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A fuzzy approach to construction project risk assessment and analysis: construction project risk management system

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Abstract

The construction industry is plagued by risk, and poor performance has often been the result. Although risk management techniques have been applied, the lack of a formalised approach has produced inconsistent results. In this paper, a hierarchical risk breakdown structure is described to represent a formal model for qualitative risk assessment. The relationships between risk factors, risks, and their consequences are represented on case and effect diagrams. Risk descriptions and their consequences can be defined using descriptive linguistic variables. Using fuzzy approximation and composition, the relationships between risk sources and the consequences on project performance measures can be identified and quantified consistently.

Keywords: Qualitative risk assessment and management; Fuzzy logic; Linguistic variables

1. Introduction

The construction industry, perhaps more than others, has been plagued by risk [1,2] and this has not always been dealt with adequately, often resulting in poor performance with increasing costs and time delays. With the need for improved performance in the construction industry [3] and increasing contractual obligations [4], the requirement of an effective risk management approach has never been more necessary. There are a proliferation of risk management software tools on the market, and while the facilities offered by these packages vary widely, their underlying methodologies are often founded on the principles and techniques developed for operational research in the 1950s and 60s. Hence, the use of statistical techniques is commonplace and little else is considered. Construction projects are becoming increasingly complex and dynamic in their nature, and the introduction of new procurement methods means that contractors have to rethink their approach to the way risks are treated within their projects and organisations.

Risk assessment is a complex subject shrouded in vagueness and uncertainty. Vague terms are unavoidable since individuals often find it easier to describe risks in qualitative linguistic terms. The work presented here is part of a much larger project, which aims towards a different approach to risk management, one which will hopefully grow with individual organisations and increase their chances of success in project management. In this paper, a scheme for classifying risks and remedial actions in a consistent way is described. Fuzzy set theory is introduced to enable qualitative risk assessment descriptions to be modelled mathematically. Relationships between risk factors, risks, and their consequences are represented on cause and effect diagrams. Using fuzzy association and composition, the relationships between risk sources and the consequences on project performance measures can be identified. A methodology for representing the risk exposures in terms of time, cost, quality, and safety changes is presented.

2. Overview of the risk management process

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 [5]. 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. Similarly, Kähkönen [6] defines a risk and project

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management process, but with fewer phases: organisation and scope, risk identification, risk analysis, risk strategy, response planning, and continuous control and feedback. Though there are fewer phases, they tend to cover the same scope as those used in PRAM. A more recent approach by the Institution of Civil Engineers and the Faculty and Institute of Actuaries [7] 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. The top-level processes within this structure are: process launch, risk review, risk management, and process closedown. The lower-level processes break these top-level processes down further.

The PRAM and RAMP approaches attempt to overcome the informality of most risk management efforts. PRAM and RAMP are essentially process models, albeit ones which have been well thought out with a considered approach to the risk management process. As such they exist as methodologies rather than as implemented software systems. 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.

3. Risk classification and underlying system logic

Many approaches have been suggested in the literature for classifying risks. Perry and Hayes [8] 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 [9] 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-breakdown structure of Tah et al. with minor modifications to the structure to provide a more enriched content.

A hierarchical risk breakdown structure (HRBS) has been developed, and the structure of this provides the basis for a stratified classification of risks and the development of a nomenclature for describing project risks. The HRBS allows risks to be separated into those that are related to the management of internal resources, which are relatively controllable, and those that are prevalent in the external environment, which are relatively uncontrollable. Internal risks may affect individual tasks or work packages or may affect the project itself, and as such are defined as local and global respectively. Risks are defined by the centre they affect within a project, and are themselves affected by risk factors. Risk factors do not affect projects or activities directly but do so through risks. This classification allows us to view the existence of risks as dependent on the presence of one or more risk 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, severity, and timing.

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 1. The items within the risk catalogue are used as the basis for defining project specific risks. Each item within the catalogue is defined by risk type, scope, centre, risk, and risk factor. Given the use of risk factors within the system, risks can be defined as either a risk or a risk factor. An action catalogue has also been developed. This 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.

Table 1
A small section of the risk catalogue

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	Site investigation

These define the remedial measures available for alleviating defined risks within the system. In addition, there is a third catalogue defining the relationships between the risks and the actions. These relationships are also generic, hence for a defined project risk a set of actions is available from which one may be selected to help alleviate or overcome the risk. These relationships are context dependent, and are based on work classification. For more detailed description of the HRBS and the use of the common language for describing risks and remedial actions see Ref. [12].

4. Risk information modelling and the risk process

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. 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 [13] was used to produce a comprehensive model of the risk management process. The use case diagram and the class diagram techniques, both components of the UML method [14], were used to produce the information model. Details of these models will not be presented due to space constraints and the reader is referred to Ref. [12] for details. The process model used for this work identifies five processes making up the risk management model: identification, assessment, analysis, handling, and monitoring. These are described in detail with respect to their use in the prototype system later.

