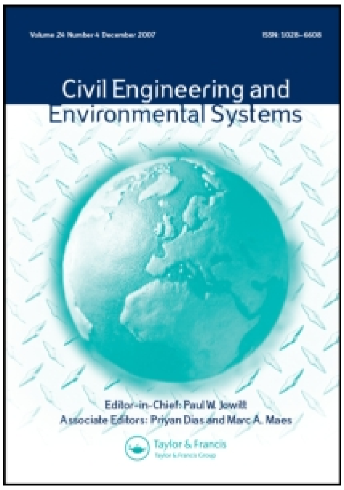

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MANAGING THE UNCERTAINTY OF UNKNOWN RISKS

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The UK industry is rethinking construction. At the heart of this rethinking must be the management of risk and uncertainty. Risk and opportunity are opposite sides of the same coin – good management can turn risk into opportunity. It follows that better management of risk can bring significant opportunities to add value to the construction team including the client. Two neglected areas of risk management are highlighted. The first is the need to integrate all types of specialist risk management procedures to provide 'whole' quality. The second is to develop ways of dealing with unexpected and unforeseen risks. Extensive research has demonstrated that few failures develop totally 'out of the blue' – there are always signs if we know how to look for them. Process modelling to identify the various aspects of 'whole' quality is introduced and a BCIOD + R (Business, Customer, Integrating, Operational, Delivery + Regulatory) classification presented. A prototype tool MARIUN (Managing Risk and Uncertainty) for identifying incubating pre-conditions to failure of a process is introduced. The purpose is to identify the patterns of information within a developing 'accident waiting to happen' so that decisions and action might be taken to remove the threat. As presently drafted MARIUN is concerned only with identifying hazardous risks – further work is needed to use it to identify opportunities.

Keywords: Risk, Uncertainty, Management, Opportunity

1 THE INDUSTRY IS RETHINKING CONSTRUCTION

The movement for rethinking construction (DETR, 1998 – known in the UK as the 'Egan Report') is gathering pace. There seems to be an increasing inevitability that it will result in profound changes in the way in which the construction industry, as a whole, operates. Recently Blockley and Godfrey (2000) have argued the need for a systems thinking approach in order to deliver the success targets set by Egan (DETR, 1998). Clearly at the heart of this rethinking is the management of risk and uncertainty. However the ideas within this thinking have a much wider applicability than the construction industry and apply to both 'hard' and 'soft' complex systems such as the NHS (National Health Service) or the railway transport systems. Thus whilst this paper is addressed to the construction industry, the proposed model is generic and applicable to all types of processes.

In this paper we discuss two very difficult aspects of the management of risk in any system that are currently neglected: a) the need to integrate risks that derive from different but related

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sources (*e.g.* technical and financial risks); b) the need to manage the processes that are at the root of difficult but often very important systems failures and opportunities – *i.e.* dealing with those events that are unforeseen and unexpected.

2 INTEGRATING RISKS

Success means different things to different people. To manage ‘all’ risks and uncertainties we must have a clear idea of our success goals at all levels in a business and in a project. An important ingredient for the success of any project is a set of shared values with a strong customer focus. Rethinking construction is about the delivery of ‘whole’ quality where all aspects of the project success are understood and pursued by all members of the team including the client. This is an essential first stage of ‘whole’ quality risk management.

To address these issues we have to think deeply about what we mean by success and ‘whole’ quality. Blockley and Godfrey (2000) have done this by using ‘process’ as a ‘peg on which to hang’ all other attributes. They describe how quality is expressed in terms of values *i.e.* those attributes of something to which we give ‘worth’ and how we use our values to express preferences. Measures of those values form the KPIs (Key Performance Indicators *e.g.* predictability of cost). Some values are much more difficult to measure but are nonetheless important (*e.g.* team spirit) and can be systematically assessed as shown by Blockley and Godfrey. All of these KPIs are the parameters of process through which hazard, risk and uncertainty will be defined and managed. ‘Whole’ quality includes all of the diverse attributes that are valued or felt to be important by all of the stakeholders – including hazard and risk of various sub-processes. Thus, for example, as engineers, we may think success is a particular technical solution to a difficult problem (based on physical ‘hard system’ parameters or KPIs *e.g.* span, yield stress etc) whereas the client sees success in terms of the way the asset adds value to the business (including hard and soft system KPIs).

Likewise we engineers are usually taught to think about risk and uncertainty in ‘hard’ physical systems (*e.g.* a steel frame structure) quite separately from ‘soft’ human systems (*e.g.* a project management system). Blockley and Godfrey (2000) demonstrate how all hard systems are embedded in soft ones which in turn are embedded in a meta-system or given context. Thus technical reliability theory with its partial set of parameters has to be seen in a context of a wider set of parameters (Blockley, 1999).

2.1 We can Deliver by Thinking Through Process

There are three inter-dependent sub processes or stages in the ‘rethinking construction’ process.

- Changing attitudes and, through that, changing the whole culture of the industry;
- Thinking through the processes for delivering ‘whole’ quality in a given project;
- Developing and using tools to aid the delivery of those ‘whole’ quality processes.

Culture is simply expressed as ‘the way we do things around here’ and is a very high level attribute (KPI) of the whole UK construction industry which is the cause of great concern. As is now well known by UK construction professionals the rethinking construction movement is about changing from a culture of confrontation (with the inevitable litigation) to one of co-operation and teamwork which recognises the need for all involved to get some added value from a project. Change management consultants are increasingly being used in this process since the particular success in rescuing the Heathrow Express (Lownds, 1998).

These types of processes present major opportunities for unforeseen benefits to the client and to the project team.

The Egan report (DETR, 1998) stressed that integrating people and processes is a key factor. Blockley and Godfrey (2000) have described a systems approach based on a hierarchy of layers of connected interacting processes. Each process has a set of attributes which are systematically identified using the key words of **who, what, why, where, when** and **how**. These attributes therefore include people, values and risks. The processes are also classified using BCIOD + R (Section 2.2).

In order to manage uncertainty to deliver success with those processes we require suitable tools such as IT decision support and project management systems. There are now many such tools available. One tool for risk management developed recently is described by Hall, Cruickshank, Godfrey (2001). Another prototype tool to be described later in this paper is MARIUN (MAnaging RIsk and UNcertainty) which is specifically targeted at dealing with unforeseen and unexpected risks. This is a particularly difficult and important but neglected aspect of risk management concerning our ability to identify an 'accident waiting to happen'.

2.2 Integrate Through BCIOD + R

Risk professionals have often developed from within their own specialist disciplines – so they tend to focus on specific types of risk. These include, for example, safety risks, operational risks, financial risks and risks to functionality (*e.g.* structural safety is the term usually used to describe structural functionality because if a structure fails it almost certainly threatens the safety of people). The integration of all of these risks is difficult and from the direct experience of the authors some risk analysts even deny it is an issue because they hold a view so firmly derived from within their own discipline. Blockley and Godfrey (2000) have suggested a framework for integrating risks by examining BCIOD + R (Business, Customer, Integrating, Operational, Delivery + Regulatory) processes. These issues are particularly important at Board level within a company.

Business processes are those of creating and maintaining the business case including all financial aspects. Whilst these processes may be owned and driven by financial specialists it is important that all members of the team understand the business case and contribute to its development and execution.

Customer processes drive a project – they provide the answers to the reasons why a project exists. The client's customers head the value chain and all members of the team need to understand the network of value adding interactions and its implications for their specialist roles.

