Towards a framework for project risk knowledge management in the construction supply chain

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Abstract

The shortcomings of current project risk management processes, tools and techniques, are identified and the case for the application of knowledge management philosophies and techniques to project risk management is made. A common language for describing risks based on a hierarchical-risk breakdown structure has been developed and it provides the basis for developing a sharable knowledge-driven approach to risk management. This defines generic risk and remedial action descriptive terms, which can then be stored in catalogues. These have been implemented in a database management system to act as a knowledge repository. A prototype system being developed to support the risk management framework is briefly discussed. © 2001 Civil-Comp Ltd and Elsevier Science Ltd. All rights reserved.

Keywords: IDEF0; Object modelling; Project risk analysis and management; Qualitative risk assessment; UML

1. Introduction

The construction industry still suffers from poor project performance due to risks, despite attracting a lot of attention in the literature [1–3]. With the increasingly complex and dynamic nature of projects coupled with new procurement methods, the tendency today is to use risk quantification and modelling more as vehicles to promote communication, team work, and risk response planning amongst multi-disciplinary project team members. However, communication of construction project risks is poor, incomplete, and inconsistent throughout the construction supply chain. Project team members adopt different terminology for describing risks, use different methods and techniques for dealing with risk analysis and management, producing different and conflicting results. Where risks have been identified, assessed and remedial measures agreed, these are not generally effectively communicated throughout the supply chain. Consequently, project members do not have a shared understanding of issues facing the project, are not able to implement effective early warning systems and contingency plans to adequately deal with problems resulting from decisions taken elsewhere in the chain. Furthermore, the proliferation of techniques and software packages purporting to provide project risk management facilities, have failed to meet the needs of project managers. These systems are primarily founded on principles and methodologies derived from operational research developed in the 50s. The focus is on quantitative risk analysis based on estimating probabilities and probability distributions for time and cost risk analysis. These techniques do not encourage project participants to develop in-depth understanding of the underlying elements and structures which constitute project risk systems and render explicit latent concepts and assumptions which are implicit in current risk assessments. Furthermore, they do not allow the risks, problems, remedial measures, and lessons learned from previous projects to be captured and re-used when developing new projects, thus facilitating organisational continuous learning and improvement.

The work presented in this paper is part of a larger project aimed at developing a comprehensive and continuous risk management framework capable of enhancing the probability of project success, and to lead the industry to establish practices that are self-sustaining and continuously improving, grounded in effective continuous knowledge capture, re-use and learning. The objectives are: to develop a common language for describing risks throughout the construction supply chain and covering the complete construction project lifecycle; to develop a risk management paradigm involving identification, classification, assessment, analyses, action planning, tracking, control, and communication of risks on a continuous and proactive

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basis using the common language; and to develop tools using knowledge-based systems techniques to support the framework. In this paper, the shortcomings of current project risk management processes, tools and techniques, are identified and the case for the application of knowledge management philosophies and techniques to project risk management is made. A common language for describing risks based on a hierarchical-risk breakdown structure has been developed and it provides the basis for developing a sharable knowledge-driven approach to risk management. These have been implemented in a database management system to act as a knowledge repository. A prototype system, developed to support the risk management framework is briefly discussed. It is hoped that the approach will facilitate effective risk handling, whilst allowing all project participants to develop a shared understanding of project risks resulting in improved performance.

2. The case for project risk knowledge management

In this section, we examine current project risk management processes, tools and techniques, identifying several shortcomings which can be addressed using intelligent and knowledge-based systems techniques. An extensive literature review was undertaken to achieve this and the results are presented under the following key areas: identification and communication; measurement and quantification; and organisation.

2.1. Identification and communication

The literature indicates that much focus has been on quantitative risk analysis based on estimating probabilities and probability distributions for time and cost risk analysis. With the increasingly complex and dynamic nature of projects coupled with new procurement methods, the tendency today is to use risk quantification and modelling more as vehicles to promote communication, team work, and risk response planning amongst multi-disciplinary project team members. However, communication of construction project risks is poor, incomplete, and inconsistent throughout the construction supply chain. Risk management tends to be conducted on an ad hoc basis and is dependent on the experience and risk orientation of individual key project participants within the industry supply chain. The individual parties involved in a project adopt different terminology for describing risks, use different methods and techniques for dealing with risk analysis and management, producing different and conflicting results. Where risks have been identified, assessed and remedial measures agreed, they are not generally effectively communicated throughout the supply chain. Consequently, project participants do not have a shared understanding of issues facing the project, are not able to implement effective early warning systems and contingency plans to adequately deal with problems resulting from decisions taken else-

where in the chain. This is due to a lack of a common language for identification, assessment, quantifying, and pricing of risks. Clearly, the success of projects is very much dependent on the extent to which the risks involved can be measured, understood, reported, communicated and allocated to the appropriate parties. It is argued that the development of a common language for describing project risks will lead to consistencies in communicating risks allowing all project team members to develop a shared understanding of risks and interdependencies within risk chains. The inter-dependencies may be better-represented and understood through risk cause-effect mapping using a visual modelling language. This should lead team members to develop and share a common explicit understanding of the behaviour of the underlying risk structures influencing project outcomes.

Project communication systems must be built upon common terminology, standard descriptions, defined metrics for measurement and consistent knowledge of processes and procedures. Current applications, which claim to improve communication efforts, do not define the framework in which managers and their teams should develop, sequence, co-ordinate or route project information. What is needed is a means of standardising and organising project management efforts through a framework that gives individual managers, project managers and their teams the methodology and structure required to support project management.

2.2. Measurement and quantification

Risk analysis and management has attracted a lot of attention in the literature with more coverage on quantitative methods of analysis. A recent survey of the risk analysis packages currently used in industry in the United Kingdom showed that most of these packages use probabilistic methods to quantify uncertainty [4]. The case of risk assessment and uncertainty has attracted a lot of consideration in risk analysis literature. Views range from those who consider uncertainty as not being exogenous to risk [5], and imply, therefore, that projects for which there is enough experience can be considered as not being risky at all, to the prevailing view that considers uncertainty as being necessarily fraught with risk [6–11]. If it is accepted that uncertainty leads to risk, then this poses two issues: first, how to incorporate the uncertainty about initial predictions in the risk model and second, how to cater for the inherent subjectivity that comes with the predictions. The first issue appears to be addressed by using probability distributions to express the uncertainty in predictions and it is far from certain that this works satisfactorily, but how does one address the second issue — the handling of subjective information?