5. Fuzzy set and fuzzy logic theory

Fuzzy sets were first proposed by Lukasiewicz in the 1920s [15] in an attempt to produce systems which were able to represent a range of truth values covering all real numbers from 0 to 1. In the 1960s, Zadeh [16] extended the work on possibility theory in to a formal system of mathematical logic for representing and manipulating 'fuzzy' terms, called fuzzy logic. This is defined as a branch of logic using degrees of membership in sets rather than strict true/false membership. Using fuzzy logic, sets may be defined on vague, linguistic terms such as *good market conditions*, *very attractive project*, or *high risk*. These terms cannot be defined meaningfully with a precise single value, but fuzzy set theory provides a means by which these terms may be formally defined in mathematical logic.

There have been limited attempts to exploit fuzzy logic within the construction risk management domain. Kangari [17] presents an integrated knowledge-based system for construction risk management using fuzzy sets. The system, called Expert-Risk, performs risk analysis in two situations: before construction, and during construction. Chun and Ahn [18] propose the use of fuzzy set theory to quantify the imprecision and judgmental uncertainties of accident progression event trees. Peak et al. [19] propose the use of fuzzy sets for the assessment of bidding prices for construction projects. Tah et al. [10] try a linguistic approach to risk management during the tender stage for contingency allocation, using fuzzy logic. Ross and Donald [20] describe a method for assessing risk based on fuzzy logic and similarity measures. This approach uses linguistic variables catering for vagueness and subjectivity to devise rules for assessing the management of hazardous waste sites. Ross and Donald [21] also use fuzzy set theory for the mathematical representation of fault trees and event trees as used in risk assessment problems. Wirba et al. [11] also use linguistic variables. This approach considers a method in which the likelihood of a risk event occurring, the level of dependence between risks, and the severity of a risk event, are quantified using linguistic variables and fuzzy logic.

Previous approaches to the use of fuzzy logic within construction risk management have proved to be either too simplistic for use in the real world, or have been very specific in their approach, targetting a particular area of construction on which to act or concentrating on specific types of risks. None of the approaches are generic and representative enough be applied generally, and no system is scalable and robust enough to be used on major problems within a construction domain. Serious thought needs to be given to a knowledge representation that is generic enough to be applied over the full project lifecycle and throughout the construction supply chain, and which is robust enough to be applicable in practice. The model presented below is part of a major project which aims to achieve these goals.

6. Fuzzy risk analysis model

The relationships between risk factors, risks, and their consequences can be represented on cause and effect diagrams. These diagrams and the concepts of fuzzy association and fuzzy composition [22] can be applied to identify relationships between risk sources and the consequences on project performance measures. The first step in this model involves the formulation of the risk problem in the hierarchical structure described previously. A conceptual model in the form of the simple HRBS shown in Fig. 1 will be used to illustrate the concepts. In the hierarchy in Fig. 1, the top node represents the local risk associated with a work package. The second level represents risks, grouped by centre. The third level represents the risk factors that influence the risks. The dependencies, depicted by directed arcs, between the nodes represent cause and effect relationships. Absence of an arc between two nodes represents conditional independence. The main objective is to evaluate

