A CBR-based Decision Support System Framework for Construction Supply Chain Risk Management

First A. Vinit Kumar, Second B. N. Viswanadham, Indian School of Business, Hyderabad, India

Abstract— Risk Management is an essential process of construction project planning. Many critical risk factors remain unconsidered during the project planning phase. When a risk event occurs during project execution, the required actions are taken by project managers using their own experience and knowledge. Due to extremely complex and dynamic structure of construction supply chains, risk management remains experience intensive. While knowledge and experience gained in past projects is very useful in identifying and managing risks in a new project, such information resides primarily in Project Managers' minds and is seldom documented in a reusable form of information. A decision support system with a case-base of previously taken actions and a record of previous risk management plans can assist managers in risk management of construction supply chains in a new project. This paper suggests the framework of a Decision Support System adopting Case-Based Reasoning approach; which can support decision makers in preventive as well as interceptive construction supply chain risk management.

I. INTRODUCTION

A construction project supply chain may contain hundreds of firms, contractors; subcontractors; material and equipment suppliers; engineering and design firms; and consulting firms etc. (see [14] and [17]). It remains highly fragmented and involves many small and medium size suppliers and subcontractors (see [4] and [5]). Many a times materials have to be imported and supply chain becomes global and more difficult to manage. Also construction projects need a high level of coordination among various stakeholders, who have conflicting interests (see [18]), during the life of the project and involve various short and long-term business to business relations.

Given the above mentioned characteristics of construction supply chains, a construction firm has to deal with various kinds of risks during construction (see [15], [3], and [11]), which are associated with project delay, cost over-run, and unsatisfactory quality. While risk management is a critical activity in construction project management, existing industry practices involve tools like risk registers, risk management spreadsheets, brain storming sessions etc. As a result many risks remain unidentified, and proper risk management becomes impossible (see [20] and [13]). Due to short-term project mentality of construction firms and return on investment issues, construction firms are averse of using Decision Support Systems for risk management.

Many industry people attribute the short-term mentality to the fact that each project is different. While each project is different in a general sense, structure of supply chain, many processes involved in construction projects, and materials remain common in different projects. As an example, every building construction will constitute processes like site preparation, masonry work, tiling, brick-laying, roofing, plumbing, electrical wiring etc. and materials like bricks, cement, sand, tiles, wire, switches, etc.

Procurement of each material and service involves risks at various nodes of the procurement channel. The similarity relations of various construction projects, as mentioned in the previous paragraph, motivate us to present the framework for a Decision Support System (DSS) which can be used for risk management of construction supply chains in multiple projects.

As risk management in construction firms is highly experience intensive, the use of knowledge engineering tools becomes an obvious choice. We believe that a DSS which supports the risk management decisions in construction supply chains and can be used for various different projects would bring enormous savings to construction firms. For the same purpose we propose a Case-Based Reasoning (CBR) based DSS which ensures return on investments.

II. LITERATURE REVIEW

Many authors have expressed their concerns about existing supply chain risk management practices in construction industries. Among them are, [13], who shows a few cases of improper risk prediction and importance of supply chain risk management in construction, and [10], who describe various causes of delays in construction projects in developing countries.

Ref. [11] provides a systematic way to quantify the uncertainty involved in construction schedules. [20] considers environmental risks in construction projects, where they discuss two case studies and suggest that the knowledge engineering tools can be used in managing environmental risks using the available knowledge in risk registers. [15] proposes a qualitative risk assessment model with a fuzzy logic approach. [2] uses Monte Carlo Simulations to analyze and evaluate construction project

F. A. Vinit Kumar works as a researcher with Centre for Global Logistics and Manufacturing Strategies, Indian School of Business, Hyderabad, India (e-mail: vinitkmishra@gmail.com)

S. B. N. Viswanadham is the Professor and Executive Director, Centre for Global Logistics and Manufacturing Strategies, Indian School of Business, Hyderabad, India (e-mail: N_viswanadham@isb.edu).

risks. [16] takes a Knowledge Engineering approach and present a qualitative risk analysis framework using object modeling for managing supply chain risks in construction projects. These efforts either provide suggestions or deal with risk analysis rather than providing a comprehensive solution for risk management.

Use of CBR systems is proposed to solve a wide range of experience-intensive problems. We suggest readers to refer to [8] which proposes the application of CBR systems in the risk analysis for electronic commerce, [19] which discusses the application of CBR-DSS for third party logistics evaluations, and [7] which proposes CRAS-CBR, a prototype CBR decision support model which supports the decision-making on the assessment of the level of control risk of the general accounting system in the manufacturing industry.