Integrating processes are those that bring processes together and are often the 'poor relations' of this group since they do not add value directly – nevertheless they benefit the outcome indirectly. Rethinking construction is an integrating process for the whole of the industry. Examples at project level are 'controlling processes', 'managing staff' which include all HR (Human Resource – Personnel) management such as paying, training, recruiting as well as all of the other 'oiling the wheels' processes such as maintaining diaries and a network of relations. Mapping and analysing project processes in the manner suggested by Blockley and Godfrey (2000) are also integrating processes. The greatest, largely unrecognised, set of opportunities for delivering added value to a project can come through better integrating processes. Various specific and specialist types of risk management need to be brought together in order to better manage the delivery of 'whole' quality and to better manage the 'whole' risk.

Operational processes are those where the system does what it has been designed to do *i.e.* to function as required. These are the crucially important processes for the client since it is through these processes that the constructed asset adds value to the business. Thus, for example, a building keeps the weather out and provides the space for its occupants to go about their daily business.

Delivery processes are those that provide and maintain the system. Thus to the client the design and construction processes are Delivery processes. However to the design and contracting engineers they are Operational processes.

Regulatory processes are external to a project and are those required to meet legal and regulatory requirements such as health and safety. Reports such as R2P2 (HSE, 1999) are providing a thoughtful basis for future development in the UK.

Normally, engineers are principally concerned with O and D (Operational and Delivery) processes and therefore O and D risks and often we look no further. Increasingly, through the Rethinking Construction movement, engineers are beginning to look at the whole process (including B – Business and C – Customer) rather than the rather narrow focus on first costs or even life cycle costs. Attention to B requires a wider view of financial matters with a consequent parallel focus on C – Client and Customer needs. Customers of clients are at the top of the value chain and a wider consideration and integration of value and risk requires an understanding of the implications of that chain on the work and success of the engineer.

All of the BCIOD + R processes must be successful for the complete success of the ‘whole’ project. Therefore, by using a common framework for considering these different but interdependent sub processes, a ‘holistic’ assessment of risk can be made. Each specialist in the team has a responsibility, not just for his or her speciality, but also for the ‘whole’ success. Procurement and contractual arrangements have to be such as to allow for this.

2.3 Risk is in the Future and it can Create Opportunities

So if we want to deliver whole quality on a project or in a business (*i.e.* to integrate all BCIOD + R aspects) – what can stop us? The answer is almost anything! There are many hazards that can get in the way of a successful outcome to a process. A hazard is commonly defined as the *potential for adverse consequences* of some event or sequence of events. It is more generally a situation that has the *potential for harm*. In the next section we will develop this definition even further. Hazards are ‘banana skins’ on which a process can ‘slip’ with some consequent damage to the process and achieving success. Hazard management is about identifying and dealing with these ‘banana skins’.

It is worth noting that there is still no settled usage of basic terms in risk and hazard management literature. Sometimes, the term risk is used in the same sense as the term hazard: to describe a precondition for failure. Sometimes, the interpretation is couched in terms of a likelihood of an event. Techniques for managing risks, therefore, are similarly varied. Sometimes risks are managed through audits, sometimes through risk predictions using risk registers and sometimes through probabilistic reliability calculations. Given these various usages it is very important in any risk exercise to be sure that all parties have a common understanding of the basic terms.

Hazards can exist in the past, present and future. There may have been a potential for failure that has existed for some time and gone unrecognised. Welds are cracked and computer programmes have bugs, but until they manifest themselves they go unrecognised. However those hazards can be foreseen since we know about their possibility. Hazards will also develop in the future and it is these that form the basis for risk assessment.

There are a class of hazards that are not foreseen and hence are almost (but not totally) impossible to deal with and it is these that MARIUN is designed to address (Section 3). For example how could anyone have included BSE in a risk register before the event? The sensitivity of the Millennium Bridge to a critical number of pedestrians was clearly a surprise to the bridge design community and the designers have been unfairly blamed by many people for not identifying this risk before the event (Dallard, Flint, Law and Smith, 2001). An historical example is the Dee Bridge (Sibly and Walker, 1977) where only very much later did we have any understanding of the phenomenon, lateral torsional buckling, that caused the collapse.

An interpretation of risk, that we will use here, is that it is the chance that a particular set of conditions will happen in a stated context. The conditions may be a hazard, an opportunity or neither. Hazards in the past and present have happened and hence are not part of risk – risk is in the future. The problem of risk is that the number of possible futures is infinite – particularly where people are involved. People have a propensity to do the unexpected. Predictions of hard systems risks *within a stated context* can be made using reliability theory. The problem is that often the context is not clearly stated or understood and the hazards in the soft systems in which the hard systems are embedded are not even addressed. Probabilistic analysis is a 'closed world' analysis where all possible futures are identified – that is not how it is in real life. Thus it is essential to see that probabilistic analysis is useful evidence concerning risk but it cannot be the whole picture.

Risk (in the future) is affected by the conditions within which it develops – the hazards. Equally, these conditions may produce success; they affect opportunity – the chance of a successful consequence in a stated context. In this interpretation, risk and opportunity can be thought of as complementary features of expectation (Blockley and Dester, 1999). Clearly we want to avoid hazards and look for opportunities. Thus whilst risk represents the chance of harm it also is basic to the chance of good. Without the taking of risk nothing would ever be achieved. In fact risk taking can be exhilarating as witnessed by dangerous sports. The perception of risk by various sections of the population is a complex subject and beyond the scope of this paper. Nevertheless it is important to understand that perception depends crucially on the context through which it is perceived.

Because the consequences of both failure and success can arise within the same conditions, risk management is as much about being prepared for taking opportunities to deliver benefits (as well as the benefit of managing risk) and adding value to a project as it can be about identifying hazards and managing them away to avoid unexpected failure. This is an aspect of risk management as yet largely unappreciated and is one of the central ways in which Rethinking Construction can bring unforeseen added value to construction clients. In fact, the concept of 'proneness to failure', the capacity (of a process) to develop failure, which is a measure of the *hazard content* of a process (as discussed in the next section), is complemented by the concept of 'the capacity to develop success' which is a measure of the *preparedness content* of a process (Blockley and Dester, 1999). However, here, in outlining MARIUN, the focus is upon the analysis of hazard.

2.4 We Look for Evidence to Justify Decisions

So if BCIOD+R provides a framework to identify integrated processes how do we justify the decisions that we make about them? Decisions about risk must be based on *evidence*. Evidence derives from past performance, present performance and possible future performance. Unfortunately present published guidance on risk management tends to focus almost exclusively upon evidence from analyses of the future and on predictions of chance that particular future scenarios will happen. Such predictions may be based on individual or collective estimates (high, medium, low) or on calculated 'notional' values derived from probabilistic reliability analyses. Of course this is not to say that such predictions are not useful – they force people to look carefully at what might happen – however such a focus tends to take attention away from trends and insights that may be available to identify the unexpected and unforeseen in the present state of the process. Our understanding of the future is necessarily based on extrapolations of past behaviours. As Magee (1973) has so eloquently paraphrased Popper 'just because past futures have been like past pasts does not mean that future futures will be like future pasts'.

Risk registers are an example of a tool which can be very useful when used appropriately but which can pose a considerable threat to the real added value that can be obtained from enlightened risk management. Risk registers require the team to identify what might happen in the future and to develop contingency plans – this is very good. However they can, in the unwary, reduce to a formula driven approach that produces the attitude that once the risk register has been written then the risks are dealt with! This tendency to reduce any activity to an exercise in form filling, as happened with many implementations of QA systems, poses a very real risk to proper risk management.