Evidence from the literature suggests that current software packages do not handle the inherent subjectivity in risk assessment effectively. The assessment of what is or what is not a risk is highly subjective and the decisions

taken are influenced by management's view of the future, and their desire to avoid poor performance, based on knowledge from past experiences. The decisions are based on a large number of factors. Many of these factors are not well defined and are not easy to quantify even though judgmental and heuristic rules can be used to combine these factors. Thus, the assessment of the level of risk is a complex subject shrouded in uncertainty and vagueness. For example, it is well known or logical in project risk assessment for management to make the assertion that if the project definition is poor then the project risk is high. The words 'poor' and 'high' in this assertion are vague and imprecise and are difficult to express using conventional techniques. Although fuzzy sets and fuzzy logic techniques have been demonstrated to be able to address the problems associated with the quantification of vague linguistic terms [12], they have not been sufficiently developed and used in practice and could benefit from further research and development. The recent advances in information technology and the internet has led to project managers being inundated with escalating amounts of project information. The rise and rise of IT within the construction workplace has mirrored that of many other industries, and acceptance of new and innovative computing techniques is becoming less problematic. Information technology and the competitive advantages it brings are becoming more obvious to construction professionals. The benefits of applying intelligent and knowledge-based systems techniques to sieve through these huge amounts of information to support decision making in complex and dynamic project circumstances should become increasingly clear to practitioners, hopefully leading to the further development and use of knowledge-based systems techniques.

The proliferation of risk management software packages which use sophisticated probabilistic methods to quantify uncertainty, do not encourage the development of a deep understanding of the underlying structure which constitute the inter-dependencies between risk sources, risks, and the effects on the performance measures of project activities. They do not allow the risks, problems, remedial measures, and lessons learned from previous projects to be captured and re-used when developing new projects [13]. It is argued that new generation of tools should exploit knowledge-based systems techniques within integrated systems for project and risk management. Experience from previous research on the application of knowledge-based systems indicates that the first generation of KBS techniques based on rule-bases have failed to make an impact in the industry due to the problems of knowledge acquisition and the reduction of knowledge into a rigid set of rules. Recent experiences with the second generation KBS based on case-based reasoning techniques have been more promising [13]. These allow experiences from previous projects to be captured and used in new situations. The development and dissemination of standard 'Best Practices' through the reuse of project lifecycle information can therefore be facilitated.

The current use of Project Risks Registers in practice is an important first step in this direction. Project Risk Registers (PRR) can be seen as a repository of a corpus of knowledge or organisational memories where experiences about risks and responses are continuously recorded. However, the PRR fails to capture the inter-relationships between risks and the systemic structure within the risks [14]. This makes it an inadequate tool for the capture and representation of risks, and the basis for analysis and decision-making. Further work needs to build on the limited demonstrations of possibilities in the literature on the use of knowledge-based systems techniques. The development of a theoretical basis for the representation of risks and related concepts leading to the establishment of appropriate knowledge representation schemes should lead to the development of more robust and scalable knowledge-based systems. The appropriate synergistic combination of a hybrid of techniques drawn from both knowledge-based, soft, and conventional hard systems should be investigated to provide the basis for the quantification of risks and determining appropriate risk allowances and tolerances whilst embracing the notion that risk is subjective and allowing for human judgement.

2.3. Organisation

Managers need to ensure delivery of projects to cost, schedule and performance requirements. To achieve this involves identifying and managing the risks to the project at all project stages from the initial assessment of strategic options through the procurement, fabrication, construction and commissioning stages, whilst taking due account of subsequent operation and maintenance (and decommissioning and disposal). Risks to be considered include not just financial, commercial and management risks, but also quality, performance, health and safety and company image. Today, projects are undertaken in an arena of immense dynamism, rapid change, and global competition. The resultant uncertainty and complexity has emphasised the need for effective risk management strategies. Work is needed on methods of developing configurable risk management processes and skills needed to integrate risk fully into business strategy. The strategy should give recognition that balancing the ratio of risk and reward in a business is a key role for senior management. More holistic integrated comprehensive, inclusive and pro-active approaches to monitoring and management need to be developed to support the processes. For the approach to be comprehensive, it must cover five key aspects of business organisation: strategy, processes, products, technology, and people. It must be inclusive, involving all levels of the organisation. It must be pro-active, aiming to anticipate risks in advance. It is clear that, tools and techniques must be developed to support managers at a strategic level to play a leading role in setting a clear risk framework. Appropriate ways of embedding risk management in organisational
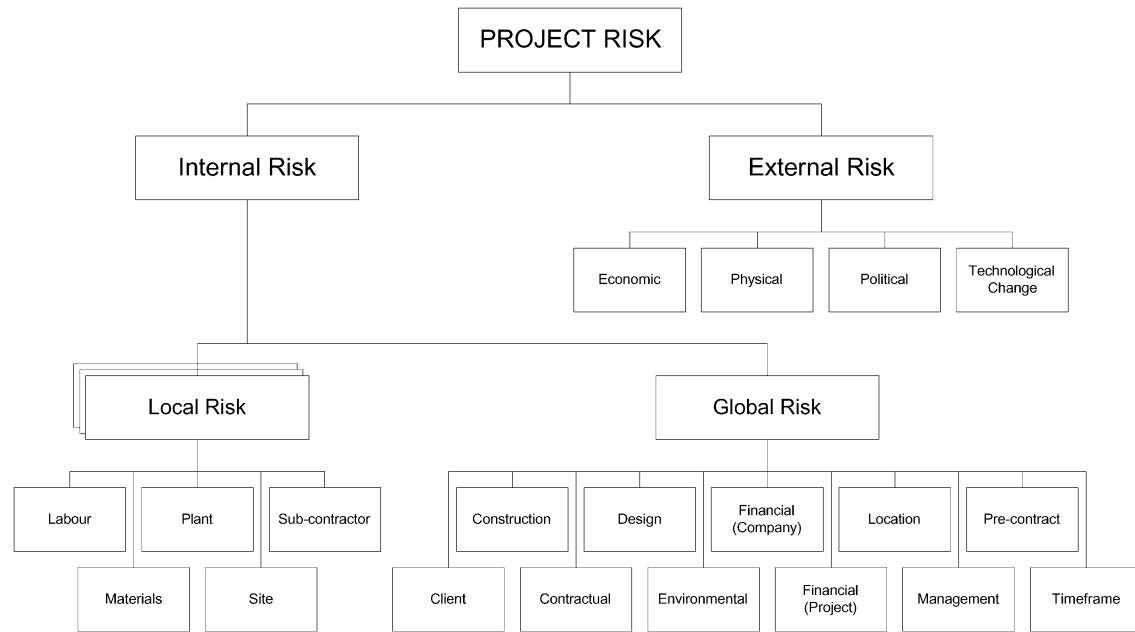
Fig. 1. The hierarchical risk breakdown structure.

