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A risk influence model applied to North Sea helicopter transport

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Abstract

Offshore helicopter transport represents a quite complex, socio-technical system. A number of factors affect the risk related to this activity, e.g. maintenance, design of helicopter/helideck, and the competence/training of the crew. The present paper presents an overall, holistic risk model, which aims at presenting the total risk picture and the risk influencing factors (RIFs) for helicopter transport. The main objective is to provide a tool for identifying the most effective risk reducing measures. The RIFs both for accident frequency and accident consequence are arranged hierarchically in a type of influence diagram, illustrating the effect of the various RIFs. Accident and incident statistics from North Sea helicopter transport are used in combination with expert judgements to assess the *weight* (importance) and the present *status* of the RIFs. The model is also used to provide numerical results.

Keywords: Risk analysis; Influence modelling; Helicopter transport; Offshore

1. Introduction

The helicopter transport represents one of the major hazards in the North Sea oil and gas production. Helicopters carry personnel to and from the offshore platforms, and this transport has resulted in several accidents. For the period 1990–1998, the statistics show a risk reduction of about 50% as compared to the period 1966–1990. But in the last decade too, (1990–99) three fatal accidents occurred with a total of 29 fatalities. These accidents were related to helideck operations and helicopter failure during flight.

This paper presents the risk model, which was used to assess how the relevant Risk Influencing Factors (RIFs) affect the overall risk level of helicopter passenger transport in the North Sea. The presentation is based on the 'Helicopter Safety Study 2', a project initiated by various oil companies and carried out in 1997–1999; see Hokstad et al. [1]. This study was a follow-up of a previous study, analysing the helicopter traffic for the period 1966–1990. The new study provided a complete update of the modelling approach and an analysis of the helicopter traffic in 1990–1998 was carried out. Some results of this study have previously been reported at conferences; see Refs. [2–4].

The influence modelling starts by specifying accident categories (e.g. *take-off/landing accidents* and *mid-air collision* (MAC)). Next, the RIFs for accident frequency and accident consequence are identified. Thus, RIFs and influence diagrams are applied rather than reliability techniques like event trees and fault trees. These more common techniques can be used as a supplement when more detailed analyses are required.

The RIFs are relatively stable factors affecting the risk of an activity (here: *helicopter transport*). Examples are 'Operators maintenance', 'Operations procedures' and 'Air traffic/Air navigation services'. A main objective of the modelling is to specify the relationships between the RIFs and the risk related to passengers/crew of offshore helicopter transport. These relations are used to predict the effect of possible operational and technical changes, e.g. risk reducing measures.

First, a qualitative analysis is carried out. The identified RIFs are organised in three levels in a kind of influence diagram. The levels are *operational*, *organisational* and *regulatory and customer*, (observe that in the present application the *customer* is the operating oil company). The diagrams visualise the interrelationship between the various RIFs, and the relation between the RIFs and the risk of various accident categories. The graphical interface will ease the communication, and will assist in identifying the risk factors with the highest improvement potential.

These influence diagrams are used when accidents are classified and analysed. Also *deviation* data, i.e. data on

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Nomenclature

ANS	Air Navigation Services
ATS	Air Traffic Services
CFIT	Controlled Flight Into Terrain
FAR	Fatal Accident Rate (Number of fatalities per 10^8 h of exposure)
FPSO	Floating Production, Storage and Offloading unit
I/A	Incident/Accident
ICAO	International Civil Aviation Organisation
IMO	International Maritime Organization
HUMS	Health and Usage Monitoring System (condition monitoring system)
MAC	Mid Air Collision
MoDU	Mobile Drilling Unit
MSA	Maritime Safety Agency
NA	National Authorities
NCAA	Civil Aviation Authority, Norway
pax	passenger
RIF	Risk Influencing Factor
SAR	Search and Rescue
SOP	Standard Operating Procedures

accidents, *incidents* and *occurrences*, can be utilised in an efficient and explicit way. The visual model is particularly important when additional input data are provided during expert judgment sessions. These sessions are a meeting place for persons with varying background and expertise, and are extremely helpful in creating a common framework for the discussions.

The risk is here given as the mean number of fatalities per million person flight hours. Statistical data are used to assess the (average) risk level for the time period 1990–98. A quantitative risk model will demonstrate the effect of the various RIFs on the risk level. Also the future risk level can be predicted by assessing possible changes in RIFs, such as improved technical standard or the introduction of radar surveillance.

The model described in the present paper is an enhancement of an approach used in previous studies at SINTEF. These studies were all related to transport (helicopter, high-speed craft and ferries), see Hokstad et al. [5] and references to internal SINTEF reports in Ref. [1]. The use of similar types of modelling and influence diagrams are described e.g. in Embrey [6], Paté-Cornell and Murphy [7], Wu et al. [8] and Moosung and Apostolakis [9]. Further, the UK Maritime Safety Agency (MSA) has issued a report on risk for high-speed craft, using so-called Formal Safety Assessment (FSA), see Ref. [10]. The Performance Influencing Factors (PIFs) used in this report correspond to the RIFs of the present paper.

The contribution of the present paper is an application rather than the development of a new theoretical model. The paper gives a practical and detailed adaptation of a 'risk influence model', and demonstrates its use. By this the authors hope to promote the future use of this kind of risk models.

2. Qualitative model

The qualitative model relates the risk of helicopter transport to a set of RIFs for accident frequency and accident consequence. The RIFs are grouped hierarchically and arranged in an influence diagram, which illustrates how these RIFs affect each other and the risk. Further, there are various incident/accident (I/A) categories, and a RIF will usually have different effects for the various I/A categories. So, first a list of I/A categories is specified. In the detailed quantitative model, there will be a separate RIF model for each I/A category, as the weights of the RIFs will differ.