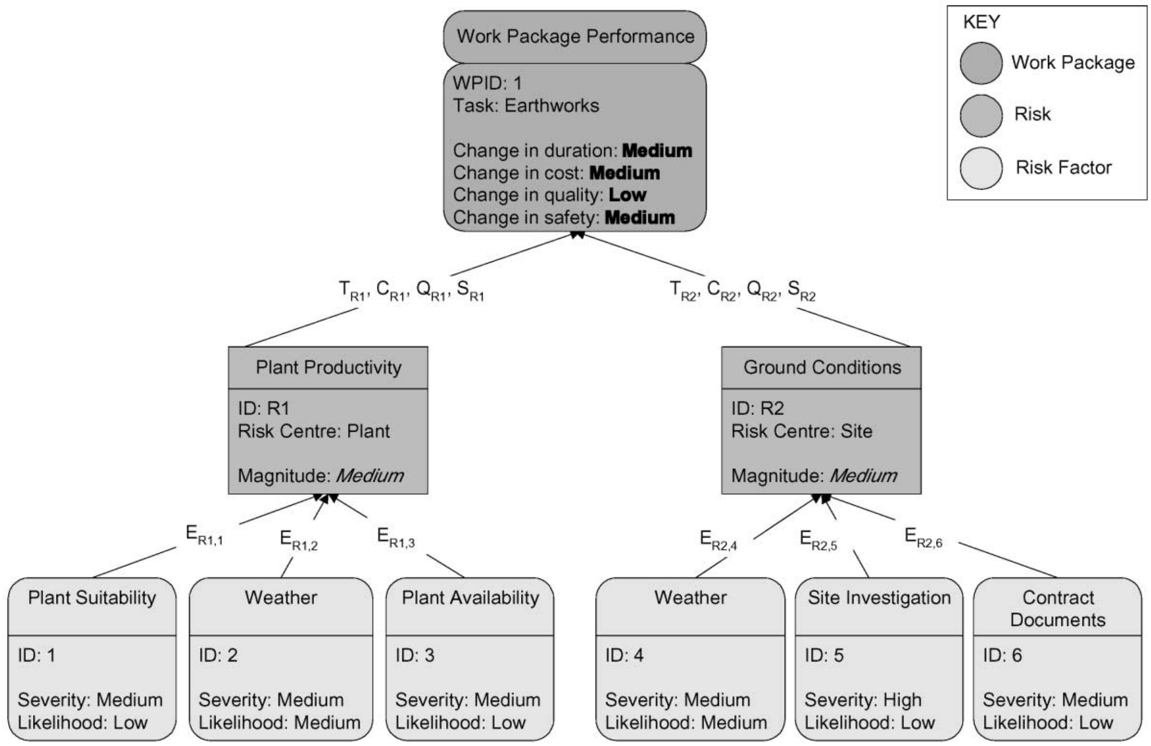

Fig. 1. An example of fuzzy calculations.

the risk exposures considering consequences in terms of time, cost, quality, and safety performance measures of the entire project based on fuzzy estimates of the risk components.

6.1. Knowledge representation

When a risk becomes a problem it leads to a system's malfunction. A system here represents a task, a work package, or a project. A risk or problem acts as a disturbance affecting the normal functional behaviour of a system. The problem is propagated into the system's structure towards its manifestations via a deterministic chain of effects, which reflect systems malfunction. The approach to risk assessment taken here assumes that risk factors influence the severity of risks, which in turn cause changes in the system's performance measures, namely duration, cost, quality, and safety. These measures can also be viewed as symptoms to be observed when monitoring and evaluating a system's status. The diagram in Fig. 1 illustrates the risk factors–risks (cause) and risks–symptoms (effects) dependencies represented as relations M and R respectively. By analysing the causality between risk factors and risks and the causality between risks and performance measures, the changes induced in the work package performance can be determined.

Let there exist a relationship between the likelihood of occurrence L, the severity V, and the effect of a risk factor E, represented by a double premise rule such that

$$\text{IF } L \text{ AND } V \text{ THEN } E \tag{1}$$

There exist many such relationships with varying values of L, V, and E. These relationships can be represented using fuzzy associative memories (FAMs.) using the method suggested by Kosko [23]. This involves assembling two FAM matrices M_{LE} and M_{VE}, to relate each premise to the conclusion for each of the two premises in the rule. Given a risk factor with likelihood L' and severity V', the effect or induced fuzzy set on E can be found independently through composition, thus

$$L'M_{LE} = E_{L'} \tag{2}$$

$$V'M_{VE} = E_{V'} \tag{3}$$

The fuzzy logic intersection operator is used to join or recompose the two induced fuzzy sets, such that

$$E' = E_{L'} \wedge E_{V'} \tag{4}$$

This will give the effect E' for an individual FAM. If m rules exist then the total effect E can be determined by performing a fuzzy union of the resultant magnitude fuzzy sets.

$$E = E'_1 \cup E'_2 \cup \ldots E'_m \tag{5}$$

The value of E is the effect for a given risk factor with a defined likelihood and severity value. Given a risk R which is influenced by n risk factors, the conventional fuzzy technique for calculating the total effect E on the risk is to perform an aggregation of the effect of all the influencing risk factors using a fuzzy union operator, similar to Eq. (5). However, this technique tends to produce average results which are not realistic for risk analysis [24]. Hence, the value of the risk factor with the greatest effect, $E_{\max}$, is used. The effects of the remaining risk factors may be used to modify this by a further amount ξ, such that,

$$E = \xi E_{\mathrm{MAX}} \tag{6}$$

The determination of an appropriate method for computing the modification factor ξ is a subject for further investigation and for the sake of expediency a value of 1 is assumed here.

Next we consider the changes the risks induce on project tasks or work packages. Given a risk with a severity effect E computed in (6), the changes in time T, cost C, quality Q, and safety S induced on a task can be represented by the following rules:

$$\text{IF } E \text{ THEN } T \tag{7}$$

$$\text{IF } E \text{ THEN } C \tag{8}$$

$$\text{IF } E \text{ THEN } Q \tag{9}$$

$$\text{IF } E \text{ THEN } S \tag{10}$$

There exist many such relationships, with varying values of E, T, C, Q, and S for each risk. These relationships are rules that can be obtained from project and risk management experts and can be represented as fuzzy associative memories (FAMs). This involves assembling FAM matrices, M_{ET}, M_{EC}, M_{EQ}, M_{ES} for each rule relating the rule premise to the conclusion. Given a risk with effect E' the changes induced in T, C, Q, and S are T', C', Q', and S', respectively, are determined by composition such that

$$E' M_{ET} = T' \tag{11}$$

$$E' M_{EC} = C' \tag{12}$$

$$E' M_{EQ} = Q' \tag{13}$$

$$E' M_{ES} = S' \tag{14}$$

If there are n FAMs for each risk effect then T, C, Q, S can be determined by performing a fuzzy union of the resultant fuzzy sets, such that

