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Risk-Based Decision Support Model for Offshore Installations

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Abstract

Background: During major maintenance projects on offshore installations, flotels are often used to accommodate the personnel. A gangway connects the flotel to the installation. If the offshore conditions are unfavorable, the responsible operatives need to decide whether to lift (disconnect) the gangway from the installation. If this is not done, there is a risk that an uncontrolled autolift (disconnection) occurs, causing harm to personnel and equipment. **Objectives:** We present a decision support model, developed using the DEXi tool for multi-criteria decision making, which produces advice on whether to disconnect/connect the gangway from/to the installation. Moreover, we report on our development method and experiences from the process, including the efforts invested. An evaluation of the resulting model is also offered, primarily based on feedback from a small group of offshore operatives and domain experts representing the end user target group. **Methods/Approach:** The decision support model was developed systematically in four steps: establish context, develop the model, tune the model, and collect feedback on the model. **Results:** The results indicate that the decision support model provides advice that corresponds with expert expectations, captures all aspects that are important for the assessment, is comprehensible to domain experts, and that the expected benefit justifies the effort for developing the model. **Conclusions:** We find the results promising, and believe that the approach can be fruitful in a wider range of risk-based decision support scenarios. Moreover, this paper can help other decision support developers decide whether a similar approach can suit them.
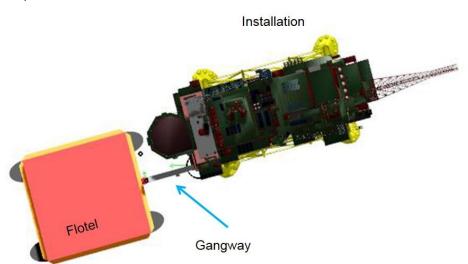
Introduction

During the autumn of 2016, we developed a computerized model to support decisions based on operational safety risk offshore. The model automatically provides a decision advice based on 28 input parameters, and was developed using DEXi (Bohanec, 2017), which is a tool for multi-criteria decision modeling. The choice of DEXi was made based on early experience two of the authors had from using DEXi in the domain of cyber-risk (Refsdal et al., 2017; Erdogan et al., 2018).

The contribution of this paper is a report on our experiences, the efforts spent on the model development, as well as a presentation of the model and an initial evaluation. The aim is to help others who face related challenges to consider whether a similar approach may be suitable for them. We start by explaining the challenge and our success criteria.

During major maintenance projects on offshore installations, flotels are often used to accommodate the personnel. A flotel ("floating hotel") is a vessel providing sleeping quarters and other facilities. As illustrated in Figure 1, a gangway connects the flotel to the installation. The flotel needs to keep its position in a very limited area close to the installation. This can be done by means of Dynamic Positioning (DP), thruster assisted mooring or mooring systems. DP implies employing a computer-controlled system that allows the flotel to automatically keep its position by using its own thrusters. However, keeping the position is challenging due to the weather, waves, and other conditions offshore.
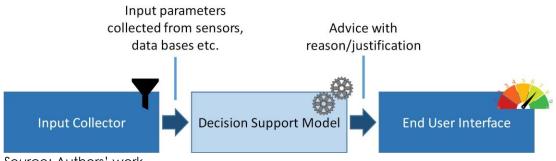
Figure 1
Gangway connection from flotel to installation

Source: Authors' work

If conditions are unfavorable, the responsible offshore operatives need to decide whether to lift (disconnect) the gangway from the installation. If this is not done, there is a risk that an uncontrolled autolift (disconnection) occurs, causing harm to personnel and equipment. The decision is difficult because many different factors affect the risk. Moreover, lifting the gangway has high economic cost, as workers will be prevented from performing their tasks on the installation. Currently, the offshore operatives make use of paper-based Location Specific Operational Guidelines (LSOG), along with a number of other sources of information, e.g. the prevailing weather conditions and the weather forecast, to guide the decision.

