Introduction to Risk Influence Modelling

Author: Jørn Vatn, NTNU, Department of Production and Quality Engineering

Participants, PK8200

Document created: 2012-06-27

Last update: 2013-01-17

Location: http://frigg.ivt.ntnu.no/ross/elearning/PK8200/IntroductionToRiskInfluenceModelling.pdf

Introduction

This memo gives an introduction to risk influence modelling and serves as an introduction to what we will cover in the course PK8200 – Risk influence modelling.

What is risk, and principle elements of a risk picture

A variety of risk definitions exist in the literature. In this presentation we only discuss risk definitions in relation to quantitative risk analysis. The baseline when risk is to be defined is to address threats to values of concern by the relevant stakeholders. This again forces us to be explicit regarding the *magnitude of the threat*, and the *actual consequences*, i.e., what values are at stake. It is common to link the definition of risk to *events* in one way or another. Often the term hazardous event is used to be explicit regarding the events that may result from the hazards or threats of concern. This then leads us to a conceptual risk definition saying that *risk is the uncertainty regarding the occurrence and severity of hazardous events*. To make the risk definition operational, we introduce three elements, events (e_i), probabilities (p_i) expressing the uncertainty regarding occurrence of the events, and finally the severity with respect to the values at stake ($\mathbf{S}_i$). This yields the quantitative expression of risk:

$$R = \{< e_i, p_i, \mathbf{S}_i >\} \tag{1}$$

When risk is expressed in terms of equation (1) this is always done conditionally on a set of aspects which here is denoted the $\mathcal{D}$, $\mathcal{U}$ and $\mathcal{V}$. $\mathcal{D}$ represents the result of dialog processes and risk communication among stakeholders that elaborate on the values and preferences domain, such as who are exposed to threats, and whose needs in the society should be focused on. Further $\mathcal{U}$ represents the relevant information, the theories, the understanding, and the assumptions which are the basis for the risk assessor, and finally $\mathcal{V}$ represents the result of any verification processes, e.g., third party verification. See Vatn (2012) for further discussions.

In the traditional or classical definition of risk, the probabilities in equation (1) are interpreted as true properties of the system being analysed. Since we have limited data and information regarding the system it is impossible to reveal the exact values of these probabilities. It is then common to present *uncertainty intervals for the risk measure*.

In the epistemic interpretation it is the other way around. Then the basis is that there is uncertainty regarding whether the undesired events will occur (lack of knowledge), and the corresponding severity. Probabilities are used to express this uncertainty, and there is no additional uncertainty in the probability statements. However, as part of the documentation of the risk analysis uncertainty is qualitatively stated in terms of discussion of assumptions and simplifications. In relation to equation (1) such arguments are stated as part of $\mathcal{U}$.

Methods and models used in risk analysis are often not affected by the interpretation of risk in equation (1). However, the way uncertainty is interpreted and presented will vary between the classical and the epistemic interpretations of risk.

To be explicit on how a risk picture would look like Figure 1 shows an example of such a risk picture related to one particular hazardous event (gas leakage). The uncertainty regarding the occurrence of the hazardous event is expressed by the probability figure p=0.1, the severity is described by possible threats to the values at stake, i.e., possible fatalities. Here the number of fatalities is split into *categories* to simplify the presentation of uncertainty regarding the number of fatalities given that the hazardous event occurs. The frequencies, F_i, are the unconditional probability of each of the end consequences (fatality category).