$$T = T'_1 \cup T'_2 \cup \ldots T'_n \tag{15}$$

$$C = C'_1 \cup C'_2 \cup \ldots C'_n \tag{16}$$

$$Q = Q'_1 \cup Q'_2 \cup \ldots Q'_n \tag{17}$$

$$S = S'_1 \cup S'_2 \cup \ldots S'_n \tag{18}$$

Where a task or work package is affected by many risks, the traditional fuzzy technique for calculating the total changes to time T, cost C, quality Q, and safety S is to perform a fuzzy union of the changes from the individual risks, as in Eqs. (15)–(20). However, once again this technique has a tendency to produce average results, and so the values of T, C, Q, and S from the risks which have the greatest impacts are used. The remaining values are then used to modify this by a further amount ξ for each performance measure affected such that

$$T = \xi T_{\mathrm{MAX}} \tag{19}$$

$$C = \xi C_{\mathrm{MAX}} \tag{20}$$

$$Q = \xi Q_{\mathrm{MAX}} \tag{21}$$

$$S = \xi S_{\mathrm{MAX}} \tag{22}$$

These reflect the changes to the performance measures of a given task. The linguistic variables which are represented by the given fuzzy sets can be determined by defuzzification. The ensuing example is used to illustrate the computational process.

6.2. Example

A simple example is used to illustrate the application of the fuzzy risk assessment model. The risks associated with a plant-intensive earthworks work package of a major project are considered. The concepts and computations which are included in this example have been coded in risk analysis and management software, described later.

The first step is to identify the risk sources. Fig. 1 shows that the stakeholders have identified plant productivity and ground conditions as the main risks affecting earthworks for this project. The diagram also shows the risk factors that render these risks active. The fuzzy associative memories (FAMs) that relate the risk factors likelihood and severity to the magnitude of the risk are shown in Table 2. This shows the rule-set defining the likelihood and severity of a given risk with its magnitude value. The letter L, M, and H in the table refer to the linguistic variables Low, Medium, and High, respectively.

The fuzzy associative memories relating the risk magnitude value with the changes it induces in the work package or tasks performance measures are shown in Table 3. These FAMs represent company policy and have been taken from the company's FAM bank dedicated to risk analysis. The FAMs would have been elicited from project managers initially, based upon the experiences of the individuals and their organisations with the problems associated with given work types on previous projects which the company

Table 2
A bank of FAM rules to determine risk magnitude

Risk severity	H	M	M	MH	H	H
	MH	LM	M	M	MH	H
	M	LM	LM	M	M	MH
	LM	L	LM	LM	M	M
	L	L	L	LM	LM	M
Risk magnitude		L	LM	M	MH	H
		Risk likelihood				

Table 3
Subjectively determined FAMs for risk consequences and the effects on the performance measures for an example earthworks work package

No	Description	Consequence	Change in duration	Change in cost	Change in quality	Change in safety
1	Plant productivity	Low	Low	Low	Very low	Very low
		Medium	Medium	Medium	Low	Very Low
		High	High	High	Low	Low
2	Ground conditions	Low	Low	Low	Low	Low
		Medium	Medium	Medium	Low	Medium
		High	High	High	Medium	High

has undertaken. These would be continuously refined through experience gained on the use of the FAMs on future projects. This is particularly important in the early stages of the use of the risk management system, to ensure that the FAM banks are accurate and that the data they contain truly reflects company policy. The FAMs are context-dependent, and the current context is the type of work affected by the risk, in this case Earthworks. Work is currently being done to determine what other changes in context affect the FAMs including the effect of different types of project.

For the current example, the membership functions for the linguistic terms set to be used are shown in Fig. 2 and the corresponding fuzzy sets are defined as:

Low = L = {1,0.67,0.33,0,0,0,0,0,0,0,0}
Low-to-Medium = LM = {0,0,0.5,1,0.5,0,0,0,0,0,0}
Medium = M = {0,0,0,0,0.5,1,0.5,0,0,0,0}
Medium-to-High = MH = {0,0,0,0,0,0.5,1,0.5,0,0,0}
High = H = {0,0,0,0,0,0,0,0,0.33,0.67,1}

The second step involves the subjective assessment of the likelihood of occurrence and severity of the individual risk factors as indicated in the leaf nodes in Fig. 1. Once done, the magnitude of each risk can be calculated based on these values. Eqs. (1)–(5) are applied in computing the magnitude of each risk and Eq. (6) is used to compute the total effect of all risk factors influencing a risk. The results are shown in Fig. 1 in italics. The final step involves computing the changes induced in the performance measures of the work package by the individual risks using Eqs. (7)–(18). Then the total effect of the individual risks is computed using Eqs. (19)–(22). The results of the computation are shown in Fig. 1 in bold.