To provide alternative decision support, ease the information handling and reduce dependency on the experience, competence and mental state of the individuals on duty at any given time, we envision a solution where advice is automatically generated based on a wider range of input parameters compared to the LSOG. This solution is illustrated in Figure 2.

Figure 2
Vision for overall decision support solution

Source: Authors' work

The Input Collector collects all the data for the input parameters, such as weather forecasts and sensor readings. The Decision Support Model aggregates these data to compute an advice. This advice is presented in the End User Interface, which should be tailored to the human offshore operatives making the decision.

The work presented in this paper concerns the Decision Support Model. We identified the following success criteria for the model:

C1: *The decision support model should provide advice that correspond with expert expectations.*
C2: *The decision support model should capture all aspects that are important for the assessment.*
C3: *The decision support model should be comprehensible for domain experts.*
C4: *The expected benefit should justify the effort required to develop the decision support model.*

The rest of this paper is structured as follows. First, in Section 2 we introduce the DEXi tool, before explaining the method used for the development in Section 3. Section 4 presents the decision support model, while Section 5 presents expert feedback on the model. In Section 6 we discuss and evaluate the model with respect to criteria C1-C4. In Section 7, we present related work, before concluding in Section 8.

The DEXi Tool

DEXi (Bohanec, 2017) is a computer program for the development of multi-criteria decision models and the evaluation of options. Multi-criteria (also called multi-attribute) models are a class of models used for decision analysis that evaluate options according to several, possibly conflicting, goals or objectives. In this section, we introduce DEXi, focusing on the parts needed to understand the rest of this paper. The reader is referred to the DEXi User Manual for further details on the tool (Bohanec, 2015).

Multi-attribute models decompose decision problems into a tree (or an acyclic graph) structure. The top attribute in such models represents the overall problem, while the attributes below the top attribute represent sub-problems, which are

smaller and less complex than the overall problem. Each attribute is assigned a value. The set of values for an attribute is referred to as the *scale* of the attribute. DEXi supports definition of discrete ordinal scales, where each step typically consists of a textual description. An example of an ordinal scale is {Unacceptable; Acceptable; Good; Excellent}.

The attributes in the model are either basic or aggregate attributes. *Basic attributes* represent the inputs to the multi-attribute model. They have no child attributes. The value of a basic attribute is determined solely by the input to (or selected value for) the attribute.

Aggregate attributes have child attributes (which may be basic or aggregate). The value of an aggregate attribute is a function of the values of its child attributes. This function is called the *utility function* of the attribute. The utility function of each aggregate attribute is defined by stating, for each possible combination of its child attribute values, what is the corresponding value of the aggregate attribute.

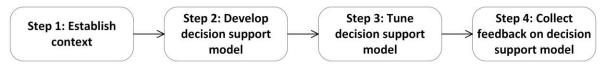In summary, developing a DEXi model implies the following:
o   Identify the attributes and structure.
o   Define the scale for each attribute.
o   Define the utility function for each aggregate attribute.

For any given set of values for the basic attributes, the value assigned to the top attribute represents the overall aggregated evaluation.

Method for Model Development

As illustrated in Figure 3, we developed the model in four steps. In the first step, we established the context by identifying the purpose and scope, as well as deciding which tool to use. In the second step, we developed the decision support model by carrying out points i–iii described in Section 2. This was primarily done during video meetings where the analysis leader shared his screen and edited the DEXi model based on input and comments from the domain experts, while the analysis secretary took notes about the reasoning and discussions. Some modifications and corrections where also done offline, through email interaction.