III. OUR CONTRIBUTIONS

We propose a CBR-DSS which can be used in construction supply chain risk management. The system features are based on the identified characteristics of construction projects and used in the development of the CBR-DSS. System developers can follow the methodology discussed in this paper to develop customized systems for their client construction firms. To the best of our knowledge, this paper is the first attempt to apply CBR in a Decision Support System for construction supply chain risk management.

IV. PROBLEM DESCRIPTION

Construction supply chain is highly complex and performance of all the stakeholders is inherently unpredictable and chaotic in nature. A construction firm seeks safety mechanisms to protect itself against these unpredictable events. While risk analysis starts right at the competitive bidding process, risk management is an essential part of the project planning stage. As the project has to be secured against various risks, which can occur any time during the project life cycle, risk management process remains an integral part throughout the project execution period.

Supply chain risk in construction can be defined as the distribution of loss resulting from supply and demand mismatch within the supply chain, among various players such as subcontractors, material suppliers, design engineers etc. This mismatch is caused by variation in material and information flow among various stakeholders, both service and material providers. Supply chain risk events finally result in project delays, cost over-run and inability to cover the project scope (quality issues) and may degenerate into huge losses to the firm. Fig. 1 illustrates a typical channel for the supply chain of an imported material. A construction supply chain may consist of hundreds of such channels (for various materials and services) and involves risks at various nodes.

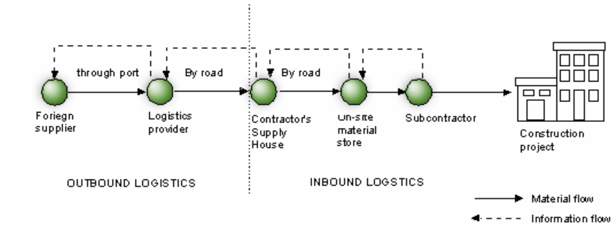

Fig. 1. A typical channel of procurement of an imported material in construction supply chains

After a construction firm signs the contract to deliver a project, the problem of handling supply chain risk due to unpredictable events is twofold, and has to be tackled at various strategic and operational levels. The first problem is of *preventive risk management,* in which the contractor has to find out various mechanisms in order to make the supply chain robust and risk resilient. For example, a firm would make its material procurement strategies, so as to minimize the occurrence of risk events, like delays in procurement. The whole process involves identification of risk events with their sources, prioritizing risks, and devising ways in which probability of occurrence of such events can be minimized. The second problem is of *interceptive risk management*, where the contractor has to take a decision on the best action that should be taken subsequent to a risk event in order to contain the loss. For example, what should be done if a critical component could not be procured? Can this component be procured from an exchange or need it be imported?

In the remaining part of this paper we describe how a CBR-DSS, which can be used to handle preventive as well as interceptive risk management, can be built. Risk analysis tools along with the theory of CBR systems are used to present the framework.

V. CASE-BASED REASONING IN CONSTRUCTION RISK MANAGEMENT

CBR is an approach to solve a problem based on its analogy with previous cases. CBR systems contain a case-base of previously experienced cases, which are composed of several well defined problems and their solutions. A case is nothing but a previous experience, where a problem was faced and solved successfully. A CBR system contains many such cases relevant to the goal of CBR system and is domain dependent.

Construction supply chain risk management is highly experience-intensive. While current practices of risk management in construction involve brain-storming techniques, it is highly erroneous because human memory is limited and many a times critical risks remain untouched during these brain storming sessions. Also previous data used in risk analysis does not serve as a good input in the risk management process because of changing practices in business environments. A CBR–based DSS for construction supply chain risk management would help risk managers in making various kinds of decisions to minimize risk.

Main process of the proposed CBR system uses the widely accepted Aamodt-Plaza or R^4 Model (see [1]). It involves four main processes namely, **Retrieval**; in which the case/cases most similar to the current problem is/are retrieved from the case-base, **Reuse**; in which the solution suggested by retrieved case is analyzed for solving the current problem, **Revise**; in which the solution has to be adapted if the solution retrieved could not be used in the current problem, and **Retain**; in which the current case with successful solution implementation is retained in the case-base as a new case. As construction supply chains are highly dynamic in nature and change from project to project because of change in location, project type, and resource availability, case revision or adaptation is a critical step. The CBR process of the system is illustrated in fig. 2.