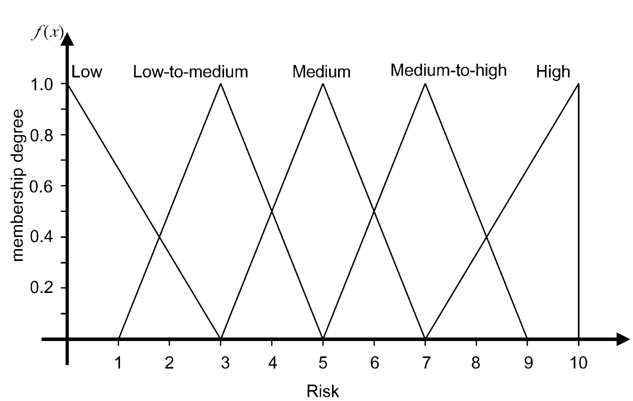

Fig. 2. Membership functions for risk.

7. The prototype system

A risk management system has been developed to test the ideas behind the work. This system is designed to aid the risk management process via a single user-friendly interface, controlling access to the data sources automatically, hence requiring no knowledge of the manner in which the data is stored and manipulated. The system has been developed using Microsoft Visual Basic, and operates under Microsoft Windows 95/98 or NT4.

7.1. System architecture

The architecture of the risk system has been developed to ensure that the final system is adaptable and upgradeable. The current system is generic, but it is acknowledged that individuals/corporations will prefer specific systems based on the rules of their particular business. To ensure that system changes are minimised, the system has been developed using a three-tier client/server architecture [25]. Within the three-tier client/server architecture the three layers are conceptual rather than physical, and they separate the user (and user interface) from the corporate rules (server) and data. Within the current system, the server level actually comprises of two servers, with the possibility to add more as required. The use of a client/server architecture allows other servers to be developed and added to the system with relative ease. This is particularly useful, as multiple servers can be developed for the analysis process, possibly using different programming languages. These servers can then be accessed using the client, allowing maximum freedom to update and customise the system as necessary.

The main benefit of using a three-tier client/server architecture is that the data is completely separated from the user. This independence enables modifications to be made to each of the modules individually with little or no impact on the others. This is useful if, for example, certain risk rules within the server need updating, as it can be done without affecting the behaviour of the other two segments. The

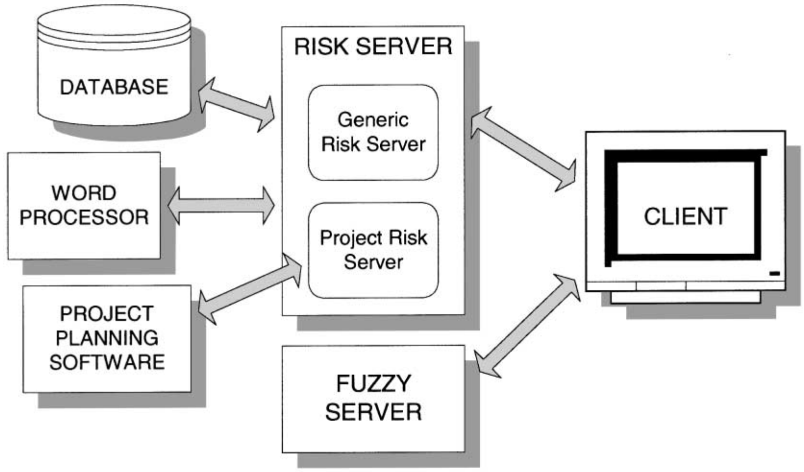

Fig. 3. The three-tier client/server architecture for the risk system.

three-tier client/server architecture for this system is shown in Fig. 3. The role of each layer is detailed below.

The *client* module is perhaps the most important as far as the user is concerned. It is the client which controls the graphical user interface (GUI) with which the user can interact in order to perform the risk management process. The client application makes calls to the server then communicates with either of the three data applications. This allows the client to store or retrieve data indirectly. The client can be thought of much like a web-browser — it performs many functions involving user-interaction, but the bulk of the processing work is done behind the scenes, in this case by the risk server.

The *risk server* application controls the information flow between the client and the data stores/sources, effectively forming the heart of the risk management system. All the information the client requires is controlled by this server on its way to and from the data stores. Within the system, the risk server has been divided into two sections — one for generic risk data, and one for project risk data. Of these, the generic risk server is only able to access certain data files within the database, specifically those relating to generic risk information, such as the risk and action catalogues, client and member data files, etc. The project risk server is able to access the remainder of the data files within the database, and can also access project specific information within the project planning software. The generic risk server is activated when the client application is initially launched, whereas the project risk server does not become active until a specific project file is opened within the client, whereupon it remains active until the file is closed (or the client application is shut down.) The reasons that two independent risk servers have been set up within the risk server application are twofold; firstly, the separation of the two areas — generic and project specific — enables the whole system to operate more efficiently, as the individual datasets can be accessed as and when they are required; secondly, it allows security measures to be implemented to ensure that only those who are allowed are able to access the project specific risk data, providing potential protection to the company using the system.

The *fuzzy server* controls the calculation of all fuzzy logic information, including linguistic variable quantification, defuzzification, plus typical fuzzy set operations and fuzzy inference. Fuzzy representations of all descriptive values can be determined and controlled through this server. The fuzzy routines and functions have been implemented in the form of a server to ensure that changes can be easily implemented where necessary, and to allow the use of other risk analysis paradigms via other servers if required. The servers within the system have been set up using OLE automation, and as such they can be used by other OLE-compliant applications if required.