So how do we manage the uncertainty of unknown risks? Clearly we cannot know what we do not know. However as long ago as 1978 Turner identified that there are regularities in unexpected disasters. The addition to the previous definition of hazard used and the one now used in this paper, following Turner, is that hazard is a set of *incubating* preconditions for failure. Turner argued (Turner and Pidgeon, 1997) that during a period of incubation, events that in retrospect are identified as contributing to disaster accumulate unnoticed. The reasons, he suggested, are varied: possibly rigidity of outlook, dismissal of 'non expert' fears or attention drawn to other problems. There might be a reluctance to fear the worst. It may be that existing rules and regulations are out of date. It may be that there are difficulties in handling information. Conditions such as these are not clearly causal but, from case histories, it can be seen that they form patterns of events that, commonly, occur in failures. The conditions do not form in any particular sequence and do not necessarily trigger failure. The evidence is that they accumulate through mutual interaction and grow to such a level that they form an *accident waiting to happen*. They represent a potential for failure that simply requires a trigger event to cause a disaster. In these terms, cultural and management conditions, for example, have the potential to incubate themselves and other hazards and consequently a process can become increasingly prone to failure.

Understood in this way hazard is a derived property of the state of a process; it represents the potential for an accident waiting to happen. Conversely there is also potential for an opportunity to be taken. Blockley and Dester (1999) have developed this idea through an analogy between mechanics and risky decision making. They have argued that actually it is even more instructive to think of a hazard as a capacity for uncontrolled work in a process and preparedness as a capacity for controlled work. On this view proneness to failure/success is analogous to the power of the hazard/opportunity. The challenge now is to produce a tool that can attempt to help identify and manage these hazards and opportunities.

3 MARIUN

MARIUN (Managing RIsk and Uncertainty) is a tool, developed at the University of Bristol, for life cycle process and product management. It has been designed to help manage hazard (interpreted as an 'accident waiting to happen' – Section 2.4) and risk. Note that the word 'accident' is interpreted very broadly as a failure or unwanted outcome of a process and an 'accident waiting to happen' is a property of the state of a process based on the set of incubating preconditions as identified by Turner (Section 2.4). MARIUN has been designed to be used to help in the management of any type of process (BCIOD or R as described in Section 2.2) in industrial, manufacturing, administrative or financial systems. It can be used from any perspective such as failure of safety, productivity, efficiency or profitability. It is not restricted to use in the construction industry – the ideas and methodology are widely applicable.

MARIUN is based on a systems theory approach that integrates people and process, entirely in line with the ideas of the Rethinking Construction movement (Blockley, Godfrey, 2001) and could also help to deliver the wider goals of that movement.

The purpose of MARIUN is to help the creative thinking of investigators who are searching for evidence of the symptoms of an accident waiting to happen. These symptoms are the complex technical, human and organisational factors that have been found to be important in case studies of technical and business failure. They are far beyond the standard issues covered by a risk register which can cover the foreseeable hazards and risks; the purpose here is to spot *incubating* hazards and risks and hence to manage them. MARIUN is a tool for recognising the 'signs' and for seeking out evidence to assess the proneness to failure of processes within a project. It facilitates a detailed examination of the progress of those processes and is a completely general 'template' for an audit of evidence that can be 'filled in' for specific applications.

In one sense the MARIUN investigators are an audit team and in another a team of detectives searching for evidence and the search must be ingenious – there is a direct analogy with the Popperian version of ingenious testing of scientific hypotheses (Blockley, 1995). The more ingenious and testing is the investigation then the more confident one can be in the eventual success of process. MARIUN is not an automated tick box audit or even a structured questionnaire rather it is a structured set of pointers and questions that investigators can use creatively in their search for evidence. From the evidence concerning the symptoms the investigators and process owners will be able to diagnose decisions and actions that can change the course of a process, avoiding failure and steering the process onwards towards success.

MARIUN is designed to be flexible so that the basic framework may be used in a variety of ways and circumstances. At the simplest level it may be used by an individual managing a small project – it provides a series of prompts and questions to allow the individual to be aware of potential pitfalls. At the most complex level MARIUN can be used by a team investigating a large and complex system such as the entire rail network of the UK.

Thus MARIUN is aimed at situations where a causal path from a hazard to a failure or preparedness to success may not be available. Models of the process may be incomplete, imprecise, ill-defined or involve conflicting data. MARIUN is aimed at what Conklin and Weil (1999) called 'wicked problems' (see also Blockley, Godfrey, 2000). These are problems that do not seem to yield to easy solutions. They have been likened to sorting out a bowl of tangled spaghetti where the more you try the more you get tangled. These problems almost always involve people and they have to be seen as a social process requiring teamwork and practical rigour (Blockley, 2001). The issue here is that some of the techniques and tools that are regularly used for risk management are really not suitable for 'wicked problems' but MARIUN has been designed specifically for them.

Note that the current version of MARIUN was designed to look only for threats. A version of MARIUN to search for opportunities will be the subject of further work.

3.1 Auditing is a Process Control Tool

In order to explain the differences between the methodology behind MARIUN and other audit systems it is worth firstly examining, briefly, commonly used audit tools such as unsafe act and condition audits or the more sophisticated 'management type audits' such as the International Safety Rating System (ISRS) (ICLI, 1988).

Audits for unsafe acts or conditions can be very effective in reducing accident rates (Monk, 1988). They may be regarded as non-specific in the sense that the precise conditions to be examined need not be predetermined or formally documented. These audits comprise systematic relatively frequent inspections of workplaces to identify unsafe acts/conditions and, importantly, there is immediate corrective action. This procedure allows for identification and removal of the type of hazard that triggers an accident or is the immediate cause of failure.

Frequent audits of this type, carried out responsibly, can improve individual attitudes towards safety and corporate safety culture. However, such audits do not assess, directly, the underlying contributing conditions (Kletz, 1988 describes them as causes) of failure such as cultural, management and organisational influences. The hazardous effects of these types of condition can be difficult to identify and predict yet such influences in hindsight have been identified as contributing to failure. For example, it has been implied that poor safety culture was a feature of the Chernobyl nuclear accident (Atom, 1987) and that culture and management practices contributed to the Clapham Junction railway accident (Hidden, 1989). Poor management practices were a feature of the Piper Alpha disaster (Cullen, 1990). A failure to learn (poor knowledge) from past incidents (poor performance) was identified by the Hillsborough football stadium disaster inquiry (Taylor, 1990).

The ISRS does include this type of condition but significantly, as with traditional audits, assessment is linked directly to a state of safety. This means that there is judgement about a straightforward link between a hazard and the potential for failure. Clearly, with unsafe acts/conditions (*e.g.* not using protective equipment, unlashed ladders, faulty switches, unguarded machinery) there are direct and immediate links to a failure state. By contrast, although lack of experience or incompetence can contribute to a failure, the link may not be so obvious or direct because of the complex way through which the effects can spread and influence other process actors. It is particularly difficult to identify causal paths from poor management practice, for example, to an actual failure event. Nevertheless it is clear that these preconditions can and do lead, via very many possible paths, from the preconditions to the failure event. A traditional audit may identify managerial incompetence but other than indicating that corrective action is needed, there is no indication of the extent of the influence; *i.e.* of how hazards emerge within a process. It might be argued that, as is the case with the ISRS, hazards can be rated (given a score) but this still doesn't indicate the extent to which a hazard can affect the different parts of a process. The point is that if a condition is assessed as being directly linked to a failure state there is no evaluation of how it affects other parts of a process.