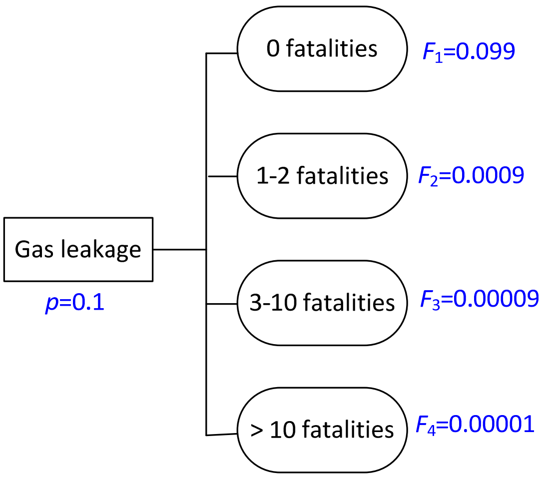

Figure 1 Example of risk picture related to one particular hazardous event

The following remarks could be made in relation to Figure 1:

- Only one hazardous event is elaborated, meaning that we are filtering the risk picture
- Only number of fatalities is emphasized, leaving out e.g., injuries, environmental damage and loss of production (filtering)
- Conditions leading up to the hazardous event are not visualized, leaving out the entire causal analysis (hiding background information)
- Conditions affecting the probability distribution over the end consequences are not visualized (hiding background information)
- Location (x-y-z) and time of the event is not visualized (no zooming)
- No distinction is made regarding which gas leakage type is considered (aggregating over all types of gas leakage events)
- No distinction is made regarding which personnel groups are exposed (aggregating)

- Some consequences are merged into one category, i.e., more than 10 fatalities corresponds to the event that 11 persons are killed, the event that 12 persons are killed etc. All these events are merged into one event.

The above comments points towards various types of *operators* applied to the risk picture. Before we these operators the risk picture is now defined as:

Risk picture: *A set of undesired events, the causes and factors that may contribute to the event, the possible consequences of the event with corresponding influencing factors, and uncertainties related to all these issues.*

The operators applied on the risk picture are:

Filtering. With filtering we mean to filter out several aspects of the risk picture. Primarily filtering means to focus on only one hazardous event and/or a limited set of end consequences, e.g., only number of fatalities.

Aggregation. With aggregation we mean the process of summing more than one event, more than one cause etc to give a sum of various events, causes and so on.

Merging. With merging we mean the process of grouping several similar outcomes into one category representing several outcomes.

Zooming. With zooming we mean to view part of the risk picture for a specific location (in space and/or time).

Hiding/unhiding. With hiding we mean to hide important information when presenting the complete risk picture. Typically we hide causes behind the hazardous event, factors that influence whether causes could lead to the hazardous event or not, and factors that influence the severity of the hazardous event, i.e., the probability distribution over the possible end consequences.

Due to limited resources when preparing the risk picture simplifications are made, merging is performed etc, hence it is not always possible to unmerge events, split up into a detailed set of failure causes etc.

Risk assessment

Risk assessment is the process of assessing the risk picture. Essentially this means to identify relevant hazardous events of concern, represent the corresponding values threatened in terms of a set of end consequences, and the uncertainty involved usually expressed by probabilities. Figure 1 shows one such hazardous event with related information.

In the following we discuss key elements in this process. The elements typically follow in chronological order, but going backwards is also often required in the analysis process.

1. *Identification*. Identification is two folded, first is the identification of *hazardous events* (or other undesired events) being the starting point of the analysis. The issue of identifying the hazardous events is not considered to be any principal problem. The second part of the identification process is much more demanding, i.e. to *identify relevant causes* to events, and factors and conditions affecting both the hazardous events, but also the severity given the

event. In risk analysis it is equally important to identify conditions and factors that affect the situation in a positive way, as those having a negative impact.

