Comparison between two organisational models for major hazard prevention

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ABSTRACT: A clear difficulty today is to find practical organisational modelling dealing specifically with major hazard prevention and to be able to compare them in order to potentially enhance their relevance. This work is an attempt to do so. This paper provides a comparison of the differences, the common and complementary features of the I-RISK model (developed within the European I-RISK project) and the MIRIAM model (developed at INERIS, France).

1 INTRODUCTION

INERIS has been working for 2 years on a methodology named MIRIAM, which stands for "Maîtrise Intégrée des Risques d'Accidents Majeurs" (Integrated Control of Major Accident Risk). The MIRIAM method, based on an organisational model introducing a human factor approach, is aimed at implementing and assessing safety management systems. A next step in this work, through its development phase, is to compare it to other existing organisational models.

The model developed under the I-RISK research program (Integrated Risk) in the EU 4th Framework Program, had as objective the production of a probability of major hazard occurrence on a chemical site, weighted by human and organisational influences. The Safety Science Group of TU Delft, with Linda Bellamy of SAVE, developed the organisational modelling (Hale et al 1999).

Both INERIS and Safety Science Group acknowledge the importance of the organisational aspects in major hazard prevention and agree on the necessity of comparing modelling to enhance the ability of modellers to introduce these important aspects into risk assessment.

In this paper, the result of the comparison of the two models is presented. These results will be particularly useful for the ARAMIS program. This program under the EU 5th Framework Program has the objective of producing a harmonised risk assessment methodology for Europe and includes the measurement of safety management effectiveness.

The paper is structured around 5 modelling areas under which the differences as well as the common and complementary aspects are discussed:

- a process approach to the organisational models,
- the interface between the technical and organisational models,
- the factors influencing the interface with the technical modelling,
- the conceptual approach to what is traditionally called the "human factor" in the risk field,
- the issue of management priorities
- the modelling representation.

2 A PROCESS APPROACH

The MIRIAM model is based on a process approach that consists in decomposing the activities of an organisation. A process is seen as a system of activities that transforms inputs into outputs using resources and constraints. The final outputs in our case of safety management modelling are the safety related activities.

The I-RISK model used the SADT, (Structured Analysis and Design Technique) for the modelling of the safety management system, which is originally a technique that is useful for system planning, requirements analysis and system design. This type of decomposition has the same inputs, outputs, resources and constraints as the process approach used in MIRIAM (figure 1).

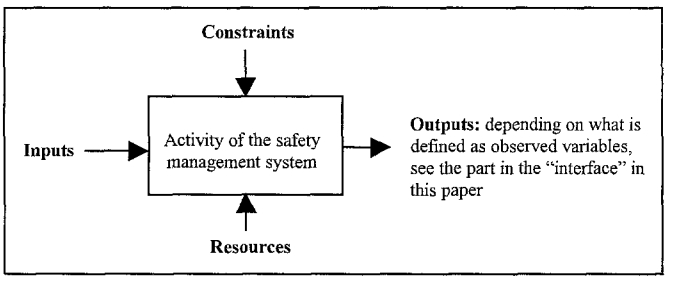

Figure 1: a process approach applied to major hazard prevention

The principle of this type of decomposition is to be functional. It is a "black box" approach that helps to focus not on "how it is done" but rather on "what it does". It is therefore relevant for anything that transforms inputs into outputs, meaning that any organisation can be described as a set of functions to be achieved, rather than in terms of the actual structure specified to achieve them. This process decomposition therefore allows a representation that suits various types of organisation and can be a support to comparing the effectiveness of their risk control – do they have the functions in place and working?

The underlying management science principle that is described through this decomposition is the PDCA, Plan-Do-Check-Act loop. It describes a feedback loop. This is a required feature of any goal-oriented systems. Safety management systems have a risk control objective, and must be moving towards this goal thanks to the application of this principle.