3. A common language for describing risks

Risk management tends to be performed on an ad hoc basis, and is dependent on individual key players within the industry supply chain. These individuals adopt different terminology and techniques for describing and dealing with risks, which inevitably produce varying results. A common language of describing risks is necessary so as to facilitate consistent assessment and quantification of impacts. The hierarchical risk breakdown structure (HRBS) provides the basis for stratified classification of risks and developing a nomenclature for describing project risks. A common language for describing risks has been developed and is described in the ensuing section.

3.1. Classification of risks

Risk classification is an important step in the risk assessment process, as it attempts to structure the diverse risks that may affect a project. Many approaches have been suggested in the literature for classifying risks. Perry and Hayes [15] give an extensive list of factors assembled from several sources, and classified in terms of risks retainable by contractors, consultants, and clients. Cooper and Chapman [8] classify risks according to their nature and magnitude, grouping risks into the two major groupings of primary and secondary risks. Tah et al. [10] use a risk-breakdown structure to classify risks according to their origin and to the location of their impact in the project. Wirba et al. [11] adopt a synergistic combination of the approach of Tah et

al. and that of Cooper and Chapman, where the former is used to exhaustively classify all risks and the later is used to segregate risks into primary and secondary risks. In this paper, risks are classified using the hierarchical risk-break-down structure of Tah et al. with minor modifications to the structure to provide a more enriched content. A major addition is the inclusion of a dynamic causal network that facilitates the identification and representation of risks into the categories of risk factor and risk. The causal network is necessarily dynamic as the inter-dependencies between risk factors are non-deterministic, depending on the particular scenarios experienced through a project's life. Thus, the risk factors at the leaf nodes of the risk-breakdown structure hierarchy form a temporal causal network of risks and risk factors.

3.2. Hierarchical risk breakdown structure

The HRBS shown in Fig. 1 provides the basis for classifying risks within a project. The HRBS allows risks to be separated into those that are related to the management of internal resources and those that are prevalent in the external environment. External risks are those, which are relatively uncontrollable, and include such things as inflation, currency exchange rate fluctuations, and major accidents or disasters. Due to their uncontrollable nature there is a need for the continual scanning and forecasting of these risks and a company strategy for managing the effects of external forces. Internal factors are relatively more controllable and vary between projects. Example internal risk factors include the level of resources available, experience in the type of work being done, the location of the project, and the conditions of contract. Some of these risk factors are

Table 1
Standard terms for quantifying likelihood

Likelihood	Description
Very very high	Expected to occur with absolute certainty
Very high	Expected to occur
High	Very likely to occur
Medium	Likely to occur
Low	Unlikely to occur
Very low	Very unlikely to occur
Very very low	Almost no possibility of occurring

local to individual work packages or categories within a project, whilst the others are global to an individual project and cannot be associated with any particular work package. No two-work packages have the same level of risk and should be treated separately. A risk breakdown structure or categorisation should, therefore, reflect these differences. In the HRBS shown in Fig. 1, the overall risk is broken down into internal and external risks. The internal risks are further broken down into local and global risks. The local risks cover uncertainties due to labour, plant, material, and sub-contractor resources. These are considered for each work package or section of work. Global risks by their very nature cannot be allocated to individual work packages and are assessed on the project as a whole. This hierarchical representation will be used to develop a formal model for risk assessment.

3.3. Characterisation of risks and risk factors

Risk factors do not affect project activities directly but do so through risks. The distinction made here between risks and risk factors allows us to make the assumption that risks are triggered by risk factors. The characteristics of risks and risk factors are important for assessment and analysis purposes. The classification above allows us to view the existence of risks as dependent on the presence of one or more risk factors. The risk due to labour productivity is influenced by factors such as weather, worker moral, trade interference, complexity of work, etc. The risk assessment process requires the assessment of the probability or likelihood of the risk and the impact. In thinking about the likelihood of a risk, it is easier to think about the likelihood of the presence of the individual influencing factors. This is because the risk factors are more concrete abstractions of

the risk and define situations that can be individually assessed with a limited amount of vague information or facts. The key attributes of risks and risk factors are likelihood and severity. Risks are also categorised by the risk centre to which they belong.

3.4. Risk likelihood and severity

The assessment of what is or what is not a risk is highly subjective and the decisions taken are influenced by management's view of the future, and their desire to avoid poor performance, based on knowledge from past experiences. The decisions are based on a number of factors as indicated in Fig. 1. Many of these factors are not well defined and are not easy to quantify even though judgmental and heuristic rules can be used to combine these factors. The assessment of the level of risk is a complex subject shrouded in uncertainty and vagueness. This complexity arises from the subjective opinion and imprecise non-numeric quantification of the likelihood and degree of exposure of various aspects of the project to risks. For example, it is well known or logical in project risk assessment for management to make the assertion that if the project definition is poor then the project risk is high. The words *poor* and *high* in this assertion are vague and imprecise and are difficult to express using conventional techniques. The vague terms are unavoidable, since such a rule would be taken from a project manager [10]. Therefore, a common language for describing risks likelihood and severity is necessary so as to achieve consistent quantification. The terms for quantifying likelihood may be defined as shown in Table 1.