Figure 3
Overview of method

Step 1: Establish context → Step 2: Develop decision support model → Step 3: Tune decision support model → Step 4: Collect feedback on decision support model

Source: Authors' work

In the third step, we tuned the decision support model by first defining a set of six scenarios based on the following criteria: 1) All scenarios should be realistic, i.e. represent conditions that might actually occur. 2) The set should include scenarios that cover all the possible decision alternatives defined in the LSOG. After describing the scenarios textually, each of the identified scenarios was translated to an assignment of a value to each basic attribute, referred to as an *option* in the DEXi tool. This allowed us to compare the advice produced by the model for each scenario with the guidelines provided by the LSOG. In cases of mismatch, we updated the DEXi model. In the fourth step, we collected feedback on the model, with focus on model structure and outcome for the six scenarios defined in the preceding step.

As shown in Table 1, the above steps were carried out in 12 meetings held within a period of three months (from August 2016 to November 2016). All the authors took part in the model development. Of these, three are domain experts with technical experience within ship technology and marine systems in the petroleum industry, as well as software systems to support the petroleum industry with respect to risk-based decision-making. The remaining two (from SINTEF) served as analysis leader and secretary. The fourth step, i.e. feedback on the model, took place in meeting 12 (with preparations in meeting 11). The feedback was collected from three offshore operatives who represented the target group and who had not participated in developing the model or been involved in any other way before meeting 12. The feedback is explained further in Section 5. All meetings except meeting 12 were video meetings, while the 12th meeting was a combined physical and video meeting where one of the offshore operatives participated remotely from an offshore location. Although the steps are presented chronologically, they were sometimes revisited to make updates and adjustments or to capture new factors that were brought forward by the domain experts. Roughly speaking, the first step took place in meeting 1 and meeting 2, the second step took place from meeting 3 to meeting 7, the third step took place from meeting 8 to meeting 10, and the fourth step took place in meeting 11 and meeting 12.

Table 1
Overview of meetings

M	Date	D	S	Activity
1	25.08.16	1.5 h	1	Establish context
2	16.09.16	2.5 h	1	Finalize context establishment, present DEXi and progress plan, and develop initial model structure
3	22.09.16	2 h	2	Continue developing model structure
4	06.10.16	2 h	2	Complete model structure, define scales for attributes and utility functions for aggregate attributes
5	13.10.16	3 h	2	Continue defining attribute scales and utility functions
6	25.10.16	3 h	2	Continue defining attribute scales and utility functions
7	27.10.16	2 h	2	Complete defining attribute scales and utility functions
8	02.11.16	2 h	3	Perform model tuning
9	11.11.16	2.5 h	3	Perform model tuning
10	24.11.16	2 h	3	Complete model tuning
11	28.11.16	1 h	4	Prepare feedback collection
12	30.11.16	6 h	4	Collect feedback from offshore operatives

Note: M=Meeting, D=Duration, S=Step in method
Source: Authors' work

The Decision Support Model

In this section, we present the decision support model. We focus on the model structure, i.e. the attributes and the way in which these have been organized. The structure is shown in Figure 4, which have been extracted from the DEXi tool and presents the model as it was at the end of the development process, before meeting 12. As can be seen from the figure, the tool allows the user to provide a description in addition to the name for each attribute, which we made use of for most of the attributes. The remainder of this section explains the main characteristics of the model structure in further detail.