3.2 The MARIUN Process

MARIUN is applied to a process model and so the first task is to describe a system (*e.g.* a project or a business) as a hierarchy of interacting processes. This has been set out in detail by Blockley and Godfrey (2001) and will not therefore be repeated here. Figure 1a illustrates the process hierarchy with top process P1. The immediate sub-processes P11, P12, P13 etc. will be BCIOD+R processes of P1. Further levels of sub-processes are developed from these and so on to an appropriate level to stop. Figure 1b shows part of a very specific high level example of a water plc which would be of interest in the Board Room. Figure 1c shows a much lower level more detailed example for the design of part of a specific asset such as a building.

Using the MARIUN tool an audit team sets out, at appropriate intervals through the life of a project, to assess the changing 'proneness to failure' of that project. This is a measure of

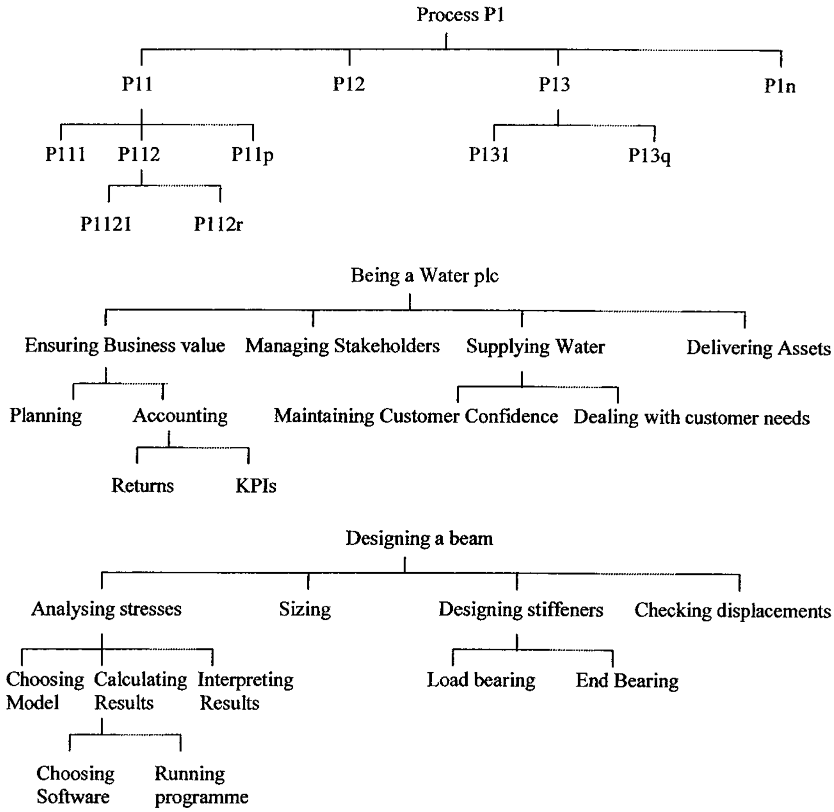

FIGURE 1 (a) Typical hierarchical representation of a process and sub-processes. (b) Typical (partial) hierarchical representation of a process and sub-processes (high level). (c) Typical (partial) hierarchical representation of a process and sub-processes (lower level).

the hazard content of a project process – it is the power of the uncontrolled potential of an 'accident waiting to happen'. The audit team is chosen as appropriate for a given situation. Thus they may be internal to a company but independent from the particular project in a self-checking audit or alternatively they may be completely external and independent. The depth and detail of an audit is easily chosen within the MARIUN framework according to need. Thus an audit can be tailored to the importance and scope of a project with smaller and simpler audits for less important projects but very full and detailed audits for very large and important projects. A full and complete audit would require every process to be examined and would require considerable resource.

The auditors examine six attributes of a process. They are:

- issues to be resolved;
- control;
- knowledge;
- performance;
- sub-processes;
- environment.

The auditors use a hierarchical model of sub-attributes of each of these attributes (*e.g.* Figs. 2 and 3) to help them to identify and evaluate the build up of hazard throughout a process. It is worth noting that by this means the evaluation incorporates the effects of

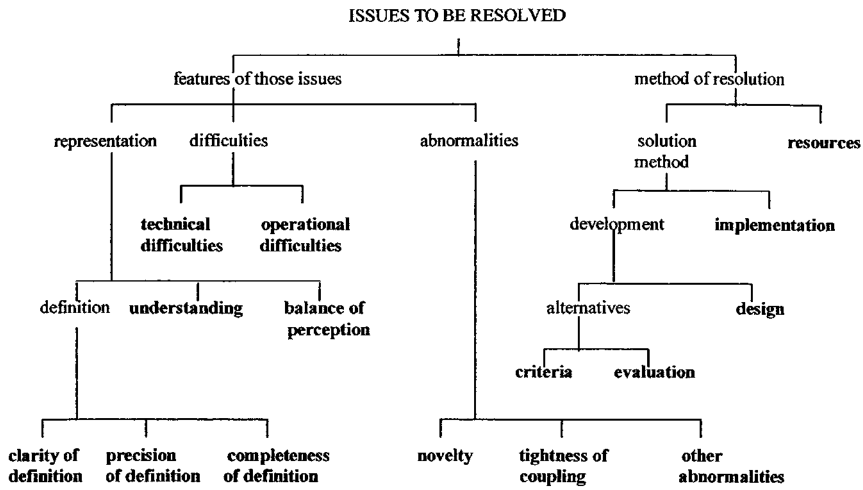

FIGURE 2 Hierarchical Model of the Attribute: *Issues to be resolved* (**bold** font indicates elemental sub-attributes).

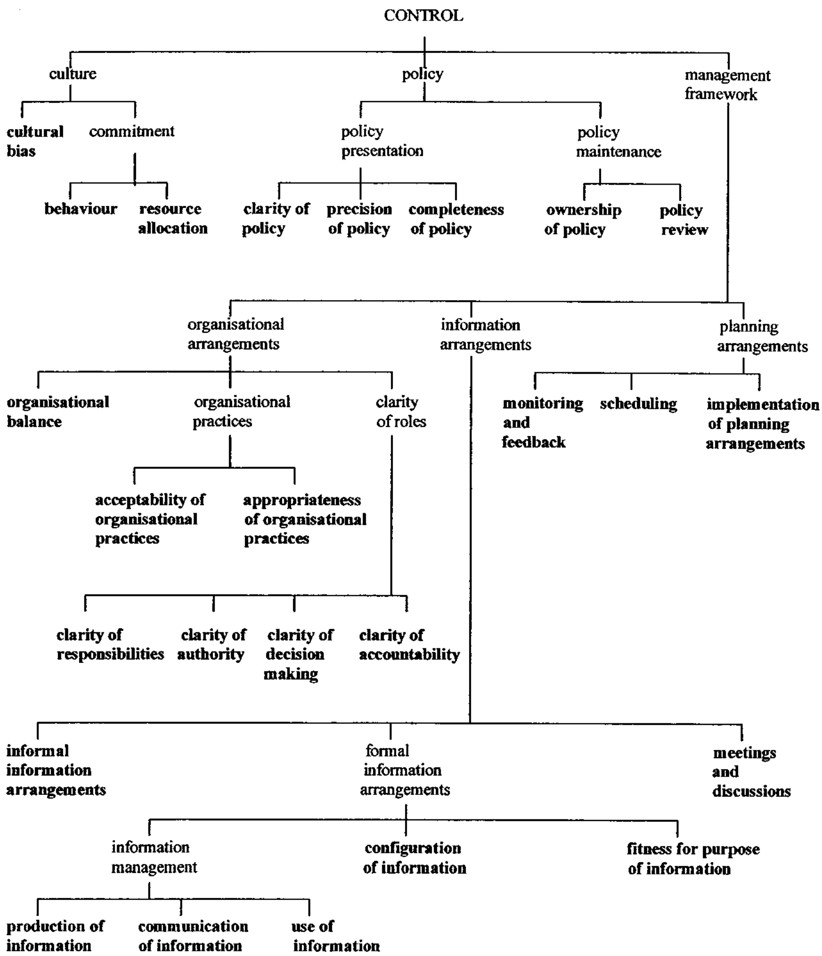

FIGURE 3 Hierarchical Model of the Attribute Control (**bold** font indicates elements sub-attributes).

interdependencies that are often ignored or presumed to be exclusive or independent in other audits. Again the auditors may not assess every sub-attribute in the hierarchical models but may choose to dig as deeply as is deemed appropriate. The hierarchy is not intended as a rigid 'recipe' but a guide for asking questions.