Risk severity should be considered in terms that are as close as possible to the corporate objectives at the time of assessment. The impacts should be expressed in terms of performance measures. There are a number of performance measures which may be used: the most common are cost and time, but others include quality, safety, and performance. The measures chosen for the current work are shown in Table 2. The values shown are only indicative, and the actual values should be determined by the corporate objectives at the time of assessment, due to the dynamic nature of project environments. Thus, the terms shown in Table 2 represent a given example and the true values will be determined by an organisation, and are likely to be modified for each project in which they are involved. Fuzzy sets can be used to quantify the linguistic variables for likelihood, severity, and risk premiums.

Table 2
Standard terms for quantifying severity

Severity	Time	Cost	Quality	Safety
Very high	> 20% above target	> 20% above target	Very poor	Injury
High	10% < target < 20%	10% < target < 20%	Poor	Safety hazard
Medium	5% < target < 10%	5% < target < 10%	Average	Average
Low	1% < target < 5%	1% < target < 5%	Above average	Above average
Very low	1% < target	1% < target	OK	OK

Table 3
A Fragment of the common language for describing construction project risks

HRBS Code	Type	Scope	Risk centre	Risk	Risk factor
R.1.1.01.03.01	Internal	Local	Labour	Productivity	Fatigue
R.1.1.01.03.02	Internal	Local	Labour	Productivity	Safety
R.1.1.02.01.00	Internal	Local	Plant	Suitability	Suitability
R.1.1.02.01.01	Internal	Local	Plant	Suitability	Breakdown
R.1.1.03.01.00	Internal	Local	Material	Suitability	Suitability
R.1.1.03.02.00	Internal	Local	Material	Availability	Availability
R.1.1.04.01.01	Internal	Local	Sub-contractor	Quality	Quality
R.1.1.04.02.01	Internal	Local	Sub-contractor	Availability	Availability
R.1.1.05.01.00	Internal	Local	Site	Weather	Weather
R.1.1.05.01.01	Internal	Local	Site	Weather	Temperature
R.1.1.05.02.00	Internal	Local	Site	Ground conditions	Ground conditions
R.1.1.05.02.01	Internal	Local	Site	Ground conditions	SiteInvestigation
R.1.1.05.03.00	Internal	Local	Site	Access	Access
R.1.1.05.03.01	Internal	Local	Site	Access	External access
R.1.1.05.04.00	Internal	Local	Site	Existing services	Existing services
R.1.1.05.04.01	Internal	Local	Site	Existing services	Below ground
R.1.2.01.00.00	Internal	Global	Construction	Construction	Construction
R.1.2.01.01.01	Internal	Global	Construction	Complexity	Complexity of work
R.1.2.01.02.01	Internal	Global	Construction	Methods	Constructionmethods
R.2.0.00.00.00	External	External	External	External	External
R.2.0.01.00.00	External	External	Economic	Economic	Economic
R.2.0.01.01.00	External	External	Economic	Inflation	Inflation

3.5. Risk and action catalogues

The risk catalogue is a collection of risks which have been defined using the common language and the HRBS. It is completely generic in nature, all the items contained in it are potential risks which have been identified. An example of part of the risk catalogue is shown in Table 3. The items within the risk catalogue are used as the basis for defining project specific risks during risk identification. Each item within the catalogue is defined by risk type, scope, centre, risk, and risk factor. Every risk which is identified and defined for a project is based on one of these generic risk catalogue items; if there is no appropriate item within the risk catalogue then a new item must be added before the risk can be defined. Given the use of risk factors within the system, risks can be defined as either a risk or a risk factor. In the risk catalogue, a risk factor is defined by setting suitable values for all five terms within the risk hierarchy, whereas a risk is defined by type, scope, centre, and risk only — its risk factor value is not defined. The action catalogue is similar in design to the risk catalogue — it has type, scope, and centre, but has action and action factor instead of the risk equivalents. These define the remedial measures, which are available for alleviating defined risks within the system. The use of risk repositories such as the risk and action catalogues, has become more accepteable recently, since the announcement that CIRIA intends to conduct research into the benefits of such schemes in practice.

3.6. Risk-action relationships

In addition to the risk and action catalogues, there is a third catalogue which defines the relationships between the risks and the actions. These relationships are also generic, hence for a defined project risk — based on a generic risk item from the risk catalogue — a set of actions is available from which one may be selected to help alleviate or overcome the risk. The risk-action relationships are all context dependent, and this dependency is based on work classification. For example, a generic risk which may apply to both earthworks and concreting activities can have different remedial actions associated with it for each of those contexts.