Both the MIRIAM and I-RISK models have this feedback and learning function that can be illustrated through the following cybernetic figure (figure 2):

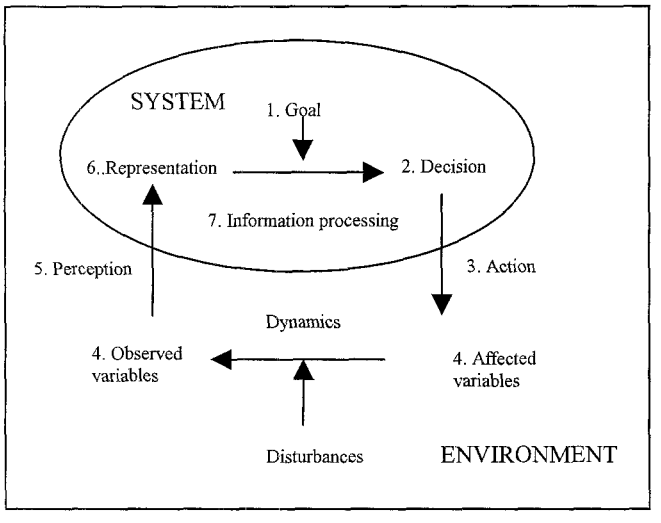

Figure 2: basic components of a control system

All these elementary components have to be defined and described through the process decomposition and all of them are equally important. For a system dedicated to major hazard prevention, these steps could be briefly described as follows:

❶ The goal

The goal of a safety management system is the control or prevention of major hazard. For that, the hazards must be identified and the risks assessed, in order to know what is the type and level of risk generated by the activity. In both MIRIAM and I-RISK risk analysis is recognised as a core activity which provides the information about what the system has to control and monitor.

❷ Decisions

From that risk analysis activity, decisions should be taken about the measures to be implemented for risk control. These are technical measures as well as human/procedural and organisational ones. Technical measures include the implementation of safety devices, human measures include the use of competent people to carry out safety procedures or diagnose unsafe situations, whilst organisational measures include the maintenance planning of the devices, or the training of the operator on safety issues etc. At this stage the safety management system has set up its objectives to be reached through the implementation of the actions. In both MIRIAM and I-RISK this decisional aspect is represented using arrows that indicate information/decision/action flows.

❸. Actions

From those decisions, actions are carried out in order to reach the objectives. These actions consist of implementing the training, implementing the maintenance planning, and all of the many other safety-related activities. In both MIRIAM and I-RISK these activities (operation, maintenance, inspection etc) are explicitly mentioned.

❹ Affected/observed variables

The actions taken must meet the objectives, and these objectives are the affected/observed variables. The choice of the affected/observed variables is crucial. Indeed these variables, in a risk control perspective, are the reference, and they are under the influence of the environmental disturbances. What should be the appropriate observed variables is not so well defined in the risk management literature. Many options are mentioned, including risk perception, safety culture or climate, procedures for safety related activities (i.e. management standard or guidance), power plays within the organisation, motivation etc. The very complexity of human activity reveals numerous relevant factors from organisational life (from psychology, organisational sociology, ergonomic, politics, etc.). The difficulty is to define the relevant ones. In the next section the interfaces created with the technical model are discussed for MIRIAM and I-RISK and the affected/observed variables chosen each will be introduced.

The environment creates disturbances, or deviations from the desired goals. These can be internal perturbations like conflicts between people, the lack of commitment due to production pressure, but also the installation itself can generate a wide variety of unpredicted outcomes threatening safety. There are also of course external disturbances like economic constraints (less time and investment in safety related activities), public opinion, regulatory enforce-

ment etc. These disturbances affect the variables that need to be assessed.

❺ Perception

This relates to the ability of the organisation to observe the chosen affected variables and steer or improve their control of them. This could be based on auditing techniques, when it comes to evaluating the level of compliance with standards or procedures. Other ways of gathering information can be applied when the observed variables concern more "intangible" aspects like risk perception, safety culture, power plays etc. and would be ensured by methods like questionnaires, interviewing, observations. In both MIRIAM and I-RISK this perception aspect is operationalised with arrows that indicate these information flows.

❻Representation

The way this information is represented at all levels of the organisation is also fundamental. How is this represented information perceived by the system? Can it be quantitative, or is it better qualitative? What sort of indicators are possible when major hazard prevention imposes a no outcome (accident) objective and requirement (zero incidents/accidents does not mean the same thing as zero risk)? How to create a picture of the state of the variables? In both MIRIAM and I-RISK the exact content of these performance indicators is left open, because of the functional approach. This representational aspect is contained in the arrows. Management has to fill them in, but the arrows imply that connections between those functions of the management system are ensured. The quality of this connection depends on the quality of the information, and therefore part of this is its representation.