Issues to be resolved: Clearly there are always issues to be resolved from the start to the end of any process. The auditor looks for evidence of the extent to which difficulties in identifying and tackling these issues is a threat to the eventual success of the process. Figure 2 shows the hierarchical model of sub-attributes. Thus at the first level down from the top, *the features of these issues* and the *method of resolution* are two key ingredients. Likewise the *features* depend on the way the *features are represented* within the process, the *difficulties* being faced and any *abnormalities*. The figure shows a further breakdown to elemental sub-attributes (ones that are not broken down any further) as shown in bold such as, for example, **clarity of definition** and **tightness of coupling** (this is a concept introduced by Perrow (1984).

TABLE I Assessment Pro-forma for **Clarity of Definition** for the Attribute: *Issues to be Resolved*.

4.1.1 **Clarity of definition**
1 How much evidence is there that issues are not defined sufficiently clearly?
2 What is your level of confidence in the assessment?
Decide the amount of evidence from the left hand column (A) then tick one of the boxes to indicate your level of confidence (B) in that assessment.
e.g. If the amount of evidence is 'none' and you have 'complete' confidence you should tick the top left hand box.

Amount of evidence (A)	*Confidence level (B)*					
	Complete	*High*	*Moderate*	*Low*	*Very low*	*None*
None						
Very little						
A little						
Some						
Quite a lot of						
Considerable						
Complete						
Don't know						

Assessment criteria:
Assess only clarity of definition as it presented; i.e. do not make assumptions about what is meant and do not judge the detail or completeness of definition since these are covered by items 4.1.2 (precision) and 4.1.3 (completeness).
Examples of questions to be put to process actors, owners, customers and stakeholders:
Do descriptions of issues conform to accepted, established standards of clarity? These standards may be traditional or prescribed through regulation and codes of practice; the appropriateness of established standards should be allowed for in the assessment; i.e. if established standards are felt by the assessor to be inappropriate this should be inclusive to the assessment, and a note made under 'auditors comments' that assessment is of the clarity that is warranted and not what is prescribed.
Other considerations of an assessment:
Is there ambiguity about the issues or the potential for ambiguity?
Poor clarity of definition of issues may result from (for example):
deletions, insertions, muddled or cluttered information,
poor grammar or spelling or confusion of similar words or phrases,
conflicting statements, over elaborate descriptions.
Auditor's comments:

Associated with each of these elemental sub-attributes are questions that will draw out the evidence that there may be a problem. For example Table I shows a pro-forma containing the questions, an assessment table and some guidance on assessment criteria for **clarity of definition** (of an *issue to be resolved*). There is also space on the form for the auditor to comment. Clearly the auditor is trying to assess whether the issues have been defined clearly and whether this state of affairs provides any evidence that the success of the process is under threat for that reason. Likewise Table II shows the assessment form for the elemental issue of **balance of perception**. Here the auditor is looking for possible ways in which the various players in the process perceive the issues to be resolved. If there is a significant difference in this then this may evidence of a possible threat to the success of the process.

For example, a common *issue to be resolved* is that the various specialist teams within a project focus on their own priorities (*e.g.* cost, time) without regard to the way their priorities interact with others to form risks to the overall success of the whole project.

As stated above it is not necessary in any given audit to develop answers to questions at every level in the hierarchy of Figure 2. In the simplest of exercises the auditors may merely assess the top level questions about *issues to be resolved* without any detailed examination of the sub-attributes. For another audit of a more detailed kind they may decide to go down to

TABLE II Assessment Pro-forma for **Balance of Perception** for the Attribute: *Issues to be Resolved*.

4.1.5 **Balance of perception**
1 How much evidence is there of imbalance in perceptions of issues?
2 What is your level of confidence in the assessment?
Decide the amount of evidence from the left hand column (A) then tick one of the boxes to indicate your level of confidence (B) in that assessment.
e.g. If the amount of evidence is 'none' and you have 'complete' confidence you should tick the top left hand box.

Amount of evidence (A)	*Confidence level (B)*					
	Complete	*High*	*Moderate*	*Low*	*Very low*	*None*
None						
Very little						
A little						
Some						
Quite a lot of						
Considerable						
Complete						
Don't know						

Assessment criteria:
Inevitably perceptions differ but in resolving issues, different perceptions need to be balanced. Judge whether any imbalance in perceptions are inappropriate.
Question:
Are there fundamental differences in perceptions about: understanding or significance of issues and alternative solutions, relative priorities or difficulties?
Is there evidence of:
dogmatism?
blinkeredness (i.e. closed minds)?
mind-set?
Auditor's comments:

assessments at the second or third levels. For extremely detailed and important audits they may indeed decide to develop the MARIUN hierarchy even further than that shown in Figure 2 for a specialist application. Initial assessments of hazard in each of the elemental (bottom level) sub-attributes are judged as evidence of hazard in the higher level sub-attributes with which they are linked. It is important that at each level the auditor thinks about judgements made at the lower levels and how each one (a child) is necessary for the assessment of the one above (parent). In this way a balanced view of the whole as well as the parts is maintained and the complex interdependencies judged at an appropriate level of detail. There is clearly a danger of 'double counting' in the separate judgements but the hierarchy and the use of assessment pro-forma helps to make sure this does not happen.

Control: Control is necessary for initiation, motivation, commitment and sustainability. It is evaluated in the same way but using Figure 3 and a set of pro forma for the elemental bottom level sub-attributes of Figure 3. Control of a process is split into culture, policy and management framework. This model is larger than that for *issues to be resolved* and elemental issues include **appropriateness of organisational practices, informal information arrangements** and **monitoring and feedback**. The assessments are made in exactly the same way as described for *issues to be resolved*.

Knowledge (including products and methods): The knowledge and information being used within a process is obviously crucially important. There is insufficient space here to include the hierarchical development of this but sub-attributes include dependability and applicability of the knowledge being used as well as the capabilities of those who are using it.

Performance: Performance is assessed by examining the past, present and projected future performance of the process. It includes any near misses, accidents, expressed concerns, incidents as well as QA and risk management systems.

Sub-processes: The success of every process depends upon the success of sub processes that may be necessary or sufficient. The auditor builds up a picture of the evidence by using assessments of sub processes and bringing them into considerations concerning the evidence for the process concerned.

Environment: A process does not exist in isolation – it is embedded in a context or meta-system. There are often issues for which it is unclear whether they should or should not be included in the management of the process. This is particularly critical if there are differences in perception between players in the process. Pugsley (1969) referred to the climatology of accidents and these factors are some of the assessments within this group of sub-attributes.