4. Project risk management process and information models

To overcome the lack of formality in construction risk management, the development of formal risk management processes has been the subject of much interest recently. The Association of Project Managers (APM) have developed Project Risk Analysis and Management (PRAM), as described by Chapman [16]. Following the pattern typical of many risk management systems, PRAM defines a number of phases of risk process description. In this case there are nine phases: define, focus, identify, structure, ownership, estimate, evaluate, plan, and manage. A more recent approach by the Institution of Civil Engineers and the Faculty and Institute of Actuaries [17] has resulted in a more comprehensive process of Risk Analysis and Management for Projects (RAMP), designed to cover the complete project lifecycle. The architecture for RAMP follows a more complex multi-level breakdown structure.
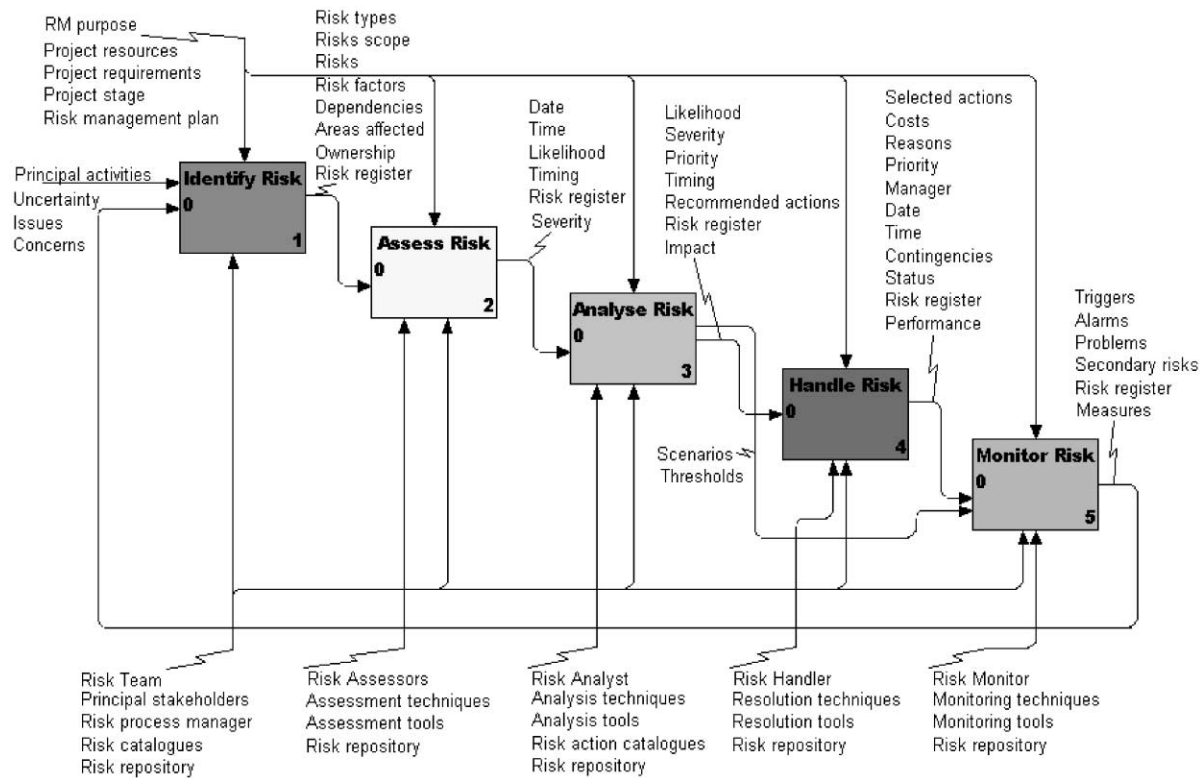
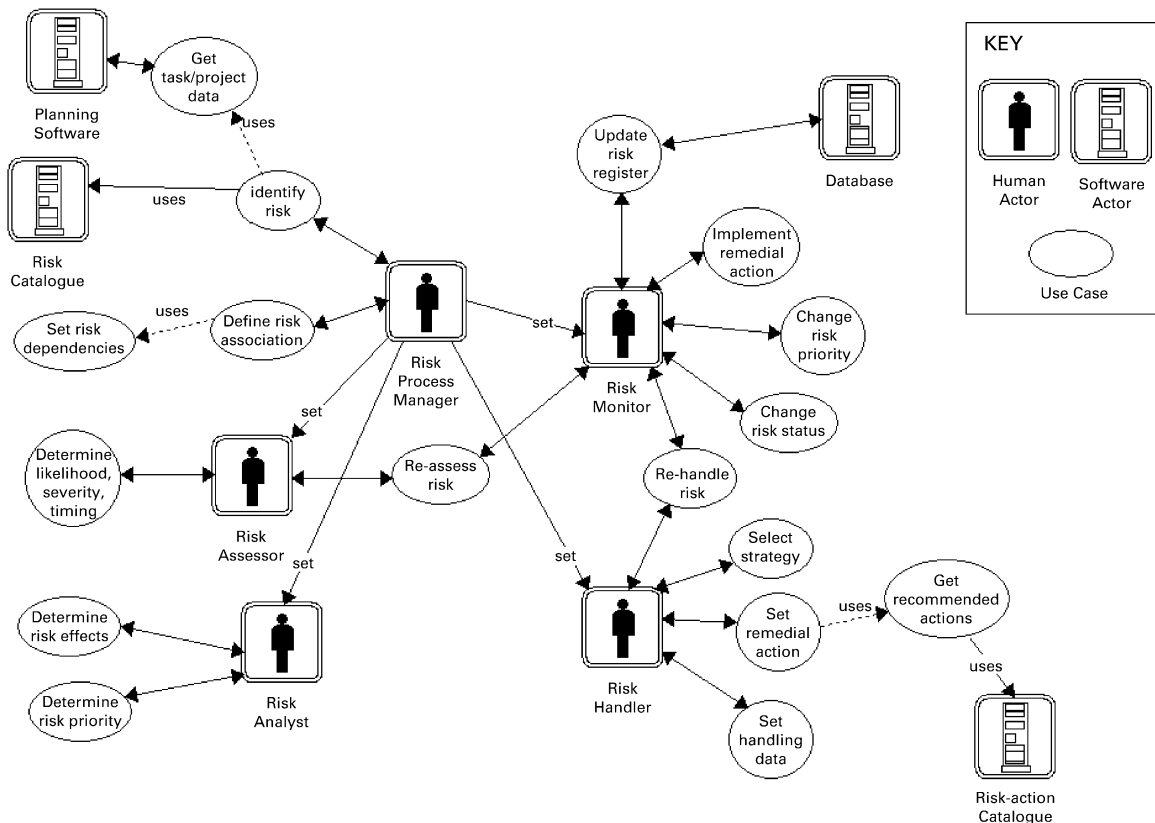Fig. 2. The risk management process model.
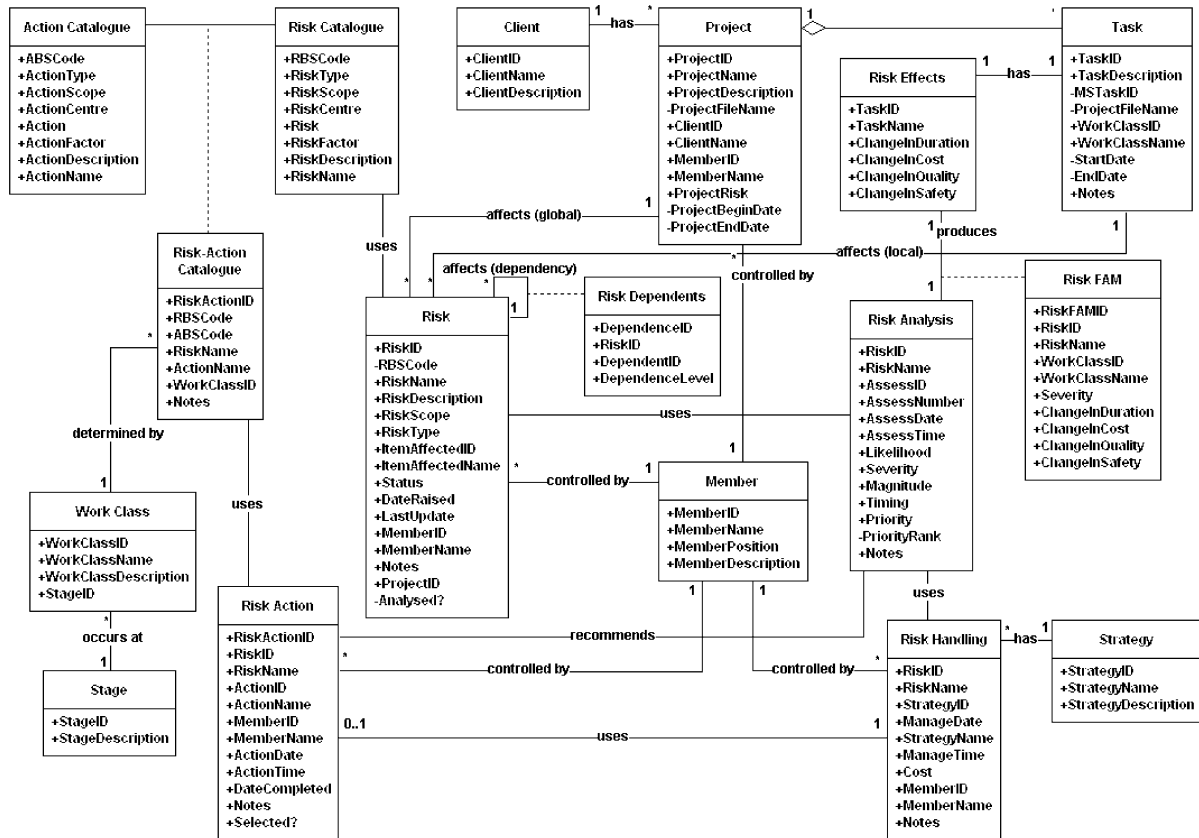