❼Information processing

Once this information is represented, how is it treated? How will good decision-making be ensured, considering this information about the state of the observed variables? In both MIRIAM and I-RISK this information-processing activity is represented through the use of arrows that indicate information/decision/action flows. The quality of this activity relies on the ability of the information's receiver to interpret properly the information that is represented in a specific way, according to the affected variables that are chosen. (See ❹ above)

3 THE INTERFACE BETWEEN THE TECHNICAL AND ORGANISATIONAL MODELS

Both models need to create an interface in order to somehow "plug" the organisational model into the technical one.

In MIRIAM, the interface is based on the prevention barriers. The technical model describes scenarios determined by risk analysis, that are prevented thanks to safety critical functions, represented by barriers chosen in the (organisational) design process. These barriers can be safety devices or safety activities, which fulfil the safety critical functions that need to be implemented at any time to ensure the level of risk control. Barriers are multiple, intervening at various stages in the development of the scenarios. This is the defence-in-depth approach. MIRIAM links to this approach by assessing the management system in terms of its ability to establish and maintain the quality of the barriers.

This interface is presented in figure 3, part of the MIRIAM modelling.

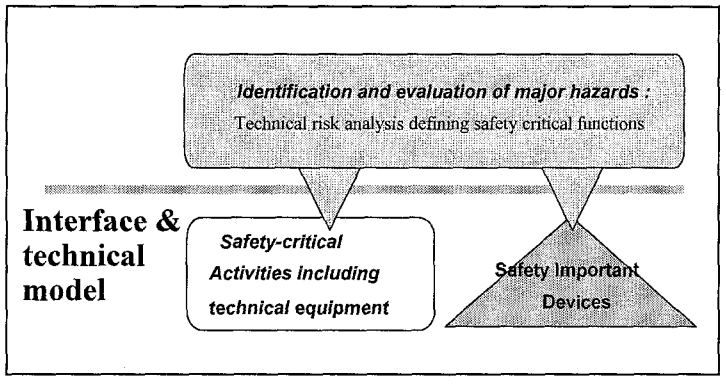

Figure 3: MIRIAM modelling, interface based on barriers divided in activities and safety critical devices

I-RISK has an approach based on the implementation of a probabilistic method (QRA, Quantitative Risk Assessment). It focuses on initiating and base events as well as barriers, found in the calculation of the failure probability through the use of fault trees. This makes the interface more detailed than in MIRIAM. It is explicitly aimed at connecting with the QRA parameters, which are the following:

- Frequency of external events.
- Failure rate of unmonitored (standby) or monitored components.
- Time between testing.
- Error in test and repair.
- Failure to detect and recover previous error in test and repair.
- Frequency of routine maintenance.

- Duration of unavailability due to routine maintenance.
- Duration of repair.
- Probability of error in operations or emergency.
- Probability of not detecting and recovering error.

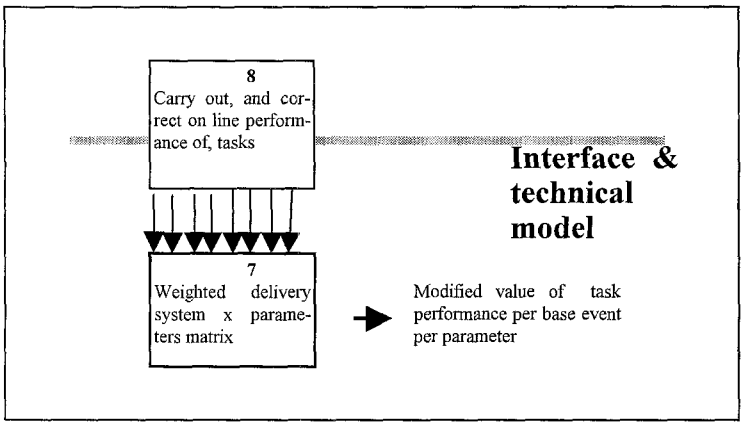

Figure 4: I-RISK modelling, Interface based on parameters used in QRA

The interface consists, therefore, in connecting these parameters with the process decomposition. This was found to be very complex, as it is really hard to decompose in practice all the activities that influence all of these parameters for all of the equipment and actions which can fail in a complex plant, as analysed by generic fault trees (figure 4). I-RISK had to resort to grouping equipment, tasks and parts of the organisation in terms of the similarity (called "common mode") of their management, in order to reduce this complexity and make the task of auditing manageable. Rules were developed for this grouping, but it remained a difficult aspect of the modelling.