2. *Structuring*. Structuring is an important step required before the modelling may start. Structuring means to present tacit knowledge, system understanding etc in such a way that the risk analyst is able to start modelling. In order to cope with the problem of identifying all causes behind events, so-called complexity attributes (Vatn, 2012) should be identified and structured.
3. *Modelling*. In risk analysis there are two types of models, probabilistic and deterministic. A deterministic model is primarily used to describe relations between physical quantities and other real world observables. Examples of such models are fire and explosions models for calculating pressures given an ignition of a specific gas cloud. A probabilistic model is a model that *enables the risk analyst to apply the law of total probability in an efficient way* when expressing uncertainty, i.e., performing probability calculus. It is important to emphasize that a probabilistic model is not a model of the world, but it is a model used to express uncertainty regarding observables in the real world. Examples of modelling tools are Markov analysis, fault tree analysis (FTA) and event tree analysis (ETA) and Bayesian belief networks (BBN).
4. *Identification of the need of data*. All models will require input data such as failure rates, human error probabilities etc. Depending on the format and level of detail in the modelling, the main objective of this step is to be specific on the need for data and model parameters.
5. *Data collection and assessment of model parameters*. When the need for data is specified the next step is to collect data and in some cases also estimate/assign model parameter based on raw data and use of expert judgments.
6. *Run the model to establish the risk picture*. When the relevant models have been identified and built, they are feed with data. Then it is possible to run the models, and achieve the risk picture.

Building blocks for risk modelling

Mohaghegh et al. (2009) present a socio-technical risk analysis (SoTeRiA) framework which is a hybrid technique formalization, merging various classes of modelling techniques. In the following we briefly list the “building blocks” of SoTeRiA. For further elaboration we refer to Mohaghegh et al. (2009) and the references therein. The two last classes of techniques are new compared to Mohaghegh et al. (2009).

Formal probabilistic risk analysis techniques refer to methods that apply a logical construct to describe the system. They include classical probabilistic risk assessment techniques, such as Event Sequence Diagram (ESD), Event Tree (ET), Barrier Block Diagram (BBD) and Fault Tree (FT).

Regression-based techniques are common in economics and the social sciences. These techniques are used to distinguish true statistical causality from “spurious correlation”. The process involves defining a set of variables and their relations, then “testing” all of the relations simultaneously. This is practiced by applying various techniques, such as Path Analysis or Structural Equation Modelling.

Bayesian belief nets (BBN) defines a methodology for representing causal connections that are “soft,” “partial,” or “uncertain” in nature. The applications of BBNs have grown enormously over the past 20 years, with theoretical and computational development in many areas. A less strict formal realisation of such "soft" causal connections is modelling by use of risk influencing factors (RIF). A RIF is then a condition or factor that influences one or more parameters in e.g., a formal probabilistic risk analysis technique. BBN is often used to model interactions between RIFs. RIFs are discussed later in this document, and will be among the most central concepts in this course.

Process modelling techniques aims at modelling the primary production processes of the organization. At a first step semi-formal process technique are adapted and applied to represent the various processes (e.g., work process) in an organization. Then, for quantification purposes, it needs to be converted to a formal technique that is consistent with other techniques in the quantification framework.

Deterministic dynamic techniques are applied when there is enough information to establish "deterministic" relations among factors of the model or some parts of it. The deterministic modelling technique can be either analytical or simulation based. Examples of simulation-based techniques are Agent-Based Modelling (ABM) and System Dynamics (SD). SD shows significant capabilities for modelling certain human behaviour and decision-making processes, making it a good technique for modelling aspects of organizational behaviour. The strength of SD also lies in its ability to account for non-linearity in dynamics, feedback, and time delays.

Energy related impact techniques are used to model the situation after loss off control of energy sources representing a potential harm. These models include gas dispersion modelling, ignition modelling, fire and explosion modelling and structural integrity modelling. The models basically utilize deterministic physical and chemical laws, biological knowledge related to critical heat and pressure levels etc. Since initial and boundary conditions are not known in advanced, and many model parameters are uncertain, the deterministic models are supported by probabilistic approaches.

Recovery analysis techniques aim at modelling the recovering process after an emergency situation has occurred. It is reasonable to claim that the system now has become rather intractable (Hollnagel et al., 2006) which means that one single event tree model cannot capture the situation. Several scenarios need to be developed and there is a challenge to select a limited number of scenarios described at an appropriate level of detail to represent the recovery process. Also here the above listed techniques are relevant.