Fig. 3. The use case diagram.

Fig. 4. The class diagram.

The top-level processes within this structure are: process launch, risk review, risk management, and process close-down. The lower-level processes break these top-level processes down further.

Although, there are several risk management standard process models or frameworks, they all share a common goal and have similar characteristics. The aim being to provide a systematic approach to risk management involving: the identification of risk sources; the quantification of their effects; the development of responses to these risks; and the control of residual risks in the project estimates. One of the aims of the current work is to build on the foundations of systems such as PRAM and RAMP, using a common language as the underlying basis for risk description, and to develop a software prototype in which the risk methodology can be tested. Standard methodologies for software development were used to produce both process and information models that represent the risk management framework. The IDEF0 activity diagram, a component of the IDEF modelling technique [18], was used to produce a comprehensive model of the risk management process. Whilst the use case diagram and the class diagram techniques, both components of the UML method [19] were used to produce the information model.

4.1. The process model

There are a multitude of phases and activities associated with the project risk management process. Within this work, five key phases which are central to the development and use of the system via the common language are concentrated on. These phases are: risk identification, risk assessment, risk analysis, risk handling, and risk monitoring. The IDEF0 risk management process model, depicting the interaction of these phases and the information flow between them is shown in Fig. 2. It is worth noting that there are a number of posts defined within the process model, such as risk assessors, risks analysts, etc. These do not represent *individuals* within the risk management process, rather they define specific *roles* to be played. These roles can be filled by individuals or groups of people, thus acknowledging current best practice in this area which suggests empowering the core project team with appropriate tools and skills as required.

4.2. The use case diagram

A use case diagram allows the typical interactions between a user and a computer system to be modelled. In essence, the use case diagram contains the essential

'players' in the system, described as actors, and the routines, or use cases, which the system must do to perform its necessary functions. The relationships between the actors and the use cases define the use case diagram. The use case diagram for the risk system is shown in Fig. 3. An actor is a role that a user plays with respect to the system. Within a use case diagram the actors are not necessarily all human — external items such as databases, which require or provide system information, count as actors too. Actors carry out use cases; an actor will typically perform many use cases, and conversely a use case may be carried out by many actors. Within the risk use case diagram there are five human actors, and four software actors. The software actors represent tables within the information repository, and show the flow of communication, both backwards and forwards, between the risk management system and the data repository. The risk process manager controls the whole risk management process and is responsible for setting the other management roles within the system. These roles may be allocated to one or more individuals associated with the organisation, or may be left under the control of the risk process manager. Thus, the software actors represent the various specific roles within the risk management process rather than individual(s) which perform them.