If there is no constraint imposed by the need to make a detailed quantitative, QRA link between technical and management models at the level of parameters, it may be appropriate to concentrate only on the barriers – the MIRIAM approach, in order to reduce the number of activities to be audited. The level of major hazard prevention would thus depend on the quality of the barriers, maintained by the quality of the management through the implementation of the appropriate activities. However, rules will still have to be developed in ARAMIS for grouping barriers into "common modes", based on the similarities of their management.

4 THE FACTORS INFLUENCING THE ACTIVITIES AND HUMAN BEHAVIOUR

The interface problem raises the question of the influence of the organisation on the elements, events, or parameters coming from the technical risk analysis. How are the parameters coming from the technical analysis influenced?

In MIRIAM these parameters are the safety critical devices and the safety critical activities. To ensure the quality of these, one needs to consider how the safety critical devices are chosen, purchased, implemented and maintained, and therefore the related activities. Concerning the safety critical activities, one needs to analyse closely how they are carried out

Considering this question leads the assessor to define how the management system influences these activities carried out by the people. Looking at the way activities are operated requires thinking about how people behave according to their social and physical context.

With a process approach, this becomes a question about the constraints and resources allocated to the people who perform a given activity that constitute the context in which activities, and therefore the work of individuals and group of individuals for any type of activities, are performed. These factors are defined as follows in MIRIAM:

Competence:

Competence is the generic term that gathers all the abilities of an actor to take on his role and responsibilities and to use the technical support at his disposal. These abilities are covered by the three following dimensions:

- ***Knowledge***: concerns all the concepts and rules known by the actors. Knowledge will help the actor understand a situation and a context but does not necessarily help make decisions and decide actions.
- ***Know-how***: concerns the part of knowledge which is action-oriented. It is applicable to practical situations and very often already automated in the actor's mind. Know-how is intimately linked to ***experience***.
- ***Safety behaviour***: consists in working out careful solutions, in accepting the cost of these careful solutions and also in investing resources to develop new careful solutions. In our research, this dimension is very much linked to the ***values***.

Co-ordination

Co-ordination is the generic term which allows work first to be divided into tasks and allocated to different human and material resources, and then for the various tasks to be co-ordinated into a coherent whole again. It provides the answer to the question *"Who does what, when, where and how?"*

Co-ordination in MIRIAM is represented by the three following dimensions:

- ***Definition of roles and responsibilities***: this represents the two following aspects that need to be managed: ***task planning*** (What is to be done, where, when?) and ***resource allocation*** (Who does what?)
- ***Modes of communication:*** what channels and modes do people use for coordination?
- ***Modes of decision-making:*** how and where are decisions made?

Technical support

This generic dimension concerns the whole set of techniques (conceptual and material) that should enable an actor to achieve his objectives or effectiveness in his activity.

Technical support answers the question "*How* and *what* should a task be done *with*?" Technical support refers to:

- ***Methods, operating procedures:*** the answer to *how* question.
- ***Tools, device, and man / machine interface***: answer to *what with* question?

These factors have been identified mainly through the body of knowledge found in organisational sociology.

In I-RISK, these influence factors are called delivery systems, to emphasise that they are delivered by management processes, linked often to specific staff functions of an organisation, which deliver resources and controls in the sense defined by SADT. These influencing factors (resources and constraints) have also been derived from the literature and previous modelling projects.

Competence: the knowledge, skills and abilities in the form of first-line and/or back-up personnel who have been selected and trained for the safe execution of the critical primary business functions and activities in the organisation (comparable to the knowledge influencing factor in MIRIAM).

Availability: allocating the necessary time (or numbers) of competent people to the safety-critical primary business tasks which have to be carried out.

Commitment: the incentives and motivation which personnel have to carry out their tasks and activities with suitable care and alertness, and according to the appropriate safety criteria and procedures specified for the activities by the organisation (comparable to the safety behaviour influencing factor in MIRIAM)

Interface and modifications: The ergonomics of all aspects of the plant which are used/operated by operations, inspection or maintenance (meets the tools, device, man/machine interface influencing factor in MIRIAM)

Spares: These are the equipment & spares which are installed during maintenance, which need to be the correct spares and in good condition for the replacement.