Note that in the literature a distinction is often made between systems which may be described in terms of linear cause and effect relations and emergent systems with complex cause and effect relations. The latter is often denoted complex systems. The above classification does not explicit reflect differences between linear and complex cause and effects. A rough classification would be to say that the formal probabilistic risk analysis techniques apply for linear systems, whereas the remaining classes of techniques apply for emergent and complex systems. But rather than classifying the techniques, we believe that the challenge of approaching emergent systems is not to choose the appropriate technique, but rather to combine the class of techniques in a way that enable us to express our system knowledge in the most appropriate way.

Although the list of techniques provided above are quite impressing we do not claim to have any final approach to determine the true risk. The techniques are only tools we apply to express our uncertainty where the aim is to provide valuable decision support. This is also highlighted by e.g., Apostolakis (2005) where he discusses the value of risk analysis. He also points out limitations with current risk analysis practices, and points towards areas for improvement and further research. One such area is human performance during accident conditions. This points towards what is denoted *recovery analysis techniques* above. Challenges obvious occur when expressing human performance, but even more challenging would be to qualitatively express relevant accidental scenarios.

Risk modelling and risk influence modelling in a historical perspective

This section reviews important aspects of risk modelling required in order to present a risk picture. Vatn and Haugen (2012, RIO book) distinguish between three types of risk analyses for use in the offshore oil and gas industry:

1. ***Strategic risk analyses*** are primarily aimed at developing a safe design and safe operating procedures. The objective is typically to assess a proposed design or an operation, to evaluate whether the risk level is acceptable and to identify potential risk reducing measures. They are characterized by being performed with a global perspective, in the sense that they are considering the effect on the risk level for a whole installation. These studies are primarily quantitative. They focus very much on technical aspects, with operational input primarily being limited to activity levels, such as the number of offshore supply vessels visiting the installation, the number of lifts being undertaken by cranes, the number of wells drilled etc. For the hydro carbon events the analyses usually starts with a blowout/gas leakage, and then proceed with event trees (ETA = Event Tree Analysis), fire and explosion models etc. to derive the risk picture. This means that they are not focusing on causes for the hazardous event as indicated in Figure 1. To some extent the barriers are modelled by fault tree analysis (FTA). These type of analyses are often referred to as total risk analyses (TRA) or quantitative risk analyses (QRA).
2. ***Qualitative design analyses*** are more detailed and more specific than the strategic analyses, and they will typically have a system focus. The most prominent examples of such studies are HAZOP and FMEA. This could be performed e.g., on the mud system or on the Blowout Preventer (BOP). These are performed to verify the design in detail, to ensure that safe (and reliable) operation is possible. They usually have a strong technical focus and are typically the responsibility of the design team or onshore staff working with technical safety, similar to the strategic studies.
3. ***Operative risk analyses*** are different from the strategic studies in almost every respect:
    a. They are typically performed as qualitative studies, sometimes using a risk matrix to classify the identified hazards/events and to determine acceptability of the identified hazards.
    b. They are performed on a much more limited problem area, typically an operation that is being planned or is about to be performed or as support for a specific, limited decision. The analyses may often address major accident risk (although not necessarily), but the link to the global risk picture for the installation, as expressed through the strategic analyses, is usually weak in these studies.
    c. The responsibility for these studies may be different personnel groups, including onshore planning/operations groups or offshore personnel, responsible for performing the work.

As discussed by Vatn and Haugen (2012) the three types of analyses are usually separate analyses where they are seen as independent analyses not being able to support each other. Several attempts have been made in order to improve the quality of such analyses. An early attempt to make the strategic risk analyses more dynamic was the ORIM methodology (Øien, 2001). The idea behind this approach was to take existing QRA models and investigate these with respect to the most important parameters, e.g., a Birnbaum like measure, say $I^B(i)$. Such a parameter could be the gas leakage frequency, or the safety integrity of a barrier. The next step was to investigate which of these parameters were most likely to change their value during the period between updates of the QRAs (typically every five year). The combination of *important* parameters and parameters that were *expected to vary* gave a list of parameters to include in a follow up regime. Then for each parameter in the list, a set of organizational factors were identified. In the following we denote these as risk influencing factors (RIFs). Then a functional relationship between the RIFs and the corresponding parameter were established. In a pilot study these relations were found by empirical analysis. To complete the approach a set of risk indicators (RI) were identified that were measuring the status of a RIF. The follow-up regime now was to obtain the values of the RIs every 3 months, calculate new RIFs based on the RIs, propagate this through the RIF model to get a change in the parameter. Now using the importance measure of the parameter, a new total risk picture could be established as well as the change in the risk level.