Data is clearly fundamental to the operation of the risk system. There are currently two data stores used. The first of these is the *database*. This stores most of the data the system uses and currently contains 34 data files; 18 of these contain generic risk information while 16 contain project risk data. The database chosen for the risk management system is Microsoft Access. This package was selected for several reasons, including: its popularity as a user-friendly relational database within industry; the fact that it is available for a reasonable cost; and, its Visual Basic support via VBA. However, its scalability and robustness will never match any of the high-end database servers used in practice, and its implementation of SQL is questionable at best. To reflect this the complete database is now being ported over to SQL Server, which will be better able to handle the large amounts of data, which the final database is likely to contain.

The second data source is the *planning software*. This stores vital information about the project tasks and the planning information, which can be updated on the fly as risks affect the tasks and the project itself. Most of the information detailing the risks is stored in the database. However, some of the project and task information, such as timing information and notes, is stored within the project file. This saves valuable space within the database, and speeds up the operation of the risk management system. The planning software chosen is Microsoft Project. There are more powerful planning packages available commercially, but Project has the advantages that it is cheap, simple to use, and is easy to link with Visual Basic using VBA and OLE. However, the use of the three-tier client/server architecture allows the use of other planning packages with minimal system changes.

Additionally, an OLE link to a *word processor*, in this case Microsoft Word, has been developed for report generation. The system is able to generate text-based reports internally, but properly formatted reports can be exported to the word processor for inclusion in project and company reports, etc.

7.2. Overview of the system in use

The use of the risk system in practice broadly follows the processes described previously with one addition — the manipulation of the generic risk data. This is project independent, and hence does not form part of the risk management process model. Each of the stages is described in general terms below.

7.2.1. Manipulation of the generic risk data

There are 18 data files within the database which contain generic risk information. These cover the contents of the risk, action, and risk-action catalogues, staff and client data, generic risk strategy information, etc. Access to this information is available for all projects, and this information can be modified and updated independently of the project data. The most important generic risk data is the catalogues themselves. All risks within the system are based on entries contained within the generic risk catalogues, hence each risk must be defined generically before a project specific version can be added to a project risk repository. These generic items are defined using the common language, hence for each risk its type, scope, centre and risk must be defined. Additionally, for risk factors the risk's risk factor value must also be defined. To ensure consistency throughout, data files contain the lists of risk types, scopes, factors, risks, and risk factors. Of these, the first two are limited in size (the list of available terms is fully defined), but the last three lists are theoretically infinite in size and can grow with organisations. Items must be defined within these data files before they can be applied in any of the catalogues.

7.2.2. Identification

This represents the initial stage of the risk management process, the birth of a new risk. The aim is to identify exhaustively all significant sources of risk within a project, as well as the causes of those risks, and as such risk identification is perhaps the most critical part of the whole risk management process — there is no way that a risk can be assessed, analysed, or controlled if it hasn't been identified in the first place. Additionally, the inter-relationships between the risks, and the classification of the risks will need to be identified. It is one of the operations which is primarily performed away from the risk system, and the processes by which risks are initially identified will vary between organisations but usually include one or more of: site visits; input from key project participants; brainstorming sessions with an assembled risk team; and from information extracted from a repository of risk data compiled from previous experience. The use of the risk catalogue enables generic risks to be identified, and the future implementation of a knowledge-base to identify the sorts of risk which applied to similar projects in the past, help in some ways, but these have a tendency to restrict original thought with respect to risk identification [26] hence the traditional risk identification methods are likely to remain for the moment. The risk catalogue at least ensures that the description of risks remains consistent through an organisation's project portfolio and history. Once identified the outline properties of the risk must be defined. perhaps the most important at this stage is the item which will be affected by the risk. This is usually the project for global risks and a task or work package for local risks, however risks can affect each other via risk dependency chains as described previously.

7.2.3. Assessment

The second process within the risk management process is risk assessment. Here the technical aspects of each risk are assessed and defined. The important characteristics considered are the timing of the risk, the likelihood of the risk occurring, and the impact of the risk should it occur. Traditionally, numerical values have been used to define the characteristics of identified risks, and statistical techniques have been applied to the analysis of the risk network. In this work, the characteristic values are defined using linguistic variables, such as low, medium, and high, with additional adverbs including *very* and *somewhat*. Descriptive phrases are used as they are representative of the type of language used by project managers to describe risks, rather than the cumbersome, and often erroneous, process of applying statistical probabilities. Fuzzy logic will be used to perform the mathematical quantification of the linguistic variable at the analysis stage as described in a ensuing section. The difference between risks and risk factors is particularly evident during assessment and analysis. Risk factors form the lowest level of the risk hierarchy, and they are used to determine the overall severity value of the risks which they affect within the system. Thus, they must be fully defined with likelihood and severity values, as the magnitude, or impact, value of the risk factor is determined using a fuzzy combination of these values. Risks, however, need not have their severity value defined, as this is determined by the risk factors which affect it. However, if risk factors are not used then risks must be defined completely.