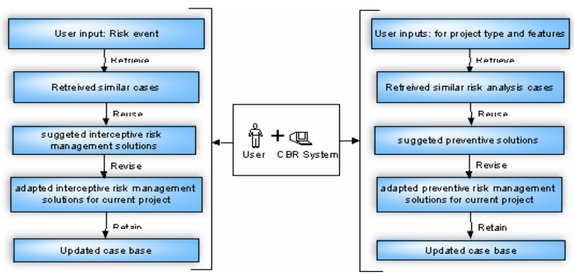

Fig. 2. CBR process for the integrated DSS: interceptive (left), preventive (right)

The whole process of CBR system is based on case representation. The case representation for preventive risk management should cover the important features of the project so that risks relevant to the current project can be covered in the retrieved cases and various alternatives to minimize the probability of risk events can be suggested. Also the system should be able to provide a measure of risk consequence associated with each risk event so that the prioritization of risks is possible. For interceptive risk management one has to make sure that system retrieves the most similar case/s of risk event and suitable mitigating strategies and alternatives are suggested. Designing an integrated CBR system for both the preventive and interceptive risk management of construction supply chain requires the clear understanding of various risks and critical project features which induce the risk events.

VI. PREPARATION FOR THE SYSTEM

A project delivered by a pre-specified delivery day (as per the contract), within the budget of the project, and meeting customer specifications can be considered as successful. Any event causing deviations from these parameters would be called as a risk event. Such a risk event can occur at any node of supply chain; it can be at supplier or subcontractor's end or can be an internal risk if it occurs in contractor's end. As an example, if the contractor has its own design team, issuing a wrong design will be an internal risk event which may cause the delay, and any kind of disruption in supplier's production plan is an external risk event. Risk analysis consists of identifying the risk events (internal & external), finding their probability of occurrence and the consequence associated with the event.

A good case representation should incorporate the important features of construction projects, which affect the risk analysis. It should also promote the effective and efficient search of the cases. For such a case representation, in present context, it is important to know the nature of supply chain risks, the sources of risks and the consequences of risk events. Following subsections suggest tools to deal with them.

A. Characteristics of construction supply chains

The CBR system proposed here is based on the following characteristics of construction supply chains in the context of risk management.

1) A particular project type (road, airport, thermal power plant etc.) involves same materials, same processes, and a similar supply chain structure. Although technical specifications of components and equipments required can be different, suppliers and subcontractor firms may change but the inherent characteristics of supply chain remain the same.

2) For a construction project, a firm has to either procure materials/components/equipments or it has to procure services like design/engineering, electrical wiring etc. Issues in Supply Chain Risk Management of material and service supply chains are different and the partition of risk events in two categories of material procurement risk and service procurement risk gives an effective way of classification in case representation which would facilitate efficient and effective retrieval of cases in CBR system.

3) Some materials/services are highly prone to risk, while others are not. If the component has to be imported, or has a few suppliers, or has high cost, or has no substitute etc., its timely procurement at specified cost becomes difficult. During risk management process one would like to focus on high risk-prone materials and leave the others. To serve an example for critical services, consider engineering projects like construction of oil platforms. Here engineering/design and site topographic survey are two highly critical services where a minor error may cause instability of platform and degenerate into huge losses. Material/service-specific supply chain risks are almost similar and remain independent of the project type. For example procurement of an industrial turbine involves almost similar supply chain risks, independent of whether it is used for hydro electric or thermal power plant.

A material/service is "critical", if the deviations associated with its cost, quality and delivery may result in a *significant delay in construction, high cost over-runs, and unacceptable mismatch in specified project quality/scope.*

Critical materials/services would change from project to project and a firm has to identify them for a project, based on the previous data of risk analysis. A description of such critical materials and services is shown in Table I and Table II respectively.