For various reasons the ORIM method was not implemented in the industry. One of the weaknesses in the ORIM was that it did not extend the existing QRA with respect to shed light on the failure causes. In the BORA project (Haugen et.al 2007) the focus was therefore changed to barriers and operative issues (BORA = Barrier and operative risk analysis). For critical conditions such as a gas leakage which in the QRA only is modelled by a single number found in generic databases, a detailed *task analysis* was conducted to reveal critical tasks that could lead to a gas leakage. For example review of real gas leakages revealed that many leakages were caused by maintenance of components and systems. This gave a much better understanding of what could go wrong, what where the critical tasks, and what RIFs influenced the probabilities in the model. This kind of modelling was very similar to HRA (Human Reliability Analysis) used in the nuclear industry. The BORA method is therefore seen as a significant improvement of the ORIM method since it have a much stronger link to the causes behind the initiating event (or failure of a critical barrier). A weakness of the BORA method was that it did not aim to update the QRA to see the total impact of the revised parameter (e.g., leakage frequency). The OMT project (Vinnem et.al 2011) was a follow-up of the BORA project where the methodology was refined. A weakness in the BORA model was that all the RIFs were threated in a flat hierarchy with only one level. It was recognised that there is a structure in the RIFs, where typically sharp-end RIFs are assumed to be influenced by blunt end RIFs (management issues). Further it was recognised that measuring the RIFs is demanding. Some companies are conducting internal audits to assess the current status of the RIFs on a regular basis (typically every second year). It is believed that this represents uncertainty, hence the RIFs were treated as random quantities and modelled by Bayesian Belief Networks (BBN) taking a two level hierarchical structure into account. The OMT project also improved the interaction modelling between the RIFs, and proposed ways to treat common cause errors similar to methods used in HRA.

Risk influencing modelling – Principal content

A primary risk model such as a combination of fault- and event trees aims to capture the core element of the course of events in the various accident scenarios. Such models represent formal probabilistic risk analysis techniques. Roughly speaking this part of the model describes the linear cause and effects identified, structured by means of formal logical statements. The more "soft" relations cannot be expressed by formal logical structures such as AND and OR gates. For example the level of competence is assumed to influence the error probability of a critical task, but we cannot model this by e.g., fault tree. Risk Influencing Factors (RIFs) and Performance Shaping Factors (PSFs) are often used to structure this part of the modelling. The various RIFs or PSFs are often structured by means of BBN techniques in order to model the influence on the basic events and barriers in the primary accident scenario model. In the following, we introduce important definitions used in risk influence modelling:

QRA parameter
Conditions that affect risk and included as single parameter in the quantitative risk model. Examples of QRA parameters are failure rates, on demand probabilities for safety systems and ignition probabilities. Primarily we assume that QRA models comprise formal probabilistic techniques like fault- and event trees, and energy related impact techniques, e.g., an ignition model.

Risk influencing factor (RIF)
A RIF is a factor or condition that influences the risk. There are three principal types of RIFs, (i) RIFs that are equal to a QRA parameter, (ii) RIFs where the value of a RIF is assumed to influence a QRA parameter, and where the influence is described in probabilistic terms, and (iii) RIFs that influence a parameter that is not explicitly modelled in the QRA. The situation in (ii) is the most important covered in this course. In most cases, the value of a RIF is not known, and the RIF is therefore treated as a random quantity.