Internal communication and co-ordination: Internal communications are those communications which occur implicitly, or explicitly within any primary business activity, i.e. within one task or activity linking to a parameter of the technical model, in order to ensure that the tasks are co-ordinated and carried out according to the relevant criteria (comparable to the modes of communication, influencing factor in MIRIAM)

Conflict resolution: The mechanisms (such as management decision, supervision, monitoring, group discussion) by which potential and actual conflicts between safety and other criteria in the allocation and use of personnel, hardware and other resources are recognised, avoided or resolved if they occur (comparable to the mode of decision making influencing factor in MIRIAM)

Procedures, Output goals and Plans: Rules and procedures are specific performance criteria which specify in detail, often in written form, a "normative" behaviour or method for carrying out an activity (checklist, task list, action steps, plan, instruction manual, fault-finding heuristic, form to be completed, etc.). Output goals are performance measures for an activity which specify what the result of the activity should be, but not how the results should be achieved. Plans refer to explicit planning of activities in time, either how frequently tasks should be done, or when and by whom they will be done within a particular time period (month, shutdown period, etc.) (comparable to the methods, operating procedures influencing factor in MIRIAM)

From this description one can say that the two sets of influencing factors in the MIRIAM and I-RISK models are very close to each other. What differences there are represent some complementarity. Merging of the two lists provides a still more complete list of influences.

The next question is how these factors (resources and constraints) are combined in the model to produce a given unwanted outcome. We use as example the event "incorrect weld performed by an operator",

found in a fault tree. A practical question is what factors lead to this error and how could/should they be avoided? Where does it appear in the models.

It falls under the maintenance activities, the welding that has to be performed. There are a number of possible reasons why the error could occur. These are represented in the influencing factors. It may be that the organisation should provide more training, because the welder is not competent. It may be that welders routinely violate procedures and the organisation should ensure more commitment. It could be that the welder did not receive clear instructions about what to do, because there is poor co-ordination between groups concerned, or that there is no procedure for checking work. Should the welding procedure be enhanced, better written? Perhaps the workplace in which the welding takes place is poorly laid out or physically awkward and should be redesigned. All these factors and more are covered under the influencing factors and their delivery systems. Both models provide the classifications and checklists of factors which allow the analyst to predict and discover all of these factors and to examine, in the specific company, how good the management systems are to prevent these shortcomings. How this evaluation is carried out will depend in detail on the conceptual framework they have in taking account of this human factor.

5 THE CONCEPTUAL APPROACH TO THE HUMAN FACTOR

Even if there is a similar vision on the influencing factors between the MIRIAM and I-RISK models, their conceptual frameworks for considering the human factor differ. For the question "how to explain observed or expected behaviours within the implementation of an activity", two types of practice, based on different human factor approaches, are described in the two models. MIRIAM goes into much more detail at this point to understand why the individuals behave in the way they do. I-RISK takes a more generic approach, emphasising the influences to manage the actions and errors. When represented in a fault tree, I-RISK limits itself to the questions shown in figure 5.

In MIRIAM the influencing factors are to be understood through the conceptual framework of a strategy. From a strategic point of view, to act is to pursue an objective (to resolve problems) by making use of specific means (to find solutions).