4.3. The class diagram

A class diagram describes the types of objects which are used within an object-oriented system, and defines the types of relationships which exist between them. The attributes and methods of each class can also be shown, as well as the constraints applying to the way objects are connected. There are two specific types of relationship defined within the UML class model: *associations*, which define the interaction between two hierarchically-unrelated objects; and, *subtypes*, which define hierarchical relationships between parent objects and child objects. The class diagram for the risk system, shown in Fig. 4, only makes use of association relationships. Each association has two roles, one in each direction of the association. Thus, in Fig. 4, there is a role for the association between project and client, and there is another role for the association between client and project. These associations may be labelled for clarity; in this case the label defines a *has* relationship between the two. Additionally, each of the roles has a multiplicity value associated with it. This value indicates how many objects may participate in a given relationship. In the given example the project-client role has a multiplicity value of one, meaning that a project can only have one client associated with it, whereas the client-project role has a multiplicity of many (the asterisk value represents any value) meaning that a client can be associated with many projects. For clarity, within Fig. 4 only the attributes associated with the objects are shown — the methods have been removed.

5. The risk knowledge management framework

Whilst there is much debate around the definition of knowledge management, there is little disagreement that businesses can benefit by improving key processes within an organisation that help people use information more effectively. "Knowledge management caters to the critical issues of organisational adaptation, survival, and competence in face of increasingly discontinuous environmental change. Essentially, it embodies organisational processes that seek synergistic combination of data and information-processing capacity of information technologies, and the creative and innovative capacity of human beings" [20]. The increasing complexity and dynamism of major construction projects can decrease a project manager's ability to identify and manage risks effectively. Project managers cannot afford to inadvertently repeat past mistakes because they were unaware of successful risk management strategies applied elsewhere or on previous projects. A smart use of information technology designed to capture risk management experience lets project managers learn from and share with others by readily tapping into a centralised or distributed corporate knowledge repository using emerging knowledge management techniques.

An environment must be created where data can be stored and organised so that individuals and teams can access it easily and intuitively, evaluate it using intelligent systems and tools, share that analysis with colleagues and act upon those findings effortlessly. Such an environment would be integrated and built on a scaleable infrastructure necessary to allow distributed knowledge-enabled software components to thrive and grow across the entire enterprise. The challenge will be in gathering all pertinent data that flows through an enterprise, and transforming information technology systems from mere databanks into true institutional memory. The long-term goal of the work presented in this paper is to develop and demonstrate the benefits of such an environment for project and risk management purposes. In this section, the focus of the current software environment is presented.

5.1. Architecture

A distributed computing architecture exploiting the Components-Based Development (CBD) approach to software engineering has been adopted to create a knowledge management environment for integrated risk and project management. Microsoft's Component Object Model (COM) technology is being used to ensure that all components inter-operate seamlessly. To this end, commercially available best-of-breed software packages for project management, database management, and development tools that support COM are being used to facilitate the development effort. A three-tier Client/Server architecture is being used in developing the environment allowing the
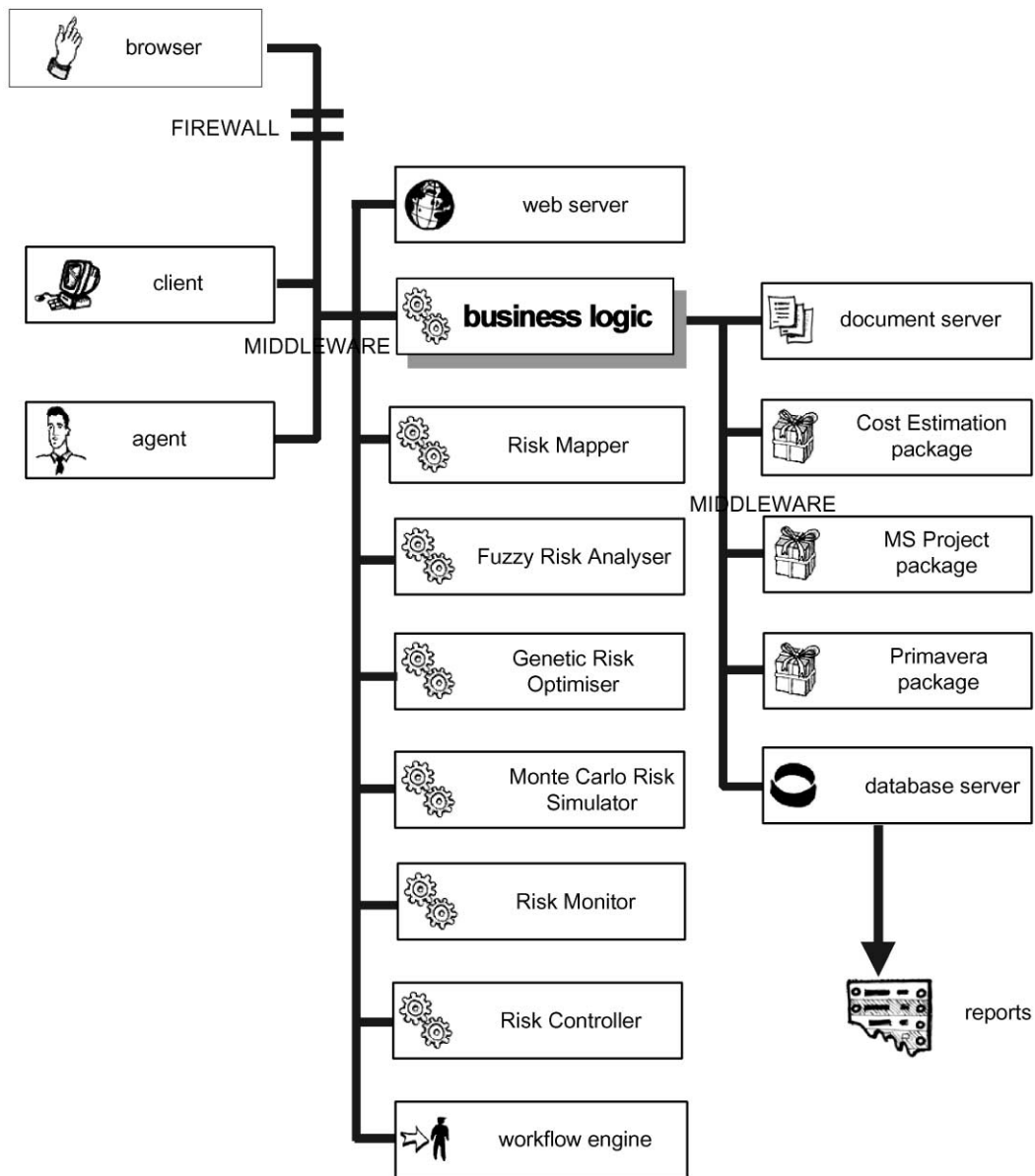
Fig. 5. The three-tier client/server architecture.

separation of the user interface from the application logic and the database in line with current best practice in software development. The architecture is depicted in Fig. 5 and its current implementation is presented in [21]. In Fig. 5, the first tier represents the user-interface, the middle-tier represents 'Application Servers' which represent the underlying logic of specialist software components, and the third tier represents the integrated database and packaged best-of-breed applications. In addition to exploiting commercial available software packages, the following software components are being developed.