2.1. Incident/accident (I/A) categories

The definitions of the I/A categories are made exhaustive and mutually exclusive, i.e. each deviation belongs to one and only one I/A category. As far as possible ICAO definitions are used to obtain consistency with today's established terminology. The I/A categories are defined as follows:

1. *I/A by take-off or landing on heliport (i.e. onshore)*. I/A initiated after the passengers have boarded the helicopter and before the Take-off decision point, or after the Landing decision point and before the passengers have disembarked at a heliport.
2. *I/A by take-off or landing on helideck (i.e. offshore)*. I/A initiated after the passengers have boarded the helicopter and before the Take-off decision point, or after the Landing decision point and before the passengers have disembarked at a helideck.
3. *I/A following critical aircraft system failure during flight*. I/A caused by critical aircraft system failure initiated after the Take-off decision point and before the Landing decision point, e.g. in main rotor, tail rotor, engine, gearbox etc. When a critical aircraft system failure has occurred, the aircraft (crew/pax) can only be saved through a successful emergency landing.
4. *Near miss or MAC with other aircraf*. Near miss (loss of separation) or collision with other aircraft during flight, although no critical systems have failed.
5. *Collision with terrain, sea or building structure*. I/A following collision with terrain, sea, or other obstructions initiated after the Take-off decision point and before the Landing decision point, not caused by a critical system failure (I/A no. 3). This category (no. 5) is mainly a CFIT accident, but it also includes collision with terrain, sea or obstructions for other reasons.

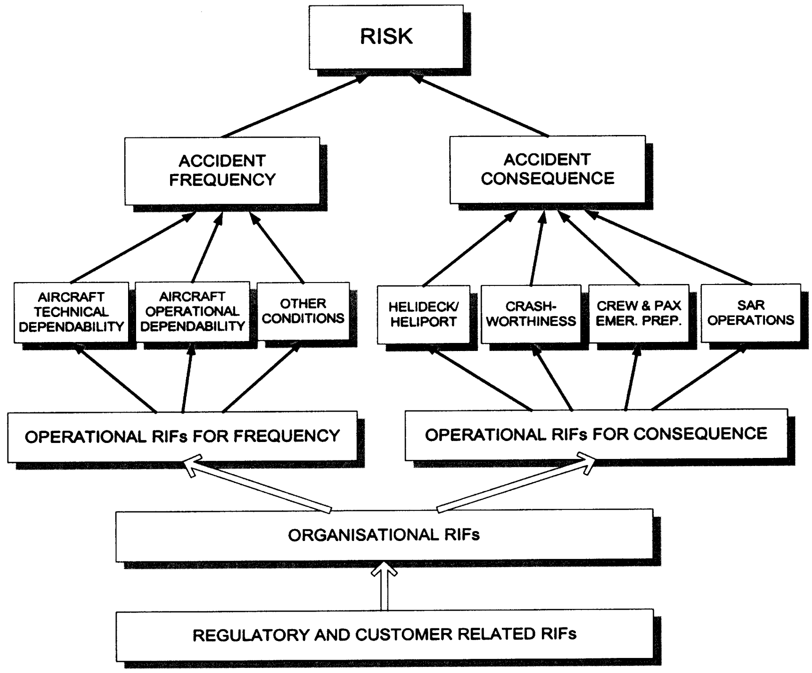

Fig. 1. Outline of general risk influencing model. Main categories of RIFs.

6. *Personnel I/A inside helicopter*. Injury to persons (crew/pax) inside the aircraft, e.g. caused by toxic gases due to fire or cargo.
7. *Personnel I/A outside helicopter*. Injury to persons (crew/pax) located outside the aircraft, e.g. tail rotor strike on helideck or heliport. Hazards to personnel other than crew and passengers are not included.
8. *Other/Unknown*. Any I/A not categorised into category (1)–(7). This could include I/A caused by lightening or sabotage.

2.2. Risk influencing factors (RIFs) and influence diagrams

A RIF is given as a set of relatively stable conditions influencing the risk. It is not an event, and it is not a state which fluctuates (say from day to day). A RIF represents the average level of some conditions, which may be influenced/improved by specific actions.

Risk is here defined as the product of accident frequency (f) and the average consequence (C) of an accident. Accordingly, the RIFs are split into two broad categories of risk *frequency influencing factors* and risk *consequence influencing factors*, see Fig. 1.

Also, some further main categories of the RIFs are defined. The accident frequency is generally split into the following three main causes related to loss of (cf. Fig. 1):

- Aircraft technical dependability
- Aircraft operational dependability
- Other conditions external to the aircraft (e.g. weather conditions).

Similarly, four main categories of consequence factors are identified:

- Helideck/Heliport (both technical and operational conditions)
- Crashworthiness of helicopter
- Crew and Pax emergency preparedness
- Search and Rescue (SAR) operations.

Next, the RIFs are organised in three levels according to their direct effect. The levels are defined as follows (see Figs. 1–3):

- *Operational RIFs* (level 1) are defined as risk influencing conditions related to current activities necessary to provide safe and efficient offshore helicopter transport on a day to day basis. The activities include conditions related to requirements concerning aircraft technical dependability, state of aircraft operational dependability and provision of necessary external services.
- *Organisational RIFs* (level 2) are defined as RIF related to the organisational basis, support and control of current activities in helicopter transport. These factors are related to helicopter manufacturers, operators, air traffic/air navigation services, and helideck/heliport operators.
- *Regulatory and customer related RIFs* (level 3) are defined as RIFs related to the requirements and controlling activities from authorities and customers.