3.3 Guidance on Making the Judgements Required to Use MARIUN

In order to describe the way in which the method works the following is an edited extract from Chapter 2 of the MARIUN Manual 'Assessing the Evidence Qualitatively; Guidance on Making the Judgements required to use MARIUN'.

Start of Extract from Chapter 2

2.1 Remember you are examining a particular process, the *current process*, so be sure to be clear what it is and *name* it.

2.2 Be clear about the level of description at which you are working in the process hierarchy. Call it the *current process level*. Keep a record of the process hierarchy handy to remind you. Be careful not to slip into thinking about some devolved part of the current process (*i.e.* a sub-process) that should be considered in a separate examination.

Now you will examine each attribute of the current process *i.e. issues to be resolved, control, knowledge, performance, sub-processes* and *environment*. Each attribute has a set of sub-attributes (*e.g.* Figs. 2 and 3). Each sub-attribute – each entry in the hierarchy – prompts you to ask various questions of the condition or situation within a process. The answers help you to judge the evidence of hazard and the confidence you have in that judgement.

2.3 As indicated in paragraph 2.2 you start by identifying the *issues to be resolved* in the current process. Consider, the 'who, what, why, where, when and how' attributes of process. Try to identify as many of them as seems appropriate – but at least the following:
– a set of *Roles* (including the *Process Owner Role)*;
– each taken by a *Player*;
– with a particular *Worldview.*

2.4 Recognise that we perceive each process and each attribute through a model of that process which is filtered through our own worldview. The methodology of MARIUN requires us to reflect on our model by asking and answering some basic questions and then deciding how to act.

2.5 Such questions are:
Example For *Role:* Is there a process owner?
Are the roles well defined?
Is the client role clear?
Example For *Objectives:* Are the objectives clear?
Example For *Stake holders:* Are stakeholders being managed effectively?

2.6 You may now have a set of *issues to be resolved* which may threaten the success of the current process. (Note that the choice of an *issue to be resolved* is not limited to the factors in Figure 2 and your thinking should not be limited to that list.)

2.7 Consider the set of *issues to be resolved*. You will now assess the evidence of hazard in the elemental sub-attributes as shown in **bold** type in Figure 2. Your assessment is guided by a pro-forma (*e.g.* Tabs. I and II). There is a separate pro-forma for each bottom level sub-attribute. As well as setting out criteria for assessment of hazard, each pro-forma provides a space for 'auditor's comments': for recording reasons for a particular assessment and any suggestions for changes to the assessment criteria. This provides for credible comparisons between assessments at different times and for continuing refinement of criteria. You are asked to assess for each sub-attribute shown in bold:

1. the evidence of hazard (threat to the success of the process) on the scale: *none*, *very little*, *a little*, *some*, *quite a lot of*, *considerable* and *complete*,
2. your level of confidence in this judgement on the scale: *complete*, *high*, *moderate*, *low*, *very low* and *none*.

Think of the possible hazard in terms of:

a) *Grounding*

Be clear about the basis on which you believe the process will be successful (*i.e.* achieve fitness for purpose with respect to an issue) – usually this grounding is *dependability.*

Example Is the clarity of definition dependable?
Example Is the design of the solution method dependable?

b) *Specification*

Consider how *appropriate/accurate* the process is for its purpose
Is the level *of detail* appropriate?
Is the level of *discrimination* appropriate?
Are the models *applicable*, *relevant*?
Be clear about the *extent i.e.* limits and bounds of the model of the process and that they are appropriate

Example Is the clarity specified appropriately?
Example Is the solution method specified appropriately?
Example Is the clarity specified with appropriate limits?
Example Are the boundaries of the solution method specified appropriately?

c) *Quality*

Be clear about the ways in which quality (Elms, 1997) is delivered such as:

Balance
Has a balanced consideration been given to all aspects of the issues?
Example Is there a lot of effort and thought being put into some aspects but much less effort into other equally important aspects?

Consistency
Are the considerations made in a consistent way?
Example Is chalk unwittingly being compared with cheese?

Completeness
Is anything important missing?
Example Are human factors being considered adequately?

Cohesion
Are there any faults?

d) *Form*

Is the generic nature of the model of this issue (its essence) appropriate? Think about the level of abstraction, the language used (*e.g.* natural language such as English or a formal language such as mathematics) and how the parts fit together *i.e.* the connectivity of the elements of the model.

2.8 Remember you are thinking about whether the conditions you perceive in the process represent a threat to the success of the process with respect to that sub-attribute. Use the pro-formas but do not allow them to constrain your thinking. You may feel that some of the criteria are not relevant and some others are missing. Record your judgements on the pro-formas and write down your reasons in the space provided for comments.

2.9 You should now have judged the level of evidence of threat as stated in paragraph 2.7 that reflects your judgement of the state of the hazard content of the current process with respect to each elemental sub-attribute shown in bold. This evidence relates only to the attributes of the *issues to be resolved* that you have been thinking about. Check you have written the judgement on the appropriate form.

2.10 Your analysis now proceeds through a step-by-step analysis working up through the hierarchy and making judgements of the evidence of hazard and your confidence level. Thus in Figure 2, judgements of **clarity of definition** together with judgements of precision **of**

definition and **completeness of definition** allow a judgement of *definition*. The hierarchy is intended as a guide to the thinking through of the evidence for hazard about the condition *issues to be resolved*. Notice also that properties may emerge in higher level processes because of the interactions between the lower level processes. Thus the evidence for the state *definition* may involve more than the simple summation of the lower three states.

2.11 *Example* Imagine you have assessed elemental sub-attributes of *issues to be resolved* in Figure 2 as:

– *a little* evidence that issues are not defined sufficiently *clearly* with *complete* confidence;
– *a little* evidence that issues are not defined sufficiently *precisely* with *high* confidence;
– *very little* evidence that issues are not defined sufficiently *completely* with *high* confidence.

Then you may decide to judge that the evidence *of poor definition* (see in Fig. 2 this is the next level up in the hierarchy) is:

a little to some with *high* confidence.

Thus by progressive analysis you evaluate the hazard content of each condition (sub-attribute) throughout the hierarchy.

Note that any tendency to average amounts of evidence must be avoided because, for example, poor 'definition' is not an average of poor **clarity of definition**, **precision of definition** and **completeness of definition**. It may be helpful first to consider how much evidence each condition is separately of the higher level condition and then to accumulate the evidence of each condition. Also note that the effects of inter-dependencies amongst conditions (*e.g.* clarity, precision and completeness–Fig. 2) are inherent to judgements about their collective significance as evidence of a higher level condition (*i.e.* definition–Fig. 2).

Confidence does not accumulate. Rather, it is a balance between relative levels of confidence in different assessments and the relative significance of evidence.

2.12 You should now have a judgement (*i.e.* an assessment of hazard content) on your first attribute, *issues to be resolved*, with respect to the current process.

2.13 Now you should repeat the procedure from paragraphs 2.7 to 2.12 for each of the following attributes of *control, knowledge, performance, environment* and *sub-processes*. This is guided by the appropriate hierarchical model, such as Fig. 3 for control, and assessment pro-forma for elemental sub-attributes. Again, although guided by models and documented criteria, there should be constant reflection. Paragraphs 2.14–2.18 illustrate some of the questions that might be relevant.

2.14 Is there adequate and appropriate *control* of the process?

Example Is there an appropriate culture?
Is there an appropriate policy?
Are all players accountable?
Is the end/beginning to the process understood?
Is success defined and understood?
Are costs defined and understood and controlled?
Are consequences of actions being controlled?

2.15 Do the players in the process have appropriate *knowledge*?

Example Is there sufficient technical knowledge?
Are the regulations understood?
Can they be implemented?
Are the *products* used in the process acceptable?