TABLE I
EXAMPLES AND DESCRIPTION OF CRITICAL COMPONENTS

Description	**Example**
Component is critical to project operation	A turbine in power plant
Continuous supply of component is required	Concrete in road building project, cement in house building project
Component has to be imported	Any component which can not be procured locally.
Fewer suppliers are available	A high-tech machinery which has few suppliers
Susceptibility to damage is high	Cement, glass materials etc.
Substitution is not possible	Technical component in which engineering is involved. Ex. Turbine, pumps etc.
A high price component	Baggage handling systems in airport

TABLE II
EXAMPLES AND DESCRIPTION OF CRITICAL SERVICES

Description	**Example**
Service is critical to project operation	Engineering & design of critical components in Engineering projects.
Long-term provision is required	Logistics services
Service requires highly technical skills	Engineering consultancy
Switching cost is high	Design services
Service has critical dependencies (logical relationships) with other sub-processes	Material procurement

B. Identifying project features

For the purpose of case representation it is important to identify the important project features which induce risk events and categorize them for efficient retrieval in CBR process. To identify these project features, one can perform a Fault Tree Analysis (FTA) for various risk events. FTA is used to identify basic causes of risk events and to find their probability of occurrence. Fig. 3 illustrates an example concerning the delay in procurement of a critical component (procurement channel is same as in fig. 1) at subcontractor's end.

FTA for various failure events suggests that some risk events are induced by the sources which are external to project features and type. Port shut-down and regulatory issues are two such examples. Other risk events are project feature-dependent and hence can be analyzed using the information regarding these features. Table III illustrates some of these project features. For example, poor connectivity of site to various suppliers induces risks of delays in procurement and cost over-run, natural disasters like flood may induce complete disruption in project execution, poor IT infrastructure and telecommunication may induce delayed information flow etc.

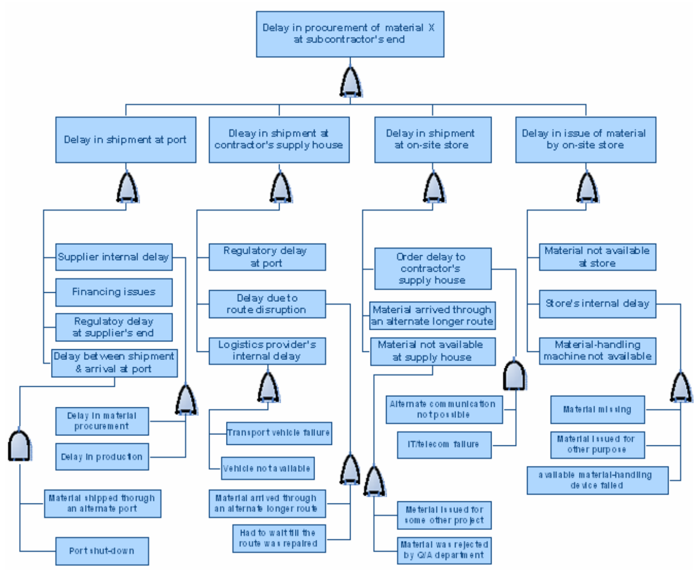

Fig. 3. Fault Tree Analysis of a failure event associated with a critical component X

TABLE III
PROJECT FEATURE CATEGORIES

Primary feature category	**Secondary feature category**
Location features	Connectivity
	Topography
	Resource availability
	Susceptibility to natural disasters
Supplier/service provider features	Lead time
	Capacity constraints
	Quality of product
	Financial constraints
	Credit rating
Support technology features	IT infrastructure
	Telecommunication
	Support equipments / machinery
Project contract features	Time and quality specifications
	Penalty clauses
	Susceptibility to project scope change

If the firm is to develop a case base using previous risk analysis records and data, it has to decide on critical components and services involved in the supply chain. Then using FTA and Cause-Consequence Diagrams, probability of occurrence of risk events and risk consequences can be found respectively. With the available data and other available knowledge sources, one can then find expected loss associated with the various risk events and possible risk mitigation strategies can then be stored in the cases.

On the other hand if the CBR system is well established, the new cases of preventive and interceptive risks have to be stored in the system, as and when they occur, as per the frame of case representation.

The CBR system proposed here is based on the above mentioned characteristics of construction project supply chains and project features. As described in the subsequent sections, we use these characteristics so that an efficient retrieval of similar past cases is facilitated.

VII. SYSTEM ARCHITECTURE

This section discusses the CBR system architecture in order to facilitate the previously mentioned system process for construction supply chain risk management. Various recommendations related to system architecture are made and a framework is presented rather than a solution of a specific case.

A. Case representation

We represent the case class as an 8 component-group as

$$< T, F, CS, R, \Pr, C, I, \Pr e >$$

where,

T is the **type of project**. It may include various project types a firm is involved in. The value of T can be airport, road, hydro power plant, railway etc.