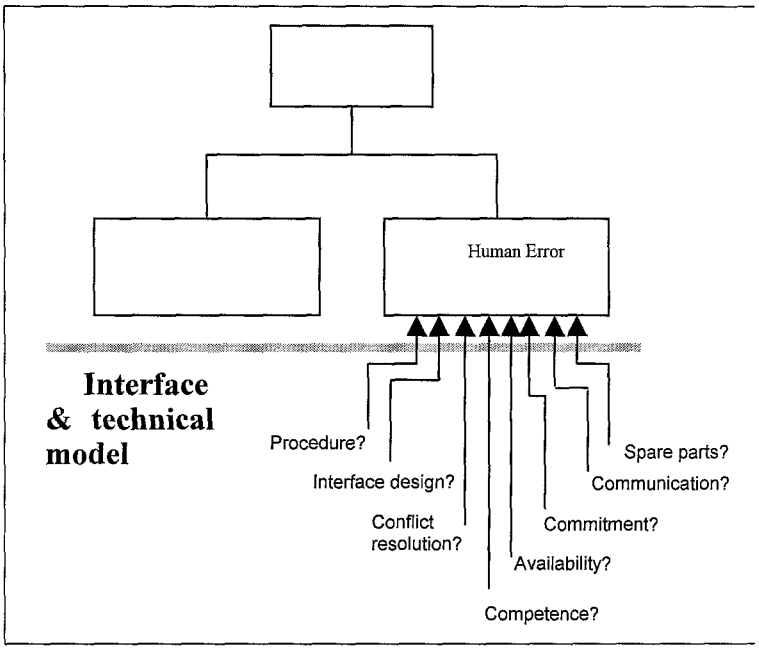

Figure 5: How do the factors influence human error ?

This theory considers that all human behaviours can be analysed as individual strategies or as the result of aggregating collective strategies. The strategies are worked out by actors. Actors are individuals or groups. The collective strategies in an organisation can be analysed like the rules of a game. The game can be easily compared to a theatre play. Each actor plays his own role; his strategy is his interpretation of the role. Performing the whole play requires (explicit and tacit) collective bargaining in order for everyone to co-ordinate.

The notion of strategy also refers to the notion of reason. To analyse human acts as specific solutions to given problems is equivalent to acknowledging that actors always have good reasons to act as they do. These reasons are always at least subjectively good, even though they may not be objectively.

This is the theoretical point of view that MIRIAM provides to help the external observer to be able, through interviews, to uncover how activities and organisations function. The aim is to understand the influences on the strategies, in order to modify them. This is necessary when they do not comply with the essential safety requirements, or do not allow the actor(s) to take appropriate safety actions when facing, for example, unexpected situations or unplanned emergencies.

Looking at strategies means looking at the informal part of the organisation, a part that is not written or found in formal procedures, but which gives a complementary view of the organisational life. This informal part, corresponding to the aggregation of collective strategies, rules daily activities and forms what has come to be known as the safety culture of the organisation. This approach, consisting in re-

vealing these unwritten rules, is a useful addition to the safety management assessment found in I-RISK.

In the MIRIAM modelling this has been represented as a separate part, where the strategy can be specifically addressed (figure 6).

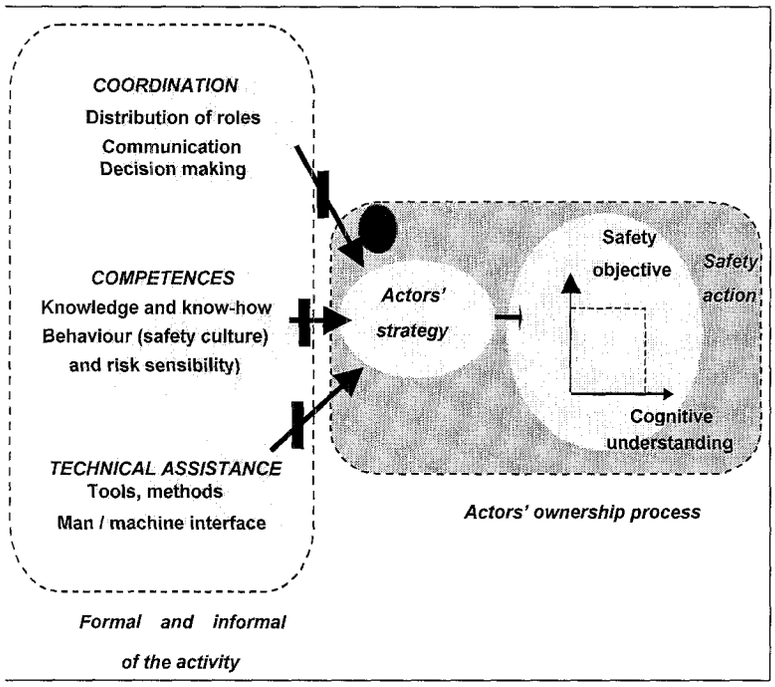

Figure 6. Actors' strategy in MIRIAM

In I-RISK this aspect of culture is relatively underrepresented. There are elements of 'the actors' strategy in the delivery systems of 'commitment' and 'conflict resolution', but these are approached from an implicitly normative viewpoint.