Risk inter-dependencies are determined during risk

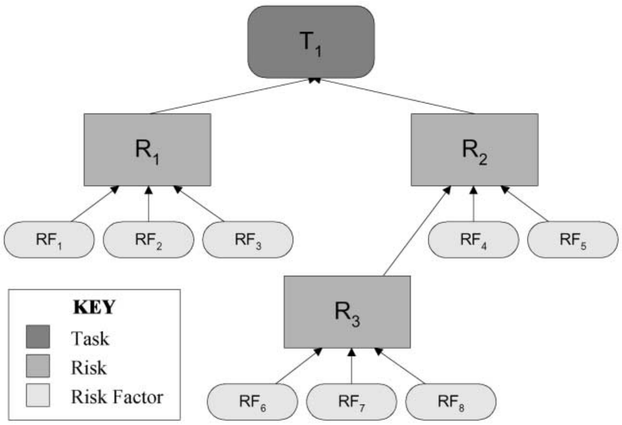

Fig. 4. A risk dependency chain.

identification and assessment, and are defined using risk dependency chains. These show all the risk factors and the risks they affect, and in turn the other risks, tasks, and the project they may affect. An example risk dependency chain is shown in Fig. 4. In this example, risk factors RF_1, RF_2, and RF_3 affect risk R_1, risk factors RF_4, RF_5 affect risk R_2, and risk factors RF_6, RF_7 and RF_8 affect risk R_3. Task T_1 is affected by risks R_1 and R_2, and risk R_2 is affected by risk R_3, hence the risk dependency chain for the risk factors, the risks, and the task is defined. The actual effects of the risk factors and risks is dependent on their likelihood and severity values, where appropriate. The relationship between R_2 and R_3 includes a dependence magnitude value, which defines the level of dependence between any two dependent risks. Risk inter-dependencies have been included in the system to allow for the fact that in practice, risks are not always independent of each other. Risk dependency chains enable risks to affect other risks in much the same way that risk factors do.

7.2.4. Analysis

The risk analysis process is the stage at which the various aspects of each risk — likelihood, severity, and timing — together with the risk dependency chains, are used to determine the effects of the risks on the project and the tasks within the project. Once the affects of the risk factors on the risks have been determined, the effect of the risks on the tasks can be calculated. As described previously, there are currently four characteristics which risks affect within the system: time, cost, quality, and safety. Only risks (not risk factors) directly affect the project and tasks. As described in the previous section, fuzzy logic has been implemented for the whole analysis process. Using fuzzy logic and the magnitude levels of the risks which affect the tasks and the project, the risk imposed changes on the characteristics for the project and each of its tasks can be calculated. The fuzzy analysis of the assessed risks is very much a background operation. However, whilst the analysis takes place in the background, information detailing it is provided for the user. Once analysis is complete the risks are prioritised according to their magnitude and timing characteristics.

7.2.5. Handling

Once the analyis process is complete, the risks and their effects have been quantified and it becomes necessary to set up procedures to handle them effectively. The manner in which the risks are handled in the system is crucial — there is little point identifying, assessing, and analysing the majority of risks unless some sort of risk avoidance or alleviation strategies are applied (unless, of course, the chosen strategy is to ignore the risk.) During this process, a risk alleviation strategy can be adopted and an appropriate remedial action can be flagged. These measures exist to be implemented should the identified risk occur within the project. The characteristics for these strategies and actions need to be defined. Additionally, the cost of the remedial actions can be determined.

7.2.6. Monitoring

Risk monitoring is the final stage within the risk management process, but it does not represent the end of the risk management cycle. This stage is very important, probably second only to the initial identification stage in the risk management process. Up until now, the project risks have been identified, assessed, analysed, and some kind of risk handling strategy has been adopted for them. Now the risk must be monitored to ensure that any avoidance measures are working, and to enable effective action to be taken should the risk occur. In this case, the status of the risk changes and the monitoring process continues to ensure that the assessment and handling procedures are effective, and if so that the remedial action and strategy are working. If any of these prove to be negative then the risk may need to be re-assessed, re-analysed, or a new handling strategy adopted. Risks may also be removed from the project, if their chance of occurrence has passed, or if they have been dealt with. Monitoring does not cease until the project is complete, which may be a very long time if the full project lifecycle is the subject of the risk management process. Fig. 5 shows a screen shot of the prototype system in use.