F is an n-tuple describing **features** of the project. It may include location features such as; topography and connectivity, Weather conditions; such as rainy or wintry; Support infrastructure features such as IT connectivity with suppliers and transportation facility condition, supplier/subcontractor related information such as production capacity, and any other features which influence the occurrence of supply chain risk.

CS is an n-tuple containing **components or services** to which the risk is associated. For example, the risk event "delay in procurement of a turbine due to port closure" will involve turbine as component and transportation of turbine as service.

R is a well defined n-tuple containing **risk events**. Risk events should be defined neatly. The events causing delay in material/service procurement can be entered as "delay in component X due to cause Y", in case of partial fulfillment of orders it can be entered as "Partial fulfillment of component X due to cause Y".

Pr is the **probability** of occurrence of the risk event.

C is the **consequence** of the risk event in terms of expected loss. Wherever consequence can not be measured quantitatively, attribute values such as high/low quality deterioration or Delay of x days can be used.

I is an n-tuple of suggested **interceptive risk mechanisms/strategies**. It may also include cost of implementing the strategy and other aspects so that decision maker can choose the optimal strategy.

Pre is an n-tuple of possible **preventive risk mechanisms/strategies** to be used. It may also include cost of implementing the strategy and other aspects so that the decision maker can choose the optimal strategy.

In case of preventive risk management, components **T** and **F** constitute the problem space and other components contain the solution space. User defines the problem by entering information regarding project type and features. Solution space consists of a list of components and services for the current project type, risk events associated with each of them, their probabilities, consequences of risk events and preventive risk management schemes.

In case of interceptive risk management, where a risk event has occurred, problem space consists of the components **T**, **F**, **CS**, and **R** and **I** (interceptive risk management strategies) form the solution space.

A case is represented in object-oriented hierarchical framework as shown in fig. 4. One can arrange the case in attribute-value form, in a structured and hierarchical framework and even using non-homogenous and noisy forms. Each class represents a set of objects and can be defined as <class name, parent class, object>. Attributes (slots) of an object are defined by various facets, in order to characterize the attribute and may contain attribute value, type of attribute value, number of acceptable values for the attribute, graphical representation of attribute values, and associated weights.

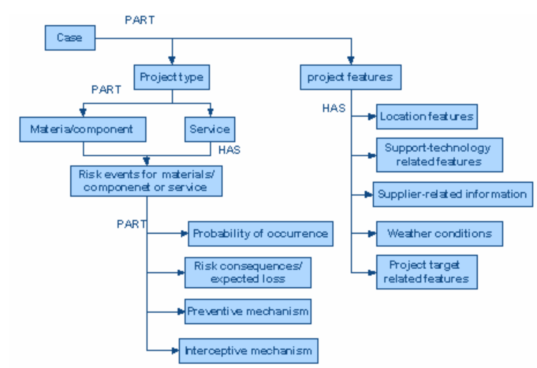

Fig. 4. Case hierarchy diagram for CBR-DSS

B. Case indexing and Retrieve process

Case retrieval process should facilitate retrieval of most similar case/s efficiently. This process is based on case indexing and defined similarity measures. Given the problem description, case retrieval mechanism involves sub-processes of identifying features, index-based partial matching, similarity measure based matching, search, and selection of most similar cases, executed in that order.

Although the case base for preventive as well as interceptive risk management problems is common, retrieval functions would be different. Retrieval algorithm uses the appropriate retrieval function conditionally based on the user's selection of the problem type: interceptive/preventive. Indexing and similarity based matching processes for both the problems would be different as well.

Indexing allows the system to focus on the relevant features of the risk management problem, and hence make the system work effectively and efficiently. For preventive risk management problem, the project type is the only index, and other features of the problems are recommended to be matched based on similarity measures. In this case it would be assumed that the firm has dealt with the same type of project in the past. For interceptive risk management problem, the indexes can be assigned to project type, some of the project features, and components/services. In the integrated CBR system indexing would be conditional based on the user's section of preventive or interceptive risk management options.

The partial index-based matching is not sufficient as the case has several other features which could not be matched using indexes and also the exact matching is highly rare in most of the practical applications. Apart from indexing, the retrieval algorithm uses a *qualitative and multi-attribute similarity* based algorithm. Nearest-neighbor retrieval is the most commonly used technique in commercial applications. It uses following evaluation function to match the cases to the current case.

$$\sum_{i=1}^{N} w_i \times sim(f_i^I, f_i^R)$$

Where, $\sum_{i=1}^{N} w_i = 1$

w_i is the weight assigned by the user to the slot(features) based on its importance for the present project. sim is the similarity function for the primitives, and f_i^I and f_i^R are the values for i^{th} feature for input and retrieved case respectively.