Figure 4
The DEXi model structure

Attribute	Description
Gangway operational risk	Operational risk for the gangway between the floatel and the installation
Floatel criticality state	Criticality state of the floatel w.r.t. gangway operational risk
DP class status	Are the DP class requirements relevant and fulfilled?
DP class compliance	Are the redundancy requirements to DP class 3 fulfilled?
Operation mode	What is the operation (station keeping) mode of the floatel?
Station keeping performance	Ability of the floatel to stay in the desired position
Drift-off collision risk	What is the drift-off collision risk level?
DP force/thrust direction	Direction of the DP force/thrust direction vector, which is obtained from the DP system
DP force/thrust amplitude	The DP force/thrust amplitude needed to counteract the weather forces, which is obtained from the DP system
Gangway criticality state	Criticality state of the gangway w.r.t. gangway operational risk
Real-time gangway stroke	Single stroke amplitude measured at the current point in time
Real-time gangway elevation	Gangway elevation means deviation from horizantal. Design limitation lies between -16 degrees and + 24 degrees.
Present heading deviation from recommendation (weather-dependent)	Deviation between actual and recommended heading from Storm gangway response tool
Present heading deviation from recommendation	Deviation between actual and recommended heading from Storm gangway response tool
Measured weather	
Gangway stroke statistics	Gangway stroke statistics as measured within the last 10 minutes
Gangway stroke forecast in six hours	Forecast from StormGeo for time now+6 hours
Number of existing gangway forecasts above alarm limit	How many of the forecasted gangway strokes (depending on heading) are avove the alarm limit?
Heading deviation from recommendation in six hours	Deviation between actual real-time heading (now) and recommended heading in six hours (now+6 hours)
Weather	The current and forecasted weather conditions w.r.t. impact on the gangway operational risk
Measured weather	Actual weather, assumed to be measured by a number of sources and aggregated/harmonized by an external system
Waves	Operational impact due to waves
Significant wave height	
Wave direction	Measured w.r.t. actual floatel heading
Wave period (Tp)	Included for completeness but has little or no impact
Wind	Operational impact due to wind
Wind speed	
Wind direction	Included for completeness, but has no impact w.r.t. gangway connection/disconnection
Sea current	Operational impact due to current (current is measured by a weather buoy)
Sea current speed	
Sea current direction	Included for completeness, but does not impact Sea current as it is now defined
Forecasted weather	Forecasted weather, assumed to be aggregated/harmonized from different sources, such as Storm and Yr, by en external system
Waves forecast	
Significant wave height forecast	
Wave direction forecast	
Wave period (Tp) forecast	
Wind forecast	
Wind speed forecast	
Wind direction forecast	Included for completeness, but has no impact w.r.t. gangway connection/disconnection
Installation criticality state	Criticality state of the installation w.r.t. gangway operational risk
Operational activity state	What is the current operational activity state?
Drilling and well activity	Is drilling and/or well activity ongoing?
POB above lifeboat capacity	Is the number of personnel on board the fixed installation above the lifeboat capacity?
Exhaust exposure	Is the exhaust exposure high enough to create problems for personnel on the installation?
Visiting vessel	Is a visiting vessel present?

Source: Authors' work

Gangway operational risk is the top attribute. The value assigned to this attribute represents the advice to the decision maker, since this advice depends directly on the risk level. Table 2 shows the scale for the attribute, and hence all the possible advice that can be produced by the model. The values are presented in order of decreasing risk, meaning that the value "Abandon operation" in the scale represents the least desirable state. Notice that to *abandon operation* in this context means to lift (disconnect) the gangway.

Table 2
Scale for the top attribute *Gangway operational risk*

Value	Description
Abandon operation	There are very strong reasons for disconnecting the gangway; an autolift or other incident is likely.
Prepare to abandon operation	There are strong reasons for disconnecting the gangway. Preparations for disconnection should be considered.
Advisory state	If already disconnected, the gangway should remain so. If it is currently connected, it may remain connected.
Normal state	The gangway may safely be (or remain) connected.

Source: Authors' work

As shown in Figure 4, the top attribute has four child attributes, each representing one of the main categories of factors that affect the risk level. The first of the main categories is *Flotel criticality state*, which capture the factors related to the flotel. *DP class compliance* refers to the requirements to the Dynamic Positioning (DP) system, which is the control system used to maintain the desired position of the flotel using thrusters. The *DP class compliance* attribute captures the degree to which the requirements for redundancy of sensors, actuators and controllers in the DP system is fulfilled, since loss of redundancy imply a higher risk of not being able to control the flotel's position. The *Operation mode* attribute records whether the flotel is currently kept in position by using only the DP system, thruster assisted mooring (which combines the use of the DP system and mooring) or by using only mooring. Since the importance of fulfilling the DP system redundancy requirements depends on the degree to which the DP system is currently used to keep the flotel in position, the *DP class status* attribute aggregates *DP class compliance* and *Operation mode*. *Station keeping performance* captures the degree to which the flotel has been able to stay within the preferred position and heading (direction with respect to the installation) recently. The last attribute under *Flotel criticality state* is *Drift-off collision risk*, which represents the risk of the flotel drifting out of the desired position and colliding with the fixed installation. This risk depends on the direction and amplitude of the forces from the thrusters required to counteract the forces from waves, wind, etc., which is registered by the DP system and captured by the attributes *DP force/thrust direction* and *DP force/thrust amplitude*.