8. Conclusions and further work

A common language for describing risks and remedial actions, grounded in a taxonomy of risks and actions based on a HRBS, has been described. The language uses a number of taxons and constructs to define generic risk and action terms which can then be stored in generic catalogues. Project specific risk information is based on the items contained within these catalogues, but it is customised for each project. However, the heritage of these items is not hidden, enabling a comparison to be made between similar risks on different projects. The language allows for consistent quantification of risk likelihood and impact values. The relationships between risk factors, risks, and their consequences have been developed and demonstrated on cause and effect diagrams. Additionally, fuzzy association

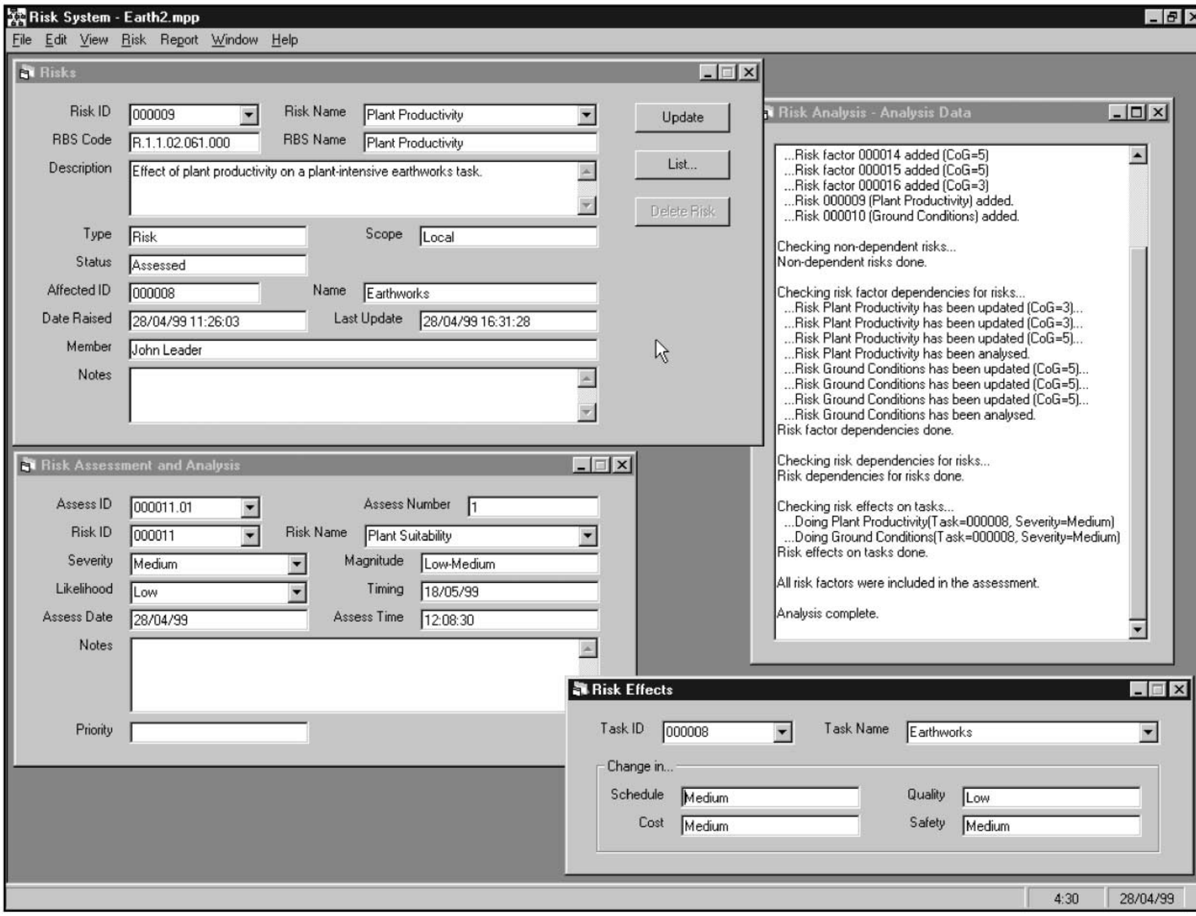

Fig. 5. The prototype risk management system in use.

and composition have been applied to identify relationships between risk sources and their consequences on project performance measures. The use of fuzzy logic allows for the use of descriptive linguistic variables for the description of risks and their consequences, whilst allowing consistent quantification throughout.

A prototype risk management system has been developed to support the risk management framework presented. This consists of a single user-friendly front end which controls all aspects of the risk management process, and integrates with a database management system, project planning software, and a word processor, allowing the system to seamlessly access all risk and project information as required. The architecture of the system is designed to be flexible, allowing the system to be customised to individuals and corporations with relative ease.

Work is currently being done to refine the prototype model, including improving the qualitative risk assessment and management modules, and investigating the use of other techniques, such as case-based reasoning. This will enable knowledge capture, re-use, and comparison facilities to be implemented for decision support purposes. Perhaps one of the greatest problems facing such systems is their acceptance by construction professionals. A formalised risk management process is still a rarity within many construction organisations, and the groundwork needs to be laid to enable risk management to become an accepted part of the construction process, much like planning and financial analysis are currently. To this end, the prototype is being used as a basis for discussion with practitioners about the practical requirements of the approach for further development to satisfy the needs of industry. Meetings are taking place with a variety of organisations, including contractors and quantity surveyors, to determine how best to approach the task of implementing formal risk management procedures within organisations, which encompass the full project lifecycle and the whole supply chain. The aim is to facilitate practical and effective risk handling whilst allowing those involved in the process to develop a greater understanding of project risks, resulting in improved project and corporate performance.

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