Risk indicator (RI)
A quantity or condition that may be assessed or measured, where the value of the risk indicator is an indirect measure of a corresponding risk influencing factor. There are two principal types of risk indicators, (i) resultant risk indicators which are reflecting the corresponding risk influencing factors, and (ii) controllable risk indicators, where it is possible by various efforts to set the value of the risk indicator, and hence change the value of the corresponding RIF. If the RIFs are treated as random quantities in the modelling, it is possible to derive the conditional probability distribution of a RIF given the value of one or more RIs. Among the models we consider, only the Risk_OMT treats RIFs as random quantities. In the Risk_OMT risk indicators are denoted *scores*.

Score (S)
A realisation of the true underlying value of a RIF. The term score were introduced in the Risk_OMT approach where the term score denote the summarized information regarding one RIF from interviews, surveys etc. A score is thus treated as a realisation (observation) of the true underlying RIF.

RIM parameter
A RIM parameter is a parameter in the risk influence model (RIM). There are several levels of RIM parameters, for example RIM parameters used in models to assign a QRA parameter given the value of a RIF, and RIM parameters used to link risk indicators (RI) or scores (S) to the RIFs.

Challenges in RIF modelling

In this section we discuss some of the main challenges with developing RIF models. A starting point for the discussion is that some quantitative risk analysis already exists. For example in the offshore oil and gas industry so-called total risk analyses (TRA) often also referred to as QRA exist for all installations. There are several reasons why we want to go into RIF modelling:

1. To get a more realistic risk picture taking "soft" factors into account
2. Link soft factors explicitly to the risk picture such that we can quantify the effect of risk reducing measures related to these soft factors
3. Establish a framework for updating the risk picture based on change of the value of risk indicators rather than updating the entire QRA to achieve a living risk picture.
4. By conducting the analysis gain more insight into risk influencing conditions, and hence be able to eliminate risk factors directly.

Identification of RIFs

Two identify RIFs we may choose between a top down, or a bottom up approach. In a top down approach we start with an existing QRA and search for the most important *RIF parameters*. To quantify the importance of a RIF parameter in this context we take into account both (i) a technical importance measure like Birnbaums measure of importance (i.e., the change in total risk by a small change in the parameter value), and (ii) the likely change in the parameter. For example in the offshore oil and gas industry gross accidents are mainly linked to well-control events, process events caused initiated by gas leakages, and structural damages caused by ship collisions. Thus the gas leakage frequency is a parameter with a high value according to the Birnbaums measure. If further, the gas leakage frequency is likely to change, or strongly affected by RIFs for which we have not really looked into, we have a good starting point to look for the most critical RIFs. In a bottom up approach we start with all possible RIFs we consider to have an impact on the total risk, and perform a screening without explicitly considering existing risk models.

Independent of a top down, or bottom up approach, we need to define the RIFs such that they relate to the existing risk models and QRA parameters. In some situations the RIF would be identical to the QRA parameter which is the easiest situation. In other situations, there will be a more or less direct link between the RIF and the QRA parameter. For example in human reliability analysis (HRA) the RIFs are denoted PSFs (performance shaping factors) and are linked directly to the so-called HEP (human error probability) which is a QRA parameter. The most challenging situation is when the level of details in the QRA is insufficient to really match the RIFs. For example in offshore oil and gas QRAs, the gas leakage frequency is modelled as one single number not taking the various failure causes into account. Failure causes for gas leakages spans over a range of technical, procedural and human error related issues, and if no model exist to map the failure cause level, it is also hard to link RIFs to an existing QRA parameter.

Extension of existing QRA models

As discussed above, existing QRA models often lack the level of details making them appropriate for linking RIFs to the QRA parameters. It is therefore often required to extend the existing QRA. Referring to the gas leakage example discussed above, a very simple approach is to split the gas leakage frequency into a set of failure causes followed by an assessment of the relative importance of each failure cause. The next step is then to link the various RIFs to one of the failure causes giving a good starting point for the modelling. Note that a cause here may be the failure of a safety barrier not directly linked or modelled in the QRA.