The second of the main categories is *Gangway criticality state*, which captures the factors related to the gangway between the flotel and the installation. The first two attributes in this category, i.e. *Real-time gangway stroke* and *Real-time gangway elevation*, capture the stroke and elevation of the gangway at the current point in time. Both are registered by sensors on the gangway, and should stay within fixed limits. Next, *Present heading deviation from recommended heading (weather dependent)* captures the degree to which the heading of the flotel is within the recommended limits, but compensating for the fact that the importance of staying within these limits depends on the weather. Notice that the *Measured weather*

attribute under *Present heading deviation from recommended heading (weather dependent)* is a so-called linked attribute, which means that it occurs more than once in the structure. We come back to the *Measured weather* attribute below. *Gangway stroke statistics* captures the number of times the gangway stroke has been outside its fixed limit during the last 10-minute period. The final attribute under *Gangway criticality* state is *Gangway stroke forecast in six hours*, which depends on gangway stroke forecasts from a separate stroke prediction system and the expected deviation from the recommended heading in the next six hours, which is also obtained from an external system.

The third of the main categories is *Weather*, which is further decomposed into *Measured weather* and *Forecasted weather*. The former captures the current weather as measured by available sensors and services, while the latter captures the forecasted weather for the immediate future. Since weather data and forecasts can come from various sources, they do not necessarily give a consistent picture. We assume that harmonization of conflicting weather data is performed before assigning values to the relevant model attributes, as this is a challenge that is beyond the scope of the work presented here.

The fourth and final of the main categories is *Installation criticality state*, which captures the factors related to the installation connected to the flotel via the gangway. The *Operational activity state* attribute captures the operational activity on the installation, as the risk may depend on whether production or maintenance activities are currently ongoing. The same applies for *Drilling and well activity*. *POB above lifeboat capacity* captures whether there are currently more personnel on the installation (Personnel on Board) than there is room for in its life boats. This is relevant because the ability to escape via the gangway is extra important if the lifeboat capacity is exceeded. The *Exhaust exposure* attribute is included because exhaust may, in extreme cases, potentially cause problems for the personnel so that they need to leave the area. Finally, the *Visiting vessel* captures the presence of supply boats or other vessels, as this may have impact on collision risk and the available space to maneuver.

Feedback on the Model

In order to validate the model, we wanted to involve offshore operatives who belong to the target group and who had not taken part in the model development. Three such operatives were able to participate, of which two participated remotely. In addition, all those who had taken part in the model development were present.

The choice of validation approach was made based on practical considerations, in particular availability of key persons, time available, and the fact that not all participants would be physically present. The validation was carried out in a single meeting. Moreover, since some of the participants had no knowledge about the project context, DEXi, or the overall envisaged solution, we had to spend the initial part of the meeting introducing these concepts.

Given the practical restrictions, we decided to take a lightweight validation approach. The evaluation focused on the model structure and the outcomes for the six validation scenarios. The participants were asked to provide their opinions on both the structure and outcomes after a presentation from the leader of the meeting. Responses were primarily requested from the offshore operatives, but all participants took part in the discussions. The following questions were asked to initiate and guide the discussion:

- o Model structure:
    - – Are there any important parameters that are omitted?
    - – Are there any parameters that should be removed?
    - – Are the parameters properly organized?
- o Outcome for selected scenarios:
    - – Does the model offer good recommendations for each scenario?