5.2. The integrated database

The conceptual information model in the class diagram in

Fig. 4 is being used to develop a risk database to store generic risks and actions using the standard vocabulary for construction risk assessment and management, described in Section 3. The risk database has been extended to include the storage of related project management information to support the integrated risk and project management environment. This will provide an integrated database dedicated to an orderly and accessible repository of known facts and related data that is used as a basis for making better project management decisions This will be implemented as an integrated project management information repository, customisable and adaptable to any organisational infrastructure. This will provide managers not only with highly structured reports, but also with On Line Analytical Processing and reporting to support tactical or strategic

decision-making. It will allow managers to extensively drill down and search multiple layers of information to provide a proactive business environment that gains insight into opportunities and identifies threats to analytical scenarios.

5.3. Application servers

A software component will be developed to support the risk structure mapping language. It will have in-built facilities to produce risk structure graphs or maps, add qualitative and quantitative details to the maps, and to create the underlying system of equations needed to turn the map into an active model for inferencing and simulation. A simulation facility will be developed and implemented to allow for various risk scenarios and mitigating measures to be evaluated.

A software component has been developed to handle fuzzy inferencing and computations. This will involve using the standard risk vocabulary to define linguistic variables to represent risk likelihood and severity of risk sources, and consequences on project performance measures. Appropriate fuzzy sets will be defined on each linguistic variable and represented graphically with a facility to edit the shape of individual membership functions. The component will maintain fuzzy rules in the form of configurable a FAM bank elicited from project/ risk managers.

A simulation model will be developed to allow the underlying elements and structures which constitute project risk systems developed in the risk mapping component to be used to explore the behaviour of project performance measures over the life-cycle of a project under various scenarios. Work is being conducted to explore the applicability of genetic algorithms to generate and test combinations and sequences of risks (risk chains or scenarios), within a given risk structure network, to optimise performance measures. This will allow the overall impact of risk scenarios on the whole-life net present value (NPV) of a project to be explored.

A risk monitoring software component will be developed to automate the collation of performance deviations from individual levels of the work breakdown structure within the project repository and pro-actively detecting potential problem situations, while escalating critical situations to a project control console. This will define warning levels of unacceptable status as thresholds, monitor status indicators in terms of measures and metrics, and trigger or alert attention to areas requiring corrective action plan implementation.

5.4. User-interface

A project control console will be developed to provide a graphical user interface into the system. This will bring together and provide assess to all the individual software components. It will be used to request additional information from the user, to maintain the information reposi-tory, to alert the user to potential problems, to offer a set of corrective control strategies. Appropriate graphical methods will be developed for representing the risk status of risk metrics for effective communication to all project participants. These will include radar-grams, and 3D graphs and animations of the model. The project control console will be web-enabled to facilitate collaborative working, providing virtual co-location to project team members.

6. Summary and conclusions

Risk management is still a problem area within the construction industry. Approaches have been suggested for dealing with the problems, but these for the most part have failed to meet the needs of project managers. Part of the problem is that communication of project risks poor, incomplete, and inconsistent. It has been argued that the development of a common language for describing project risks will lead to greater consistencies in communicating risks allowing all project team members to develop a shared understanding of risks and interdependencies within a project. Project communication systems must be built upon common terminology, standard descriptions, defined metrics for measurement and consistent knowledge of processes and procedures. Additionally, evidence suggests that current software packages do not handle the inherent subjectivity in risk assessment effectively. To help overcome this fuzzy logic technique may help to address the problems associated with the quantification of vague linguistic terms.

As part of a larger project, work has been done towards overcoming some of these problems. A common language for describing risks based on a hierarchical-risk breakdown structure has been developed. This is key to developing a sharable knowledge-driven approach to risk management. The common language uses a number of taxons and constructs to define generic risk terms, which can then be stored in a risk catalogue. Project specific risks are based on these generic risk terms, but are customised for each project. A similar scheme is used to develop an action catalogue for risk mitigation measures. These have been implemented in a database management system to act as a knowledge repository. A prototype system is being developed to support the risk management framework [21]. A component-based development approach exploiting the three-tier client/server architecture is being adopted to allow the user-interface to be separated from the underlying application logic and the integrated database. The system consists of a web-enabled user-friendly front-end, several business logic components, and an integrated database repository which feeds off best-of-breed project management packages, allowing the system to seamlessly access all risk and project information. The architecture of the system is designed to allow it to be customised to individuals and corporations with relative ease. Further work is being undertaken to develop

qualitative risk assessment and analysis modules based on graph-based representation of risk scenarios for simulation and decision support purposes.

The prototype is being used as a basis for discussion with practitioners about the practical requirements of the approach for further development to satisfy industry needs. This is being done in part to determine the system modifications required to benefit its use in practice, but also to help overcome the natural reticence, which construction organisations seem to have with implementing formalised risk assessment and management procedures. It is important that practitioners understand the benefits of a formalised risk management process, both in terms of time and cost savings, and in terms of the overall benefits to the reputations of their organisations and industry as a whole. This formalism of describing project risks and mitigating measures coupled with knowledge-driven risk management will hopefully facilitate effective risk handling whilst allowing all project participants to develop a shared understanding of project risks resulting in improved performance.

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