Example Has equipment performance been specified clearly?
Have materials been properly tested?
Is computer software dependable?
Are the *methods* used in process implementation applicable?

Example Are design methods relevant?
Are working methods practicable?

2.16 Is the *performance* good enough?

Example Is the safety record acceptable?
Have incidents been investigated?
Is the risk analysis appropriate?

2.17 Do the *sub-processes* that have been delegated to another role represent a hazard to the current process? Evidence for this will be obtained from a previous examination of sub-processes.

Example Have the sub-processes been clearly understood?
Has the delegation worked?
Is there appropriate accountability?

2.18 Is the *environment* of the process having an influence?

Example Are there undue pressures of a financial, political, environmental or professional kind that are a hazard to the current process?

Example Does the process affect other processes?

2.19 Now consider all aspects of the process that you have examined so far (*i.e. issues to be resolved*, *control*, *knowledge*, *performance*, *sub-processes* and *environment*) to come to an overall judgement about the threat – the hazard content – to the success of the current process.

Note: This method of analysing hazard content is more than just a structured list of characteristics linked to potential failure. It enables an:
- assessment of the total hazard content;
- assessment of relative levels of hazard content;
- identification of potential vulnerabilities;
- identification and assessment of uncertainty.

2.20 Now proceed to the next process/sub-process in your process hierarchy and repeat the above procedure.

End of edited Extract from Chapter 2 of the MARIUN Manual

3.4 Diagnosing Action and the Benefits of Using MARIUN

Figure 4 shows an example of how evidence may be collected for *issues to be resolved*. MARIUN is not a predictive tool but is rather a structured guide to an ingenious test (analogous to a Popperian view of the progress of science) or audit examination (Section 3). The confidence in the conclusions depends on the extent and thoroughness of the testing examination. Thus MARIUN investigators will try to test as *ingeniously* as possible within an

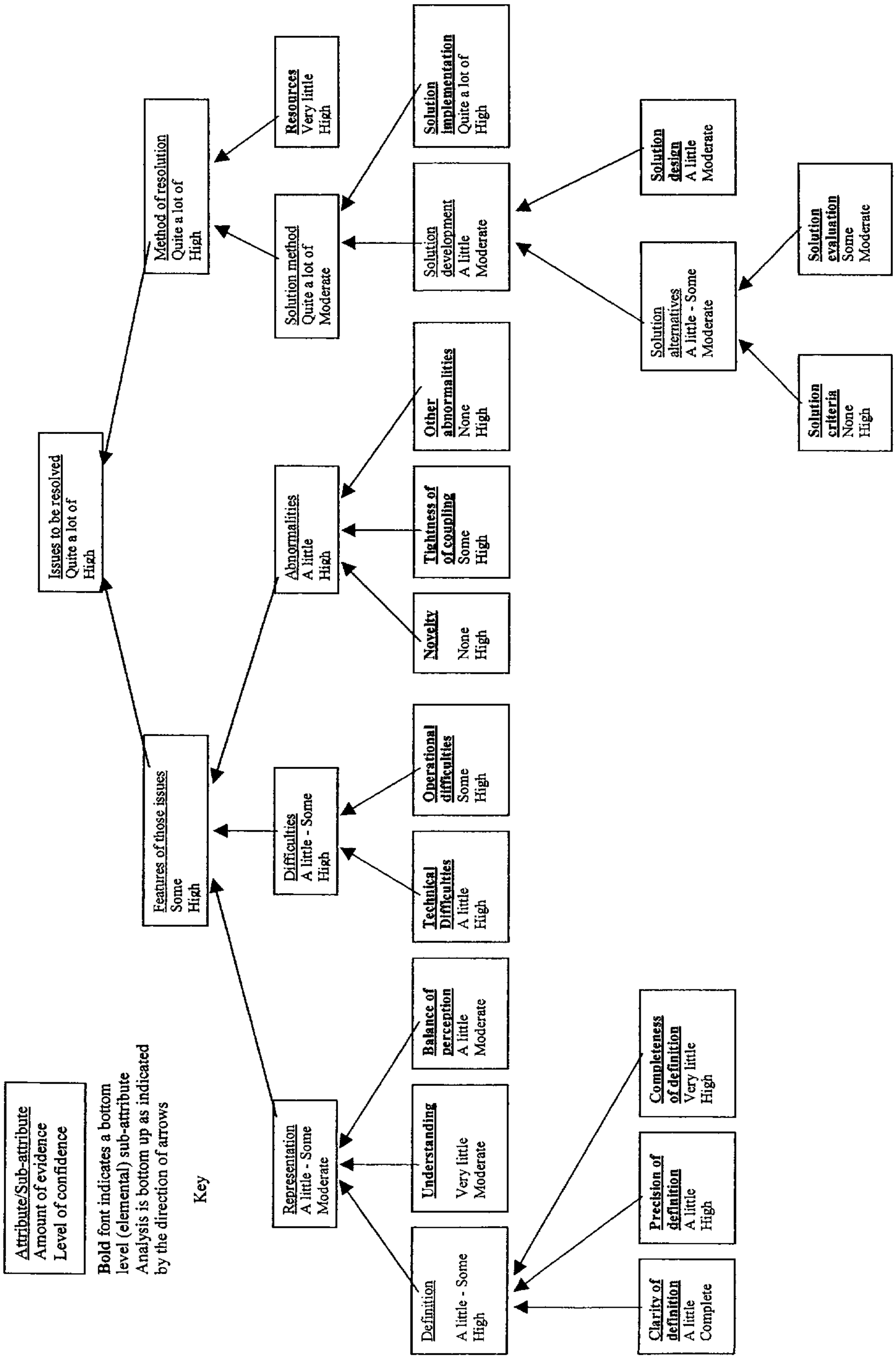

FIGURE 4 An analysis of the evidence of hazard in the attribute: *issues to be resolved*.

appropriate level of resource the hazard content of a process by collecting evidence from past and present performance and from risk predictions.

The audit team will use Forms – examples of which are Tables I and II about two of the sub-attributes in Figure 2. There are a total of 81 such forms in the present version of MARIUN covering the elemental sub-attributes of issues to be resolved, control, knowledge, performance and environment. The auditors use the prompts and questions to search for evidence and to come to judgements as shown in Figure 4. These judgements are collected and assimilated together as in Figure 4. The process is bottom up in that evidence is collected about low level attributes which feed into judgements about the higher level attributes.

The top level conclusion shown in Figure 4 is interpreted as: "there is 'Quite a lot of' evidence with 'High' confidence that the process under audit may fail because the issues to be resolved are not being addressed adequately. This result, and the underlying reasons will then be brought together with results for all of the attributes (control, knowledge etc) to form a judgement about the 'whole' process. Then in turn those results will be combined with those for the other processes (as shown in Fig. 1) to form judgements about higher level processes. The auditors will have detailed notes regarding all of the factors that led them to their conclusions (*e.g.* from Fig. 2). This will allow them to discuss with other investigators and the process teams (those actually responsible for steering the process to success) to diagnose what actions are needed. In this way clear evidence of an accident waiting to happen will be revealed and required actions diagnosed and communicated to others and made available for individual and corporate learning.

Of course one potential criticism is that different investigators may produce different judgements. Almost certainly the investigators will be examining unmeasured characteristics and so must use judgement. However MARIUN facilitates a structured examination that allows the audit team to share their judgements with each other, to discuss them to look at them from various points of view and in this way to make their subjective judgements objective in the way discussed by Blockley (1980, 2001) Blockley Godfrey (2001). The individual judgements and opinions will be tested within a process by critical discussion and observation. Ultimately MARIUN can only be tested by the effect it has in reducing, or not, the occurrence of unexpected events in practice. Judgements about effectiveness may, of course, be influenced by any observed changes in quality and productivity.