6 EXPERT JUDGEMENT AND MANAGEMENT PRIORITIES

An issue which I-RISK has dealt with explicitly, but which remains implicit in MIRIAM is the question of how important each of the influences is on the ultimate achievement of the safety goals (the control of the parameters in I-RISK, or the barriers in MIRIAM). The approach relies on an expert judgement procedure to identify among all the influencing factors defined, which are the most important ones. Expert judgement consists in asking to experts in a specific field to answer questions about a subject, using systematic elicitation techniques (Cooke 1991. In a series of pilot studies (Hale et al 2000) experts in maintenance management were asked to use a paired comparison technique to compare the effect of influencing factors, drawn from the 8 I-RISK delivery systems (see section 4 above), on maintenance parameters (see section 3 above). A mathematical treatment of the answers showed which areas generated a sufficient level of agreement for the results to be meaningful. This provided an empirical basis for priorities in auditing and proposals for change. The I-RISK approach is more empirical than MIRIAM in this respect, being driven by the requirements of quantification (QRA context).

7 THE MODELLING REPRESENTATION

The organisational modelling in both MIRIAM and I-RISK is a mental representation that helps an assessor to structure his/her approach to the organisation, for assessment purposes.

They are representations of a reality which is very complex and which can be observed from various angles and therefore be modelled in different manners. The modelling chosen depends on the constraints and objectives within which the modellers designed it.

The MIRIAM representation had as constraint that it must be transferable to industrialists. This constraint led the modellers to emphasise the visualisation of the model, through the use of colours and to simplify it, to have less elements as well as less visible connections between these elements.

Moreover the MIRIAM model separated the modelling into two parts, in order to emphasise the conceptual human factor approach. The strategy is the core concept of that approach, and its application for safety purpose is highlighted by a second representation.

Because it had a more quantitative objective, I-RISK had to be as complete as possible about the factors which make a significant difference to the risk numbers. The expert judgement studies in section 6 above were aimed at filling the gaps in knowledge about which these are. In the absence of such data I-RISK had to make the assumption that all factors were significant. This drove the study to greater levels of detail than MIRIAM. This gives it more of an expert perspective. Communication to the user was an issue, which did lead to the abandonment of the full SADT analysis as representation, but was less of a constraint than for MIRIAM.

As a consequence, the difference between the two models is that MIRIAM looks simpler than I-RISK, which contains more visual information about the dynamic aspect of the organisation. The feedback loops are explicitly represented in I-RISK, in several recursive loops, but are only implicit in MIRIAM, though learning is acknowledged as a fundamental aspect of a safety management system there too.

It is not within the scope of this paper to create a new modelling out of the two previous ones. However the ARAMIS project will tackle that task and try to build on the strengths of both models to provide both clarity for outsiders and detail of the reality of the dynamic feedback loops of organisations, and integration of the strategic dimension of human behaviour.

8 CONCLUSION

The comparison of models is a fruitful exercise that allows modellers to exchange their views on complex issues. It is a long process where "paradigms" must be understood from both sides in order to integrate the best of each, depending on the purposes.

The MIRIAM and I-RISK models have been shown to be compatible with few conceptual differences. The models are both based on a functional process decomposition in order to represent the dynamic nature (PDCA, feed back loop) of organisations. They are both independent from the technical modellings (fault trees) for which a relevant interface has to be defined. The two different interfaces – base event parameters and safety barriers – are alternatives relevant for two different purposes. The parameters match existing QRA models better, but the barriers provide more appropriate insight into risk control options and their management.

The two interfaces describe influencing factors that are very similar. The main difference between the models lies in the conceptual approach to the human factor. In MIRIAM it is seen through the eyes of the body of knowledge of organisational sociology, and specifically through the strategy of the actors. In I-RISK the emphasis on this cultural aspect of organisations is less explicit and it is left to expert judgement to define the most relevant influencing factors. However I-RISK does, by this means tackle the issue of prioritising management influences.

Finally the question of the modelling representation is raised. The purposes of the modelling, qualitative or quantitative, for risk analyst, practitioner or manager, for assessment or improvement, must drive the representation used. I-RISK and MIRIAM are different in this respect, but their complementarity of content means than they can potentially be combined.

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