User should remember that for the preventive risk management problem the retrieval algorithm should retrieve the most important risk events so as to make preventive risk management cost effective. This can be accomplished by using a comparison-based function in the retrieval algorithm so that the cases are retrieved in the decreasing order of expected losses.

C. Case adaptation in Revise process

After the most similar cases are retrieved the user has to select the appropriate preventive or interceptive mechanism (as applicable) based on the current case. With more and more cases in the case base, the case base would be bulky and it would be difficult to select the best case for the present problem. At this point of time system needs an adaptation process. Based on the project features and other relevant user inputs, the risk preventive and interceptive strategies are adapted to the present problem. The case adaptation process becomes highly important in construction supply chain risk management owing to the fact that with each new project, the applicability of the suggested risk mitigation strategies can not be guaranteed.

Adaptation process starts as soon as similar cases are retrieved. Adaptation looks for most prominent differences in the retrieved and current case/s. As for the retrieval process, the adaptation process also uses a similarity function or metric and based on certain defined rules will retrieve the cases which take the differences between retrieved and current case/s into account. Rule-based case adaptation is widely used and is suitable for our problem. Rules are defined which restrict the application of suggested risk management strategies based on certain constraints. After the cases are adapted to the current project, user has to make a risk management strategy based on the solutions suggested by the CBR system.

D. Retaining the case

Subsequent to a risk event if a successful risk management mechanism is identified, the experience should be retained in the case base as a new case. At this point in time the managers should also identify possible interceptive risk mechanisms which can be used to prevent the occurrence of the risk event. New cases should be retained with the approach suggested in fig. 5.

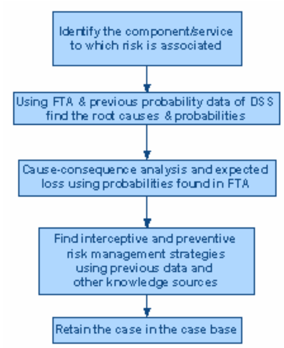

Fig. 5. Proposed approach for retaining a new case

VIII. A SAMPLE CASE

The case study of £100 Million Durand Centre shopping mall (constructed on an existing site in southwest London, UK during early 1990's) construction considered here is described in detail in [12].

The general contractor Stone Builders held contracts with various subcontractors. Standard penalty clauses for liquidated damages were in place. The two main subcontractors were Seaview Steelwork, who was responsible for off-site steel fabrication and on-site steel erection, and Boulder, who was responsible for concrete construction. Steel erection was on the critical path and Boulder's job was to follow the steel erection process of Seaview. After the concrete construction was over other subcontractors were to perform fire protection, blockwork, screed, cladding, and inverted roofing. The construction site was divided in six areas and Seaview was to follow the on-site steel erection sequence of areas 1>2/3>6>4/5.

A delay in steel fabrication resulted a delay of six weeks in steel erection on-site. The delay was not anticipated and didn't become apparent until it occurred on-site. This case is a classic example of how supply chain risks affect a construction project. The company incurred an additional acceleration cost of £231,000 because of these risk events.

A brief record of Stone's monthly reports is given in Table IV to give the reader a clear idea about the events.

TABLE IV
A BRIEF RECORD OF STONE BUILDERS' MONTHLY REPORTS

Date	Remarks
28.4.	Handover to Seaview made on time.
26.5.	Steel erection work on area 1 is over and the area is handed over to Boulder. Seaview started work on area 2/3
23.6.	Rain and heavy wind caused a loss of 100 crane hours. Seaview is in possession of area 2-5. Area 6 will be handed over to Seaview on June 6
28.7.	Weather conditions are better but have caused a delay in steel work. Area 2/3 is expected to be handed over on time, but areas 4/5/6 are 3 weeks behind the schedule. In spite of the weekend working and night shifts for steel work, delay in area 6 is inevitable
29.8.	A fire on the ground level at the end of July disrupted works and requires replacement of some existing beams. Boulder reports delay in its work because of delay in handover by Seaview. Area 2/3 and 4/5 have not been handed over to Boulder as per the schedule. First floor section of area 6 is 6 weeks late. Seaview's failure to complete sections of work and to give accurate revised dates would delay the work of other subcontractors.
22.9.	Steel erection has improved. Seaview has announced 6 weeks delay in the handover of area 6 to Boulder. Stone has to take the action to contain the loss because of delay.