In other situations it is required to develop new risk models to get confidence in the mapping of RIFs to the risk model. For example in the Risk_OMT methodology several task analyses were carried out to really catch critical activities during maintenance that influences the gas leakage frequency. An advantages developing detailed models is that we also get a better qualitative understanding of those issues that may cause e.g., a gas leakage. Such understanding is of great importance when searching for explicit risk reducing measures.

Defining the scale of the RIFs

Every RIF in a risk influence model has a value (known or unknown) which depends on the scale being used. Now, let r be the value of a RIF. A neutral scaling regime would be to define r=0 to be the industry average of a RIF, r=-1 be the worst case we can imagine, and r = +1 be the best we can imagine within a reasonable time horizon. Another approach is to use an arbitrary scale, for example in the ORIM model r = 1 corresponds to the worst case, and r = 5 to the best case. In the BORA and Risk_OMT models character values were used, where r = A corresponds to best practice, and r = F corresponds to the worst case, or unacceptable state.

It is recommended to use the same scale for all RIFs. Later on we will also discuss risk indicators (or scores) as a means to assess the value of a RIF. It is recommended to use a matching scale for risk indicators/scores. However, this is more demanding, since for example a risk indicator may be measured in terms of e.g., n = number of personnel having a certain formal certificate. In such cases, a mapping is required, for example n = 0 corresponds to the character F, $n \in [1,2]$ corresponds to E and so on. Such a mapping is not straight forward and requires careful considerations.

Structuring RIFs

Usually more than one RIF are influencing a QRA parameter. In simple models a weighted sum is calculated to represent all the RIFs, and this sum is then used to adjust the QRA parameter. In more advanced modelling, two aspects are considered. The first aspect relates to the fact that a weighted sum will not take into account interaction effects between the RIFs. In some situations a bad value of two or more RIFs is considered more critical than the individual contribution from these two bad values, i.e., there are some interaction effects we would take into account. The second aspect relates to dependencies between RIFs. For example if we split into “sharp end” RIFs (e.g., time pressure) and “blunt end” RIFs (e.g., management of work organization) the latter RIF is assumed to influence the first RIF. If we collect data and combine into scores to reflect the value of the RIFs on different levels, we need to develop an influence model to connect the RIFs, and BBN methods will be a good starting point.

Linking risk indicators and scores to the RIFs

In simple models we link risk indicators to the RIFs by simple weighting formulas. If RIFs are treated as random quantities, the risk indicators (or scores) are only considered to be *indicators* for the true underlying value of the RIF. We then need to express how strong evidence a value of a risk indicator really is. A simple way to express this is to say that given a value r of a RIF, the risk indicator or score, will be a random variable, say S, where E(S) = r, and in addition a precision parameter is required to express Var(S). This will enable inference, i.e., assessing a probability distribution over the RIF, or simultaneous distribution over a set of RIFs by e.g., BBN methods.

Linking RIFs to the QRA parameters

Independent of whether RIFs are treated as random quantities, or fixed known values, it is necessary to link the various RIF values to corresponding QRA parameters. If r is the value of a RIF, and p is a corresponding QRA parameter, we need to establish a functional relation:

$$p = f(r) \tag{2}$$

In order to establish such a relationship we often ask what will be the value of p when the RIF take the best and the worst value respectively. For values of the RIF in-between we often choose between linear or geometric relations.

Let p_L and p_H be the lowest and highest value the QRA parameter of interest can take respectively. Further let r_L and r_H be the lowest and highest value a RIF value r can take respectively[1] (considering only one RIF). A linear interpolation is now given by:

$$p(r) = p_L + \frac{(r - r_L)(p_H - p_L)}{(r_H - r_L)} \tag{3}$$

and similarly a geometric interpolation is given by:

$$p(r) = p_L \left(\frac{p_H}{p_L}\right)^{\left(\frac{r - r_L}{r_H - r_L}\right)} \tag{4}$$

Generally a geometric interpolation is recommended if the range of the parameter variation spans more than one decade.

