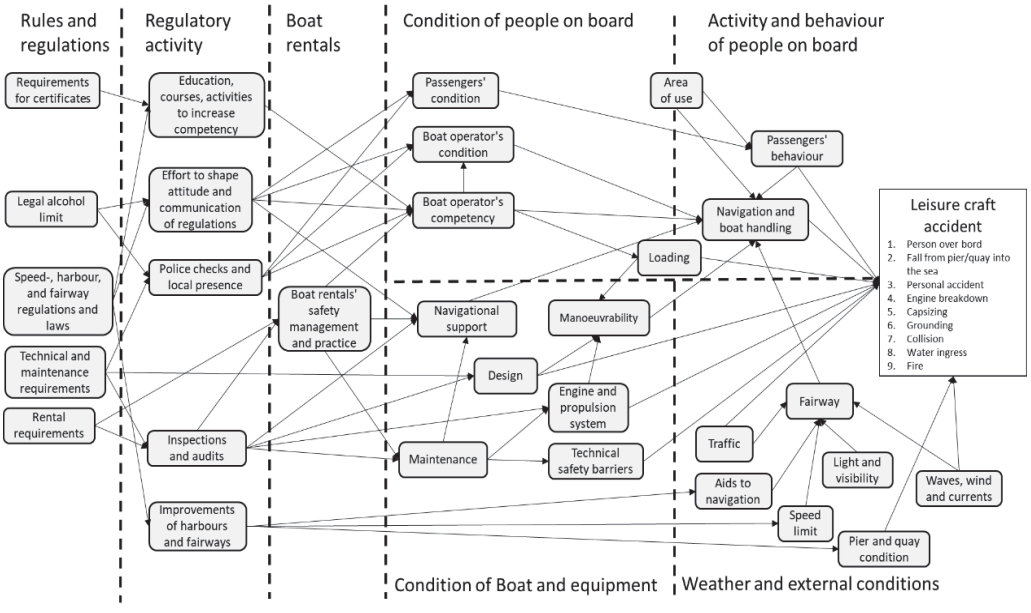

Figure 3. Risk influence diagram for leisure craft accidents.

3.3. *Identification of indicators and weighing*

Indicators to quantify the risk model are currently being developed and assessed. Hence, no details can be provided here on the quantitative relationships. Indicators are being developed from available data sources (internal and external to the RCP project). One challenge of the indicator development is that the data often is not collected coherently. Normalization and adaption of the data to the context are necessary. Additionally, many data sources contain personal data and hence privacy issues need to be resolved. Data sources for indicator development that are considered in the RCP are:

- NMA's recreational craft accident database and recreational boat certificate register;
- RS's operation log;
- RS's boat and equipment register;
- Norwegian coastal administration's (Kystverket) data on hazardous waters and Automatic identification system data;
- Police's operational logs and accident database;
- Rescue logs from emergency services;
- KNBF Boating-life survey (Kongelig Norsk Båtforbund, 2018), providing data on recreational craft users, the recreational craft fleet and equipment on board;
- Meteorological data from the Norwegian meteorological institute;
- Norwegian map authority's (Kartverket) nautical charts;
- Statistical data from Statistics Norway (SSB) on use, users and sales of recreational craft;
- Sales statistics of recreational craft and equipment from NORBOAT;
- Data on harbours and marinas from coastal Norwegian municipalities.

As indicators have not been identified yet the steps (v) through (vii) are not further detailed in this article.

4. Discussion

This paper presents on going work and the full process described in Section 2, has not been applied yet. The goal is to share our experiences and findings to open up for dialogue with the international community, as in our previous paper it was found that there is a lack of information exchange in the international community (Thieme et al. 2022). Unfortunately, it is not possible yet to share all experience, as the process is executed in praxis and still ongoing. Yet, some applications of the risk model and that are envisioned shall be mentioned:

- Assess the effect of measures and actions taken by setting evidence for the indicators and seeing the effect. For example, increasing the number of alcohol controls in an area;
- Visualizing the risk level based on available data and expected conditions in certain areas. For example, use the predicted increase in recreational craft users in the Norwegian counties to identify counties with increased risk and prioritize actions;
- Serve as a basis for visualizing statistics with respect to recreational craft users, providing a risk-based view in the RCP. For example, provide relevant statistics for each risk factor, such as, *number of controls where boat drivers were under found to have consumed alcohol* for the risk factor *regulatory activity*;

This paper presents only the frequency model for risk assessment. A model for the consequence needs still to be developed. In addition, so far only motorboats, sailing boats and personal watercraft are considered. Risk models for other recreational craft, such as, kayaks, canoes, rafts, sail boards, etc., remain to be developed.

The influence diagram and the resulting risk model was developed through expert judgment from the NMA and other partners in the RCP project. The influence followed the method of the NSRM approach. However, it is quite different from the risk model for commercial ships, due to the different peculiarities of recreational craft. For example, the ownership relations are much more complex for commercial ships compared to recreational craft, where the owners are often also the operators. Another example is navigation and boat handling. Recreational boats are smaller than commercial ships and require different competencies, attention and actions than commercial ships.

The influence diagram and the risk factors were validated with help of previous research, i.e.,

Thieme et al. (2022). Validation at this stage, consisted of ensuring that important identified factors were included in the model, either as risk factors or as indicators. Not included in the influence diagram are the navigational rules, i.e., are the international regulations for avoiding collisions are at sea (COLREGs, IMO, 1972), as these are not expected to change and the processes around their update are to a very limited degree influenced by the NMA. In addition, risk factors, such as, *Age*, *Sex*, *Alcohol usage*, Human error, or *Children on board*, are not explicitly included. *Age*, *Sex*, *Children on board*, and *Alcohol usage* relate to the condition of passengers and boat operators and are considered being indicators. Human error is a consequence of the passengers' or boat operator's condition and hence is implied in the risk factors *Passenger's behaviour* and *Navigation and boat handling*.

Some risk factors, such as, rules and regulations and regulatory activity that are little mentioned in the literature have been included in the presented risk model. The literature (summarized in Thieme et al. (2022)) mentions only requirements for warning labels (corresponding to technical requirements), education and requirements for certificates, and alcohol related laws, campaigns and checks

5. Conclusion and future work

This paper presents the preliminary findings of the risk modelling process of recreational craft accidents. In this paper, the influence diagram, risk factors and sources for quantitative risk indicators are outlined. The model shall assist the NMA and partners in the RCP project to make decisions and see the influence of measures and actions that they take to reduce risk related to recreational craft usage.

The next steps in the RCP will be to finish the indicator development process and to build an operational risk model based on the indicators. This model will be implemented in the data platform that is currently being developed in the RCP project. Furthermore, the process shall be applied to model the consequences of recreational craft accidents.

Acknowledgement

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