For the second part of the evaluation (outcome for selected scenarios), one of the domain experts who took part in the development of the model had defined, as part of the preparations for the meeting, six scenarios to represent in the model. These had been selected to cover cases that address several aspects while being realistic and interesting, and had been approved by another domain expert. The same scenarios had been used in the final phase of the model development to tune the model, in particular the scales and utility functions.

All participants agreed on the overall model structure. At the detailed level, we received three suggestions for additional attributes to be considered as descendants of one of the four existing attributes directly under *Gangway operational risk*. In addition, there was one suggestion to remove the *Exhaust exposure* attribute, as it was judged to have little impact on the decision on whether to lift the gangway. Finally, there was one attribute (*DP class compliance*) for which a refinement of the scale was proposed in order allow a more fine-grained distinction between states than our original scales offered.

With respect to the outcomes for selected scenarios, the offshore operatives were asked whether they agreed with the advice produced by the model for the scenarios. They unanimously agreed for five of the six scenarios. For the sixth scenario, where the advice provided by the model was *Abandon operation*, two expressed doubt or disagreement, even though the advice was consistent with the LSOG. The offshore operatives emphasized that the LSOG represents guidelines, rather than a set answer. One of the operatives said that he had experienced a similar scenario earlier. He then prepared to lift the gangway, but called a meteorologist to check the expected weather before making the decision. Since the weather was decreasing, they did not lift the gangway.

Discussion and Evaluation

Based on our experience, we now discuss and evaluate the fulfillment of criteria C1-C4 defined in Section 1.

C1 (*The decision support model should provide advice that correspond with expert expectations*): In our context, expert expectations are represented by the opinions of the offshore operatives taking part in the evaluation in the final meeting, as well as the LSOG, which is based on expert knowledge. As explained in Section 3, we made sure that the advice produced by the model were consistent with the LSOG for the identified scenarios. DEXi proved to have the expressive power to achieve this without any problems. For the one scenario where the offshore operatives did not agree with the model, the disagreement was due to a discrepancy between the guidelines in the LSOG and the opinions of the offshore operatives. Hence, the contended scenario is actually an issue of resolving discrepancy between different experts. We consider our results promising, although a thorough evaluation of criterion **C1** requires a more extensive validation, preferably using more scenarios based on historical data, as well as involving more domain experts.

C2 (*The decision support model should capture all aspects that are important for the assessment*): The feedback on the model showed that the offshore operatives

agreed with the overall structure and attributes. Incorporating their proposed modifications would not be a problem. Hence, we are confident that all the factors that the domain experts identified can be captured in the model. The aspects covered by the LSOG, which represent the current solution, is a proper subset of the aspects covered by the model.

However, one aspect not captured by the model is uncertainty. For example, input parameters, such as the weather forecast, are more or less uncertain. Even though the weather services provide an assessment of the uncertainty, this is ignored by the model. We considered including and aggregating uncertainty in the model, so that the advice offered as output could be accompanied by an aggregated assessment of the uncertainty. However, we saw no way to achieve this without significantly complicating the model, and the LSOG does not address the uncertainty of its guidelines. We therefore decided not to include uncertainty in the model.

While discussing **C2**, it is also interesting to touch on the issue of scalability. The most important aspect in this respect seems to be the size of the utility function for each attribute, i.e. number of possible combinations of values for its child attributes. This is determined by the number of child attributes and the granularity of their scales. The DEXi manual states that defining a utility function is quite hard for a size of 100 (Bohanec, 2015). In our model, the largest utility function, which belongs to the top attribute *Gangway operational risk*, has size 144. For this attribute, it was not acceptable to reduce the number of the child attributes, as the structure illustrated by Figure 4 was considered most appropriate. Reducing the number of steps in the scales was also not acceptable. We found the size 144 to be manageable, due to functionality that DEXi offers for checking consistency of a utility function and automatically suggesting possible values for missing entries based on already inserted entries. Still, we believe that utility functions larger than ca. 150 would be highly impractical.