If we have more than one RIF that is influencing a QRA parameter, we need to develop an *interaction model* to combine the RIFs.

Structuring QRA parameters, RIFs and RIs/scores

Ideally we would like to make a clear distinction between QRA parameters, RIFs and RIs. The QRA parameter represent the quantity used in the QRA models which are the starting point of the risk influence modelling. Then RIFs are introduced to represent conditions that are influencing the QRA parameter, where the aim is to give a RIF a theoretical interpretation like competence of maintenance personnel. In order to assess the value of a RIF, the RIs are introduced. In some situations we build a very rigid risk influencing model by formal e.g., a formal BBN model. For example in the Risk_OMT model some 5-8 RIFs were introduced in a hierarchy to show the influence on a particular QRA parameter. In the Risk_OMT the RIFs were more or less identical to variables used in safety audits, and hence there were a one to one relation between the RIF and the RI (where the term score was used rather than a risk indicator). In other situations less effort is made to structure the various RIFs, and at the extreme we may leave out the explicit definition of RIFs and link the risk indicators directly to the QRA parameter, for example by a weighted sum.

---

[1] We here assume that a low value of the RIFs gives a low value of the corresponding QRA parameter to simplify the presentation

Hybrid vs full BBN models for the entire QRA modelling

If the RIFs are treated as random quantities, equation (2) may be used to get a probability distribution over the parameter *p*. This represents a so-called parameter uncertainty which we in principle may propagate in the QRA model. Since fault- and event trees in principle may be converted to BBNs, and since a BBN is also used to model the distribution over various *r* values, these BBN models may be combined to give a full BBN model for the total quantitative risk model. Experience from the Risk_OMT project has shown that this is impossible due to memory and time constraints within existing BBN implementations. To create an approximated full BBN model requires careful consideration, and deep knowledge into application of BBN modelling.

A hybrid model applies equation (2), but rather than finding a probability distribution over *p*, the uncertainty regarding the RIFs is being integrated to give an expected value of the QRA parameter. This value could then be used in existing QRA models represented by fault and event tree rather straight forward. Such an approach, is however, not conservative since if the same RIF influences several QRA parameters, we then will ignore the "state of knowledge" dependency in the value of the RIFs, and hence "underestimate" the risk. More research is required, to find ways to improve such hybrid modelling.

References

B.A. Gran, R. Bye, O.M. Nyheim, E.H. Okstad, J. Seljelid, S. Sklet, J. Vatn, J.E. Vinnem. 2012. Evaluation of the Risk OMT model for maintenance work on major offshore process equipment. *Journal of Loss Prevention in the Process Industries*, Volume 25, Issue 3, May 2012, Pages 582-593

J.E. Vinnem, R. Bye, B.A. Gran, T. Kongsvik, O.M. Nyheim, E.H. Okstad, J. Seljelid, J. Vatn. 2012. Risk modelling of maintenance work on major process equipment on offshore petroleum installations. *Journal of Loss Prevention in the Process Industries*, Volume 25, Issue 2, March 2012, Pages 274-292

Øien, K. (2001) A framework for the establishment of organizational risk indicators. *Reliability Engineering & System Safety*, 74, 147-167.

Haugen, S., Seljelid, J., Sklet, S., Vinnem, J.E. and Aven, T. (2007) *Operational risk analysis: total analysis of physical and non-physical barriers*. H3.1, Generalisation Report, Rev. 1

Vatn J (2012). Can we understand complex systems in terms of risk analysis? Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, 2012

Sarshar, S., Gran, B.A., Haugen, S and Skjerve, A.B. (2012) *Visualisation of risk for hydrocarbon leakages in the planning of maintenance and modification activities on offshore petroleum installations*. ESREL/PSAM 2012.

Vatn, J and Haugen.S. (2012). On the usefulness of risk analysis in the light of Deepwater Horizon and Gullfaks C. RIO book

Hollnagel E, Woods D D and Leveson N (Eds.) (2006) Resilience Engineering – Concepts and Precepts. Ashgate Publishing Company.