The benefits of this approach are that the evidence will help decision makers understand the uncertainty in the hazards and risks they are managing. This will allow them to make informed decisions that will help them steer their processes to success. Of course the residual risk of some phenomena previously unknown is still present because one cannot know what one does not know. These 'totally out of the blue' failures are actually very rare as has been shown by Turner (Turner and Pidgeon, 1997).

Repeated use of the methodology will encourage a learning approach to project and process management and the documented audit will allow lessons to be shared within a company and project for corporate learning. In this sense MARIUN has the potential to be a learning tool at all levels in an organisation from operative to Boardroom. It is an entirely appropriate vehicle for rethinking Construction.

3.5 MARIUN is a Flexible Prototype and Needs Testing

MARIUN presently is a prototype of a unique tool aimed at particularly difficult situations and has been designed after extensive study by engineers and social scientists into why major disasters happen. There are patterns of development but, as discussed in section 3, causal links can be difficult to identify even though the hazards, themselves, may be apparent to some people on the project. Unfortunately, this knowledge can be rejected or overridden by other considerations. For example 'We are here to build a railway, not to get involved in these time wasting 'soft' issues'. Specialists quite naturally and properly focus on their roles in a process but it is also essential that they are aware of the dangers and missed opportunities if there is insufficient attention given to integrating with others. The modelling in MARIUN is purposely generic so that the judgements of different specialists can be more easily integrated.

MARIUN is flexible so that it can be used simply and quickly on 'normal' projects but will be able to detect when there is a 'build up' of difficulties that then justify much more detailed examinations. At its simplest MARIUN can be reduced to a series of questions that all involved in construction projects should ask themselves. At its most detailed MARIUN facilitates a deep search of many factors within project processes. It is currently paper based and has been tested only in very simple situations so it has yet to be exhaustively field-tested. Assessments can be made qualitatively as described in this paper or they can be made quantitatively using interval probability theory (Cui and Blockley, 1990) with Italian Flags (Blockley and Godfrey, 2000) as colourful indicators. However great care has to be used in interpreting the interval probability mathematics and there is a risk that users will become overly reliant on the calculus. However the calculus can bring great benefit in maintaining the rigour of the audit development. The skill and experience of the audit team is a necessary requirement for successful exploitation of the tool.

MARIUN is ready to be developed to a stage where it can be adopted for simple audits. It is apparent that auditors will need some significant training to be able to use it for more extensive audits and that a computer based tool will be required.

4 CONCLUDING COMMENTS AND SUMMARY OF MAIN POINTS

1. The rethinking construction movement is gathering pace. Within this change there are significant opportunities for adding value to all involved, especially clients, by improving the management of risk and uncertainty.
2. Two neglected aspects of risk management are highlighted as having the potential to provide significant opportunities for adding value. They are:
   - managing 'whole' risk by improved processes for integrating risks as derived from within specialist processes (*e.g.* safety and financial risk processes);
   - developing better ways of dealing with unexpected and unforeseen risks.
3. Process modelling as described by Blockley, Godfrey (2000) is the basis for improvement. 'Whole' quality is provided by thinking through BCIOD+R processes.
4. Current tools for risk management such as risk registers are very useful if used properly. However they present a risk to proper risk management if they degenerate into form filling exercises.
5. The terminology of risk management has not settled and people still use the basic terms differently. It is crucially important that all parties to a particular project agree definitions for the terms they use.
6. Here hazards are defined as sets of pre-conditions to a failure that incubate. Almost no failures happen 'out of the blue'. The incubation process enables patterns of development of accidents and disasters to be identified before they happen.

7. There are currently no tools to help identify those patterns. MARIUN is a prototype tool developed for this purpose and is, as yet, untested.
8. MARIUN is tool to facilitate an ingenious test, examination or audit of the progress of a process. MARIUN is a structured investigation to help auditors look for evidence of incubating hazard. Assessment is grouped around six attributes: Issues to be Resolved, Control, Knowledge, Performance, Sub-Processes and Environment. The tool is not predictive rather it is used to facilitate a creative search for evidence which can then be used to diagnose action to steer a process to success.

References

Atom (1987). Ministerial statement on the Sizewell B nuclear power station. *Atom*, **36**, 367.

Blockley, D. I. (1995). A personal tribute to Sir Karl Popper. *J. Civ. Eng. Systems*, **12**, 179–180.

Blockley, D. I. (1999). Risk based structural safety in context. *J. Struct. Safety*, **21**(4), 335–348.

Blockley, D. I. (2001). Thinking out of the box. *Structural Engineer*, **79**(20), 22–29.

Blockley, D. I. and Godfrey, P. S. (2000). *Doing it Diferently.* Thomas Telford, London.

Blockley, D. I. and Dester, W. S. (1999). Hazard and energy in risky decisions. *J. Civ. Eng. Environ. Systems*, **16**(4), 315–337.

Conklin, E. J. and Well, W. (1999). Wicked problems, naming the pain in organizations. http://wwwgdss.com/wicked.htm.

Cui, W. C. and Blockley, D. I. (1990). Interval probability for evidential support *Int. J. Int. Systems 5*, Part 2, 183–192.

Cullen, W. G. (1990). The public inquiry into the piper alpha disaster, Report by the Rt Hon Lord Cullen, HMSO, London, UK.

Dallard, P., Flint, A., Law, R. A. and Smith, R. (2001). The millennium bridge, London: Problems and solutions. *The Structural Engineer*, **79**(8), 15–17.

DETR (1998). Rethinking construction, London (the Egan Report).

Elms, D. G. (1997). System health approaches for risk management and design. *Proc. ICOSSAR '97*, Kyoto, Japan.

Hall, J., Cruickshank, I. and Godfrey, P. S. (2001). Software supported risk management for the construction industry. *Proc. Inst. Civ. Engrs.*, **144**, 42–48.

HSE (1999). *Reducing Risks, Protecting People.* HSE Books, London.

Hidden, A. (1989). *Investigation into the Clapham Junction Railway Accident.* HMSO, London, UK.

ILCI (1988). *International Safety Rating System.* Institute Publishing (Division of International Loss Control Institute), Loganville, GA, USA.

Kletz, T. A. (1988). *Learning from Accidents in Industry.* Butterworths, London, UK.

Lownds, S. (1998). Fast track to change on the heathrow express. Inst. Personnel and Development, London.

Magee, B. (1973). *Popper.* Fontana Modern masters, London.

Monk, D. (1988). The fine art of safety audits. *Chemical Engineering Progress*, **84**(9), 34–37.

Perrow, C. (1984). *Normal Accidents.* Basic Books, New York.

Pugsley, A. G. (1969). The engineering climatology of structural accidents. *Int. Conf. Struct. Safety and Reliability*, (ICOSSAR '69), Washington, pp. 335–340.

Sibly, P. G. and Walker, A. C. (1977). Structural accidents and their causes. *Proc. Instn. Civ. Engrs.*, Part 2, **62**, 191–208.

Taylor, P. (1990). The Hillsborough stadium disaster. Inquiry by the Rt Hon Lord Justice Taylor, *Final Report*, HMSO, London, UK.

Turner, B. A. and Pidgeon, N. P. (1997). *Man Made Disasters*, 2nd Edn. Butterworth Heinneman, Oxford, UK.