C3 (*The decision support model should be comprehensible for domain experts*): This criterion implies that the domain experts should be able to understand the algorithm by inspecting the model. This increases trust in the outputs from the model, and means that the model can also facilitate knowledge sharing and learning. None of the domain experts who participated in the model development had any knowledge about DEXi before the process. Even so, after a brief introduction, they quickly grasped the DEXi concepts and were able to contribute to the model development. Throughout the process, the comments, suggestions and discussions demonstrated that all participants were able to understand the details of the evolving model. Thus, we avoided the misunderstandings and problems typically encountered when an executable algorithm is implemented in a language not understood by the domain experts. Basically, the DEXi model served as a combined specification and implementation of the assessment algorithm that was fully transparent for all participants.

C4 (*The expected benefit should justify the effort required to develop the decision support model*): Our estimate indicates that the model development amounts to ca. 150 person hours in total. This includes ca. 100 hours spent on meetings 2 to 11. The estimate does not include meetings 1 and 12, as no model development or updates were done in these meetings. Ca. 50 hours was spent on work between meetings. Of the latter, ca. 16 hours was spent by the domain experts on checking the model and defining scenarios, while the remaining 34 hours was spent by the analysis leader and secretary on taking notes and correcting the model. We are not aware of other works reporting on the effort required to develop this type of model. However, for the

model-based risk analysis method CORAS (Lund et al., 2011), the authors state that the expected effort required to carry out a CORAS analysis is typically from 150 to 300 hours. This gives at least an indication that the amount spent on developing our decision support model is reasonable.

Of course, a thorough evaluation of criterion **C4** would require that we quantify the benefit, as well as the cost. This is very hard, and we have not attempted to do so. Still, we believe that the benefit justifies the effort. First, the model produces consistent advice which may be a valuable supplement to a largely experience based decision-making process. There is also a potential for reuse of (parts of) the model to support related decisions. Second, the process of developing the model collectively in a group creates learning and raises the awareness of those taking part. Third, the resulting model codifies and documents knowledge from all those taking part in the development, thus serving as a vehicle for knowledge transfer throughout the organization. While the first point was a central part of our motivation for initiating the work, and known in advance, the added benefit of the last two points became clear to us during the process.

Given the practical limitations and approach for obtaining feedback on the model, there are some obvious threats to validity. Since only three offshore operatives who had not taken part in the development of the model took part in the validation, the feedback we received was very dependent of these particular individuals. On the positive side, all three were in the core target group for the envisaged solution.

Only six scenarios were considered for evaluation of the advice provided by the model. Since the model includes 28 basic attributes, each with two or more possible values, the six scenarios cover a small proportion of the theoretically possible combinations of values for basic attributes. However, the six scenarios had been carefully selected by one domain expert (and approved by another) to cover cases that address a wide range of aspects while being realistic and interesting. For each scenario, the model outcomes were shown to the three offshore operatives before they were asked whether they agreed. Such an approach implies that there is a chance that the respondents give a confirmative answer without thinking it through to arrive at their own conclusion. However, the expression of disagreement for one of the scenarios, for which clear arguments were provided, indicates that the participants did indeed take the effort to make up their own opinions.

Related Work

The field of multi-criteria decision making consists of many different approaches. Velasquez et al. (2013) present a comprehensive literature review addressing multi-criteria decision making methods including Multi-Attribute Utility Theory (MAUT) (Fishburn, 1967; Fishburn et al., 1974; Keeney 1977), Simple Multi-Attribute Rating Technique (SMART) (Chen et al., 2010), and Analytic Hierarchy Process (AHP) (Saaty, 1980; Saaty, 2008). For each approach, they provide a description and present advantages, disadvantages, and area of application.