The risk model for frequency and consequence are

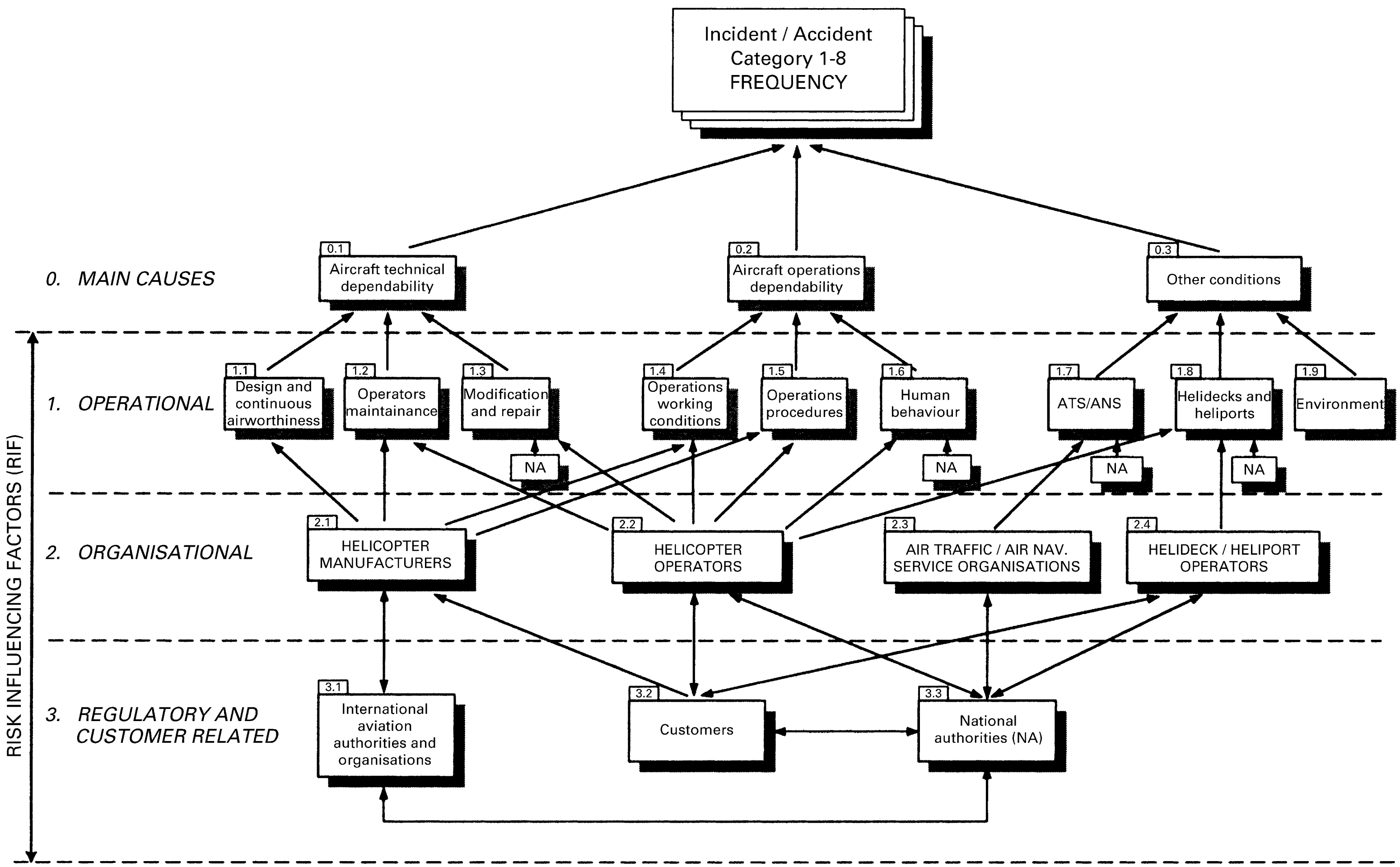

Fig. 2. Influence diagram for the frequency of incidents/accidents.