As steel erection was on critical path, a delay of six weeks could have been very costly. As per the contract, a six weeks project delay would have cost £300,000 with the liquidated damages of £50,000 per week. There could have been an extra cost of the allowance for claims from subcontractors for alterations in schedule also.

Stone decided not to let the delay propagate throughout the project, and spent £231,000 extra to pay the subcontractors for the acceleration of the project after the negotiations and discussions. Price paid to each subcontractor for acceleration is given in Table V. It is mentioned in [12], that there could have been a better solution to the above mentioned problem, and the cost of project acceleration could have been lowered.

TABLE V
PRICE OF ACCELERATION PAID TO SUBCONTRATORS

Subcontractor	Price to accelerate the program (in £)
Floor slabs	146,000
Fire protection	34,800
Blockwork	19,500
Screed	0
Cladding	0
Inverted roofing	30,700

After the delay was reported, the project management team of Stone Builders took an action based on the available information and experience of the team members. The knowledge available with this team was limited; hence the number of feasible solutions that could have been thought of by the team was limited as well. A CBR-DSS which contains past similar cases of delay in steel erection could help managers find the various successful alternative actions that had been taken in the past and then the managers could have decided on the best possible solution to contain the loss due to delay. Such a system might provide feasible solutions which the current project team can't think of. A sample of user-system interface screen of CBR-DSS is shown in Fig. 6. The figure shows only a few features in brief.

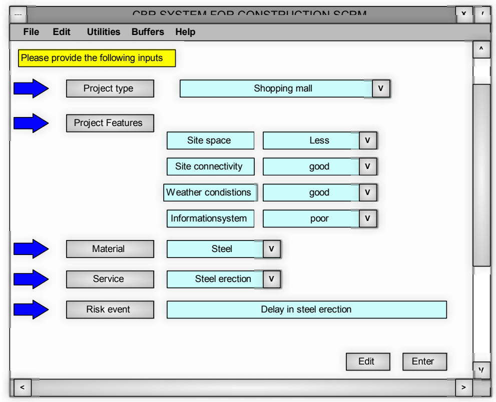

Fig. 6. User-system interface of CBR-DSS

After the user provides the necessary inputs, the system would retrieve the similar past cases and the action taken. All the retrieved cases won't provide the feasible solutions and user would be required to provide rules in order to find the feasible solutions to the present case in the **Revise** process of CBR-DSS. Sequential steps of user-system interface for the considered case have been presented in Fig. 7.

INPUT Project type, Project Features, Material/service, Risk event
OUTPUT Retrieved cases
INPUT Adaptation rules

1. Screed acceleration price=0
2. Cladding Acceleration price=0
3. Concrete construction acceleration price= £146,000
4. No acceleration possible in steel erection

OUTPUT Adapted cases

User analysis of suggested cases

INPUT Show in increasing order of cost of solutions
OUTPUT Case display in increasing order of cost of solutions
INPUT Selection of lowest cost solutions and feasibility study

Fig. 7. Sequential steps of user-system interface during decision making

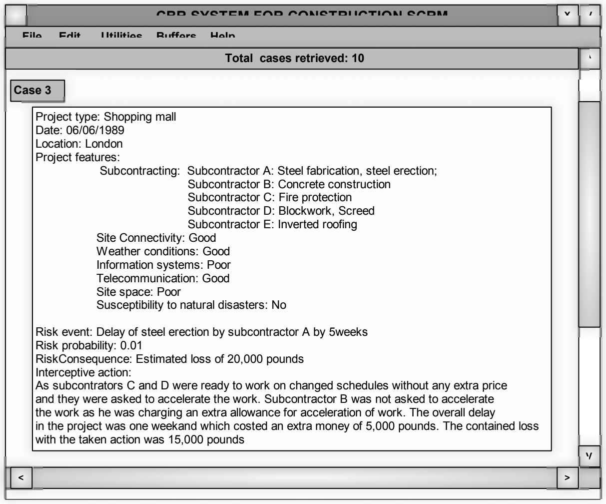

Fig. 8. A sample retrieved case providing feasible solution

Fig. 8 shows a sample retrieved case providing a