Compared to DEXi, the advantage of MAUT is the inclusion of uncertainty, while the disadvantage is that MAUT requires a very large amount of input at every step of the procedure to accurately capture the decision maker's preferences (Velasquez et al., 2013). The Simple Multi-Attribute Rating Technique (SMART) is a simpler approach to MAUT and one of the main advantages of SMART is the flexibility to use any type of weight assignment techniques (i.e., relative, absolute, etc.). However, similar to MAUT, the procedure in SMART to determine weight coefficients is not convenient because of its complicated framework (Konidari et al., 2007). Like DEXi,

the AHP is also easy to use and scalable in terms of adjusting the hierarchy structure to fit many sized problems. The disadvantage of AHP is related to interdependence between criteria and alternatives, which in turn may cause inconsistencies between judgement and ranking criteria (Konidari et al., 2007; Velasquez et al., 2013). This is possible to avoid in DEXi by making use of scale orders.

DEXi has been applied in many different domains. Some of these are "health care, finance, construction, cropping systems, waste treatment systems, medicine, tourism, banking, manufacturing of electric motors, and energy" (Bohanec et al., 2013; Bohanec, 2017). To the best of our knowledge, neither DEXi nor the abovementioned approaches (the latter is according to Velasquez et al. (2013)) have been used to assess safety risks within offshore as reported in this paper.

However, DEXi has been applied to assess safety risks within highway traffic (Omercevic et al., 2008) and ski resorts (Bohanec et al., 2015). These approaches use DEXi models as the underlying algorithm to compute an advice based on relevant input data and are thus similar to our approach. In particular, the approach provided by Omercevic et al. (2008) use DEXi models in a framework where input data is collected via sensors in the highway. This is in line with our envisioned automated solution illustrated in Figure 2. The details of the End User Interface and the Input Collector are beyond the scope of this paper and therefore not explained further. However, we are confident that our envisioned solution is feasible as we have in fact taken part in implementing a similar approach in a framework for real-time cyber-risk assessment (Refsdal et al., 2017) developed by the WISER-project (WISER, 2017). The focus of the WISER framework, however, is on cybersecurity risk and not safety risk. Moreover, the risk assessment in the WISER framework produces risk levels which indicate the severity of security risks, while in our approach the decision support model produces advice on whether to disconnect/connect the gangway from/to the installation. In addition to risk levels, the WISER framework also suggests risk treatments for the assessed risks, which are advice decision makers can use to select appropriate risk-mitigation strategies.

Unlike most of the existing publications on DEXi, we have focused on the overall approach, in addition to presenting details of the model. In particular, we address the efforts spent to develop the model, the involvement of domain experts, and the comprehensibility of the model, as well as the quality of the final result. These aspects are important for others who consider a similar approach.

Conclusion

In this paper, we shared our experiences from using DEXi to develop support for risk-based decisions for offshore flotels and presented the resulting model. The results indicate that the decision support model provides advice that correspond with expert expectations, captures all aspects that are important for the assessment, is comprehensible for domain experts, and that the expected benefit justifies the effort required to develop the model.

Threats to validity are mainly related to the practical limitations and approach for obtaining feedback on the model. The feedback was dependent of three offshore operatives, and only six scenarios were considered for evaluation of the advice provided by the model. However, on the positive side, the offshore operatives (who had not taken part in the development of the model) were all in the core target group for the envisaged solution, and the six scenarios had been carefully selected and approved by domain experts to cover cases that address a wide range of aspects while being realistic and interesting.

Our motivation was to make others who face related challenges aware of the possibilities, and help them to consider whether a similar approach is suitable for their needs. We have focused on the issues that we think are of general relevance. Based on our experience and overall evaluation, we consider our results quite promising, and believe that the approach can be fruitful for a wider range of risk-based decisions. In future projects, we hope to explore these possibilities further.

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