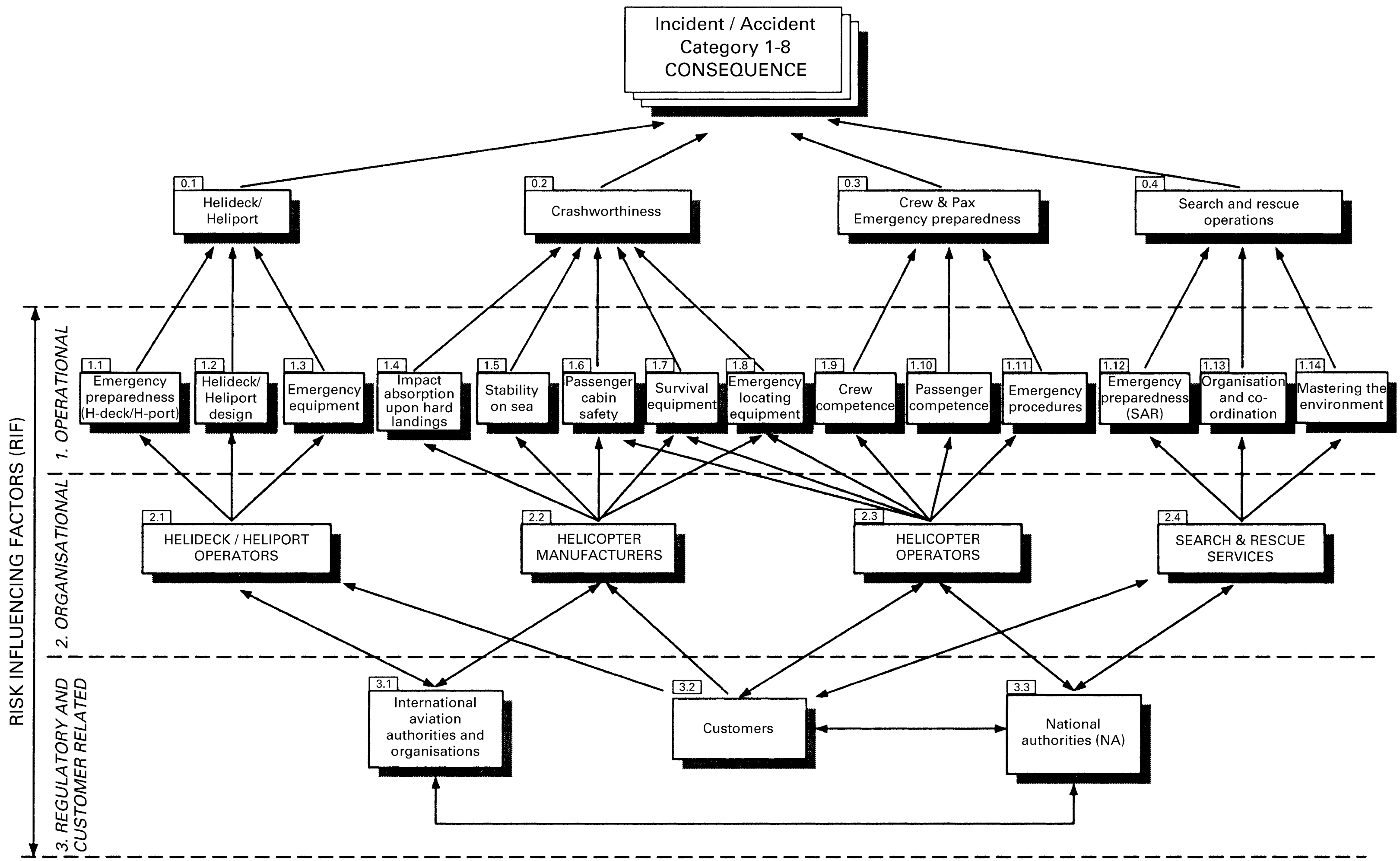

Fig. 3. Influence diagram for the consequences of incidents/accidents.

elaborated in Figs. 2 and 3, respectively. Each box at levels 1–3 represents a RIF, and has a dedicated number (1.1–1.9, 2.1–2.4 and 3.1–3.3). Level 0 represents a grouping of the level 1 RIFs. Arrows indicate influences. Each RIF (i.e. box) has a *status* which is a measure of how 'good' or 'bad' it is with respect to factors that affect the safety of helicopter operation. Further, each arrow has a *weight*, indicating the strength of the influence from one RIF to another.

Depending on status and weight, a RIF will influence the status of the RIFs to which it is connected at the level above. Looking at the frequency RIFs in Fig. 2, for example, the status of the *National Authorities (NA)* at level 3 influences the status of e.g. the *Helicopter Operator* and the *Helideck and Heliport Operators* at level 2. Most of the arrows in the diagram connect RIFs at one level to RIFs at the next level above. However, this is not a requirement, as we can see e.g. by the arrows from the NA to the RIF 1.7 (ATS/ANS), indicating a direct influence from regulations to operation. Observe that, in order to reduce the number of arrows and to simplify the figure, there are no *direct* arrows from (NA) to the RIFs two levels above. The relevant influences are indicated by small boxes titled (NA), connected directly to the RIFs in question. Arrows between RIFs at the same level or to a RIF at a level below can be considered a kind of feedback/communication and will not be discussed in the present paper.

The strength of the influences between the boxes in the diagram can be very different, giving different weights on the arrows in the diagram. Further, the strength of the influences will depend on the I/A category being investigated. Thus, separate models are established for each of the eight I/A categories; see the discussion on the quantitative model below. However, Figs. 2 and 3 represent the *common* basis for all these models.

The consequence part of the model is illustrated in Fig. 3. The interpretation of the boxes and arrows are the same as for the frequency model described above.

2.3. Detailed specification of a RIF

Actually, rather detailed definitions/descriptions of each RIF must be provided if this model shall be useful in practice. As an illustration, consider this specification for *one* of the RIFs.

2.3.1. RIF1.1 for frequency: design and continuous airworthiness

Definition. The suitability, quality and reliability of aircraft design, production, equipment, maintenance and performance necessary for performing the intended operations at a defined/intended level of safety.

Description. Includes the manufacturer's (type certificate holder's) contribution to *Aircraft technical dependability*, such as

- development, design and production of the aircraft type
- aircraft suitability with regard to types of operation
- aircraft instruments and equipment with regard to types of operation
- individual aircraft conformity with types specification (production quality)
- quality of spare parts and material delivered to customers
- design and modifications and repairs for individual aircraft on customer request
- issuance of service bulletins/letters in order to maintain and/or restore airworthiness
- aircraft maintainability and maintenance documentation
- customer support in general.

The following limitations apply:

- User-friendliness of cockpit design and other elements pertaining to the ergonomic design and physical work environment in the aircraft are considered as part of RIF1.4 for frequency (*Operations working conditions*). However, the reliability of all equipment is part of RIF1.1 for frequency.
- Aircraft Flight Manual and other operations documentation issued by the manufacturer are considered part of RIF1.5 (*Operations procedures*).
- Consequence reducing factors such as crashworthiness and emergency equipment are not considered as part of RIF1.1 for frequency.

It is realised that such a definition/description is required to clearly distinguish the RIF1.1 for frequency from other operational RIFs. Similar details for other RIFs are found in the report [1].

2.4. Use of the model for incident/accident analysis

One application of the above model is to provide a tool for classifying and analysing accidents and incidents. This classification is carried out in a top-down fashion, following the steps below:

- First, an I/A is classified into one of the eight I/A categories. If the event is an incident, it is not always easy to identify the I/A category. However, the event will be classified according to the anticipated course of events, *if* the incident had actually developed into an accident.
- In the *frequency* model, the relevant *immediate causal factors* at the I/A event are identified (cf. Fig. 2): *Aircraft technical dependability*, *Aircraft operations dependability* and/or *Other conditions*. Note that *several* causes can be allocated to an I/A.
- In the *consequence* model, (cf. Fig. 3) those *main consequence* factors which are considered to represent an improvement potential are identified (i.e. those factors that could reduce the consequences of the accident if in a different and better state).
- For each identified *immediate causal* factor and *main*

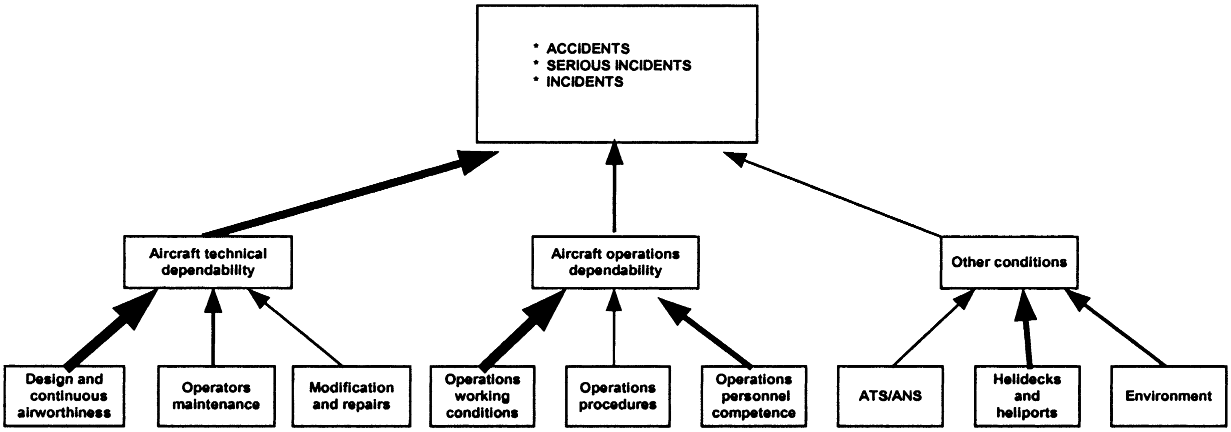

Fig. 4. Example of a possible influence pattern resulting from I/A analyses.

consequence factor, the contributing RIFs at the operational level are identified.

- For each identified operational RIF, it is investigated whether there are RIFs at the *organisational* and *regulatory and customer related* levels which, with an adequate degree of certainty, are contributing factors.

As mentioned above the arrows between identified boxes illustrate the influence of those RIFs which contribute to the I/A. When several accidents and incidents are analysed and classified in this way patterns will occur in the diagram, and arrows that are often marked will be visualised by drawing a thicker arrow. Thus, thick arrows represent a strong contribution and thin arrows represent a weaker contribution. Fig. 4 illustrates a hypothetical example. For simplicity only the two top levels of the model are shown in this example. This method offers a quick and simple way of illustrating the most important causal relationships.

3. Quantification model

The objective of the quantitative model was to carry out actual predictions. Hence, the complexity of the model has to be adapted to the possibility of obtaining required input data. Even with a relatively 'simple' model as chosen here, a significant number of parameters has to be estimated for each of the eight I/A categories. The estimates of the parameters were obtained from analyses of accidents, incidents and occurrences; supplemented by expert judgments and questionnaires (i.e. information provided by personnel from helicopter operators and aviation authorities).

3.1. Risk quantification

The risk, R, of the activity is here quantified as $R = fC$, where f = accident frequency, i.e. the mean number of accidents per million flight hours, and C = accident consequence, i.e. the mean number of fatalities in one accident.

Now let

$f_j = f(\text{I/A no.}j)$ = Accident frequency for I/A-category no. j; $j = 1, 2, \ldots 8$.

$C_j = C(\text{I/A no.}j)$ = Accident consequence for I/A-category no. j; $j = 1, 2, \ldots 8$.

Then the total risk for helicopter traffic equals

$$R = f_1C_1 + f_2C_2 + \ldots + f_8C_8$$

A model is then established to relate each of the above frequencies, f_j and consequences, C_j to the status and weight of the RIFs, cf. Figs. 2 and 3.

3.2. Effect of operational RIFs

The quantitative risk model accounts for the effect of the operational RIFs (i.e. RIFs at level 1). For quantification of accident frequency the following notation applies

Status($1.y$) = Status of RIF$1.y$ = Probability that the RIF1.y is observed to have a 'bad state' during one flight hour; i.e. the probability that a *deviation* will occur during one flight hour, *and* that this deviation is considered to be caused by the RIF$1.y$.

$W_j(1.y)$ = Weight ('strength') of RIF$1.y$ in an I/A of type j = Probability that I/A no j occurs during one flight hour, given that RIF$1.y$ has a bad state. ($y = 1, \ldots 9$; $j = 1, \ldots, 8$).

Contrib$_j(1.y)$ = Contribution of RIF$1.y$ to an *accident* of I/A type j = Probability that an *accident* will occur during one flight hour, and that this event is considered to be caused by RIF$1.y$.

Here RIF$1.y$, ($y = 1, 2, \ldots 9$), represent the nine operational RIFs for frequency (cf. Fig. 2). Observe that, at present we ignore the intermediate level of 'Immediate

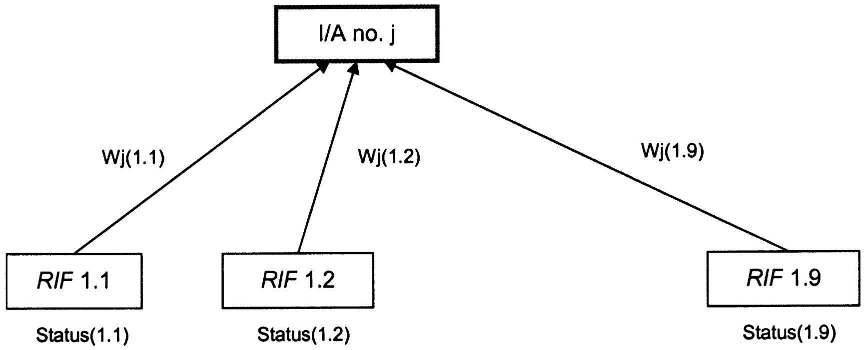

Fig. 5. Weights and statuses of operational RIFs.

causes', located in between the I/A-event and the operational RIFs in Fig. 2. Thus, in the quantification the nine operational RIFs for frequency are connected *directly* to the I/A-event, see Fig. 5.

The status of a RIF will be quantified independently of the I/A category. Observe that the status of a RIF is related to the occurrence of *deviations* (i.e. the sum of *accidents*, *incidents* and *occurrences*). For obvious reasons the number of reported occurrences is much higher than the number of incidents/accidents (by an order of 100). So, by analysing deviations, a large amount of actual statistical data is available to estimate the Status($1.y$) of RIF1.y, ($y = 1, 2, \ldots 9$).

The weight, $W_j(1.y)$ of an operational RIF for frequency tells how likely it is that a bad state of RIF1.y results in an accident of an I/A-category j. The weight can be seen as the quantification of the arrow from the RIF to the accident of the relevant I/A category. Note that the RIFs can be given different weights for the various I/A categories. Expert judgments are required to estimate these parameters.

Observe that

$$\text{Contrib}_j(1.y) = W_j(1.y)\cdot\text{Status}(1.y),$$

$$y = 1, 2, \ldots 9;\ j = 1, 2, \ldots 8.$$

So estimates of Contrib$_j(1.y)$ are given by the estimates for weight and status. Further, analysis of actual accidents can also give *direct* estimates for the Contrib$_j(1.y)$. In the Helicopter Safety Study 2 a total of 15 events in 1990–1998 were classified as accidents. Sufficient data were not available for all these to be included in the analysis. However, a couple of events related to SAR operations and training were available, and were included. So a total of 14 helicopter accidents in the North Sea for the period 1990–97 were analysed, giving direct estimates for the Contrib$_j(1.y)$. These estimates were combined with data obtained for $W_j(1.y)$ and Status($1.y$) to give overall estimates for these contributions. In this way data from accident analyses, analyses of deviations and expert judgments were combined to obtain the overall estimates for Contrib$_j(1.y)$.

These estimates for of Contrib$_j(1.y)$, ($y = 1, 2, \ldots 9$; $j = 1, 2, \ldots 8$) can be arranged in a 9×8 table, which is a very fundamental result for the modelling. The *contribution* of an operational RIF for frequency directly tells how much it contributes to the frequency of the I/A category in question. By summing over the nine RIF contributions for I/A no j, we obtain the frequency f_j of accidents for this category:

$$f_j = [\text{Contrib}_j(1.1) + \text{Contrib}_j(1.2) + \ldots + \text{Contrib}_j(1.9)] \cdot 10^6 = 10^6 \cdot \sum_y \text{Contrib}_j(1.y)$$

(Note that the frequency is given as the number of accidents per 10^6 flight hours.) The elements of this sum provides the model for the f_j, showing the relative importance of the nine operational RIFs for this specific I/A category.

Similarly by summing over the eight I/A categories we get the *total* contributions of the various operational RIFs to accident frequency, f.

$$\text{TotContrib}(1.y) = \text{Contrib}_1(1.y) + \text{Contrib}_2(1.y) + \ldots + \text{Contrib}_8(1.y) = \sum_j \text{Contrib}_j(1.y)$$

These nine total contributions directly gives a ranking of the nine operational RIFs for frequency, with regard to overall impact on the accident frequency, f.

In conclusion the model for accident frequency, $f = \sum_j f_j$ is particularly simple, as we just split each f_j into nine contributions. The model for C_j is somewhat different. Data, combined with expert judgments, give rather reliable estimates for today's values of these consequences. However, accident data/reports provide very scarce information on the influence of the operational RIFs for consequence, and it is also rather challenging to obtain such information through expert judgments. However, an expert judgment session was carried out, which for each I/A

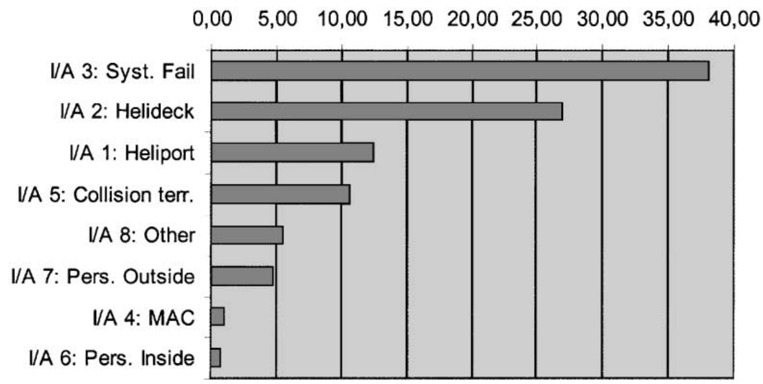

Fig. 6. Contributions to accident frequency (in %) from the eight I/A categories.

category provided a 'score' for each of the 14 operational RIFs for consequence. The effect on C_j of changing the status of an operational RIF for consequence is assumed to be proportional to this score for I/A category j. So the score here corresponds to the weights used for f_j. Thus, the model for consequences, C_j, is considered more uncertain than that for f_j, but the approach is considered adequate to perform a ranking of the operational RIFs for consequence. However, it is not straightforward to compare the influences of the RIFs for frequency and the RIFs for consequence; this would require a 'comparison of apples and oranges'. For this reason the operational RIFs for frequency and consequence are treated (e.g. ranked) separately in the presentation of the main results.

Observe that the quantitative risk model includes the effects of operational RIFs only, (i.e. level 1 RIFs). The effect of the organisational RIFs (at level 2) is to change the status of the operational RIFs. Expert judgments were used to obtain scores, indicating the strength of the influence from the organisational RIFs to the operational RIFs. However, the organisational RIFs and the regulatory and customer related RIFs are essentially used in the qualitative analyses. They are included in the influence diagram to show the overall influences, and to demonstrate possible ways to change the operational RIFs.

4. Main results of helicopter safety study 2

This section presents some numerical results obtained from the quantitative model outlined in Section 3. Throughout, only 'best estimates' are given, and so the uncertainty of the estimates and predictions is not provided. First, an overall estimator for the risk is presented, based on the statistical data. Then a ranking of the 9 + 14 operational RIFs is presented. Finally, the model is applied to assess the risk reduction during the period 1990–1998. Because the statistical data is by no means sufficient to provide such an estimate, it is necessary to rely on the model to assess this change in the risk level.

4.1. Historical data for the risk of the North Sea helicopter traffic

The accident data for the period 1990–1998 have been analysed, and the statistical analysis resulted in the following estimates for risk.

4.1.1. Statistical risk level, 1990–1998

Accident frequency: 0.96 accidents per million person flight hrs
Accident consequence: 1.93 fatalities per accident
Risk: $0.96 \times 1.93 = 1.85$ fatalities per million person flight hrs.

Observe that the observed risk corresponds to a Fatal Accident Rate (FAR) equal to 185.

These figures are accepted to represent the (average) risk level for the period 1990–1998. Below the focus is on *relative* contributions to this risk (in %).

4.2. Risk of various incident/accident categories

Fig. 6 presents the contributions in % of the 8 I/A categories to total accident frequency. This is a representation of $(f_j/f)100\%$, see Section 3.2, and shows that I/A 3: *System failure during flight* is the most frequent I/A category.

Fig. 7 presents accident consequence, C_j per I/A category, (i.e. the mean number of fatalities, given that an accident of this category has occurred). This input to the analysis is based on actual data, combined with expert judgments.

Fig. 8 combines the results of Figs. 6 and 7. This takes into account that the different I/A categories have different (mean) consequences, and it provides the contributions in % to *risk* from the eight I/A categories. Observe that I/A 5: *Collision with terrain*, *sea or building structure* is the I/A category which contributes most to the risk. Although this category did not contribute very much to the accident frequency (Fig. 6), a large consequence is expected if it occurs (Fig. 7).

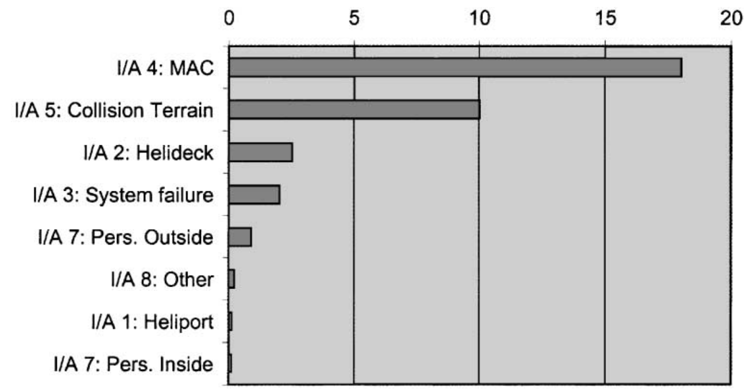

Fig. 7. Accident consequence. Average number of fatalities per accident.

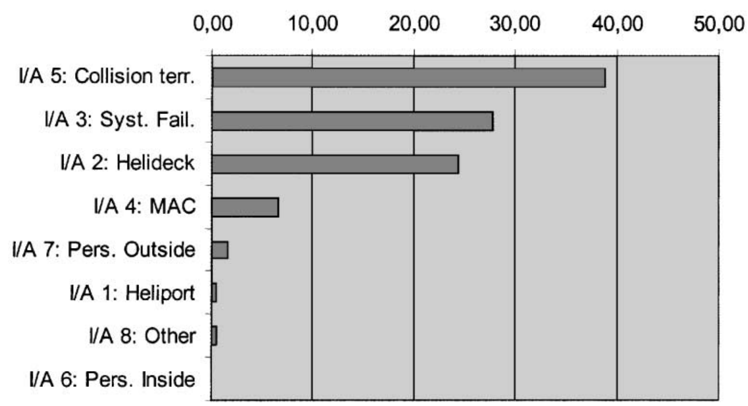

Fig. 8. Contributions to risk (in %) from the eight I/A categories.

4.3. RIF contributions to the present risk level

Fig. 9 presents the contributions to accident frequency for each of the nine operational RIFs for frequency (when accident consequences are fixed). Thus, this is the presentation (in %) of the TotContrib(1.y), $y = 1, \ldots, 9$. RIF1.1 *Design and continuous airworthiness* is seen to be the operational RIF that contributes most to the occurrence (i.e. frequency) of accidents.

Fig. 10 presents the contributions to risk for the same nine operational RIFs, (still when accident consequences are fixed). The major contributors to risk are:

- Human behaviour, (i.e. pilot performance)

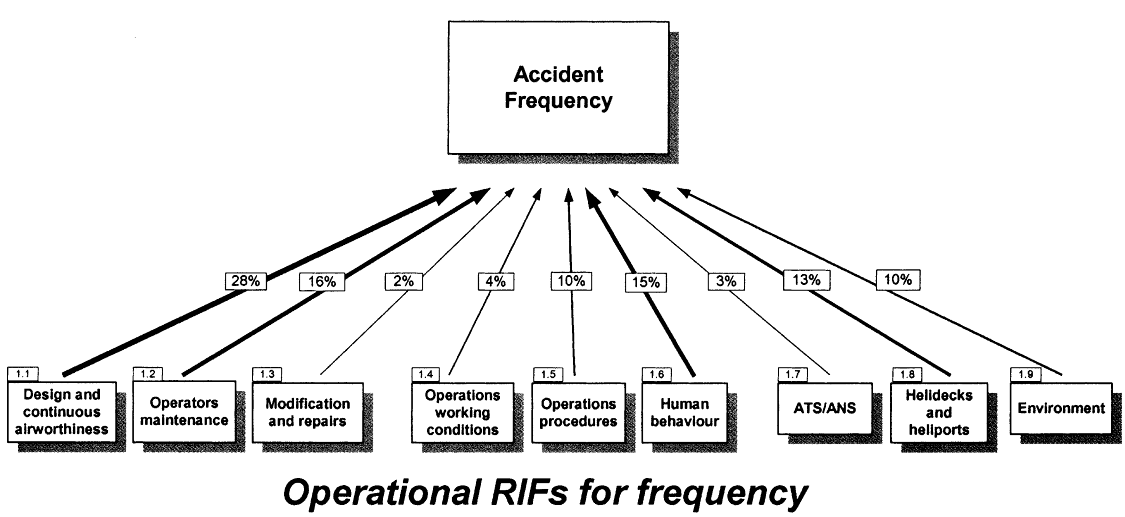

Fig. 9. Relative contributions to accident frequency of the nine operational RIFs for frequency.

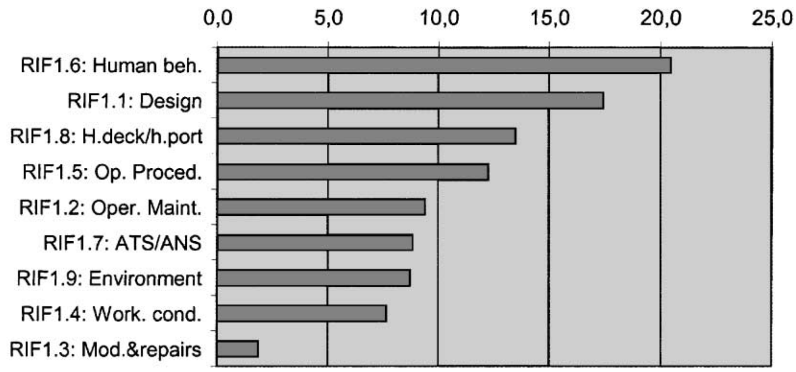

Fig. 10. Relative contributions to risk (in %) from the nine operational RIFs for frequency.

- Design and continuous airworthiness
- Helidecks and heliports, (includes both design and operation)

Similarly, Fig. 11 presents the 'contributions' to risk for the 4 main categories of operational RIFs for consequence (when accident frequencies are fixed). These are referred to as RIF0.1–RIF0.4 for consequence (see level 0 in Fig. 3). Thus. Fig. 11 summarises the relative contributions of the 14 operational RIFs for consequence. The RIF0.2 *Crashworthiness* is the main contributor. Observe that separate rankings are provided for the operational RIFs for frequency and consequence, respectively, (cf. comment at the end of Section 3.2).

4.4. Estimated changes in risk for the period 1990–98

The model was also used to provide an estimate for the change in risk over the period 1990–1998, and to assess the main causes of this change. Information on the actual changes that had occurred during the period was provided, and these changes were related to the relevant operational RIF. Expert judgments were also obtained on the corresponding changes (in %) of the status of this relevant RIF. There is, of course, considerable uncertainty related to such an approach, and the obtained estimates of risk reduction should not be taken too literally. Nevertheless, it is beneficial to analyse all changes related to risk in a systematic way, and a few results are presented below to illustrate this use of the model.

- The estimated reduction in risk from 1990 to 1998 is 12%. If it is accepted that the average risk for this period equals 1.85 (see Section 4.1), this reduction corresponds to 0.24 fatalities per million person flight hours.

The estimated risk reduction is mainly due to the following factors (giving *net* risk reduction in parentheses, after subtracting possible risk increases):

- '*Aircraft technical dependability*' (2.8%). A major contributor to this improvement was the introduction of the HUMS (a technical condition monitoring system for helicopters). The general opinion is that the introduction of the HUMS probably was the most significant isolated safety improvement measure during the last decade. Furthermore, it has been suggested that the implementation of the ISO 9000-series has increased the consciousness and willingness to adhere to the documented maintenance requirements.
- '*Aircraft operations dependability*' (3.3%). The improvement is mainly related to the working conditions in cockpit. Also, it has been suggested that the implementation of the ISO 9000-series has increased the consciousness and willingness to adhere to the Standard

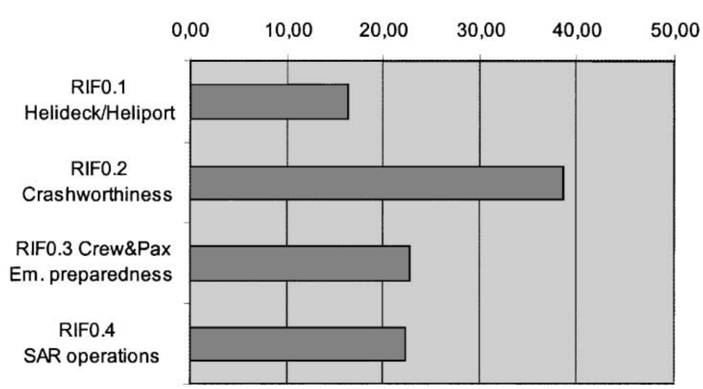

Fig. 11. Relative contributions to risk of main categories of operational RIFs for consequence.

operating procedures (SOPs). At last, but perhaps not least, the concepts of *Safety Management* in general and *Flight Safety Programs* in particular have been introduced during the last decade. There is reason to believe that the general attention to these issues have contributed to an increased safety consciousness in aviation and, hence, a risk reduction.
- '*ATS/ANS*' (RIF1.7 for frequency, 3%). The improvements relate e.g. to Class E air space at Statfjord control area, radio/radar coverage and conditions/procedures at the heliports.
- '*Crashworthiness*' (RIF0.2 for consequence, 3%).This improvement relates e.g. to *impact absorption* (RIF1.4), and *stability on sea* (RIF1.5) for the (new) helicopters.

In conclusion, there has been a positive trend with respect to the total risk. However, some changes have contributed to a risk *increase* as well:

- '*Helidecks and heliports*' (RIF1.8 for frequency and RIFs1.1–1.3 for consequence). As stated above there have been both improvements and deterioration regarding the helideck and heliport conditions. The risk increase relates to poor location of helidecks, particularly on FPSOs and MoDUs, an increased number of unmanned installations/helidecks, reduced helideck sizes and an increased number of takeoffs and landings per million flight hours (e.g. more shuttling).

5. Conclusions

A method is presented, which relates the risk of an activity (here helicopter traffic) to so-called Risk Influencing Factors (RIFs). This approach is useful to get the overall picture of the factors at all levels, which affect the risk. All types of influences are included, also those being external to the organisation which performs the activity. The main advantage of the approach is that, in principle, all aspects relevant for the risk can be visualised and taken into account. This is becoming increasingly important, in particular as the impact of human and organisational factors on the risk is now widely acknowledged. In total, the model is used to:

- illustrate and communicate influences on the risk,
- assist in the classification and analysis of accidents and incidents,
- predict the risk improvement potential by implementing various risk reducing measures,
- estimate the change in risk level for a certain period of time.

The limited level of detail in such an analysis may be a drawback. However, this type of risk influence modelling can be used in combination with more standard risk analyses techniques. If, for instance, a risk influence analysis has been carried out, more detailed analyses (e.g. using Fault Trees) may be carried out for critical areas. Such standard reliability techniques can also be used to support the estimation of the weights of the RIFs, e.g. by constructing a fault tree/event tree of a specific I/A category.

It can also be a problem to get reliable input data to this type of analyses. Hence, part of the input is usually provided by expert judgments.

In total it is demonstrated that the risk influence model is a useful tool for describing major sources of risk, and it provides rough predictions for the effect of changes (e.g. risk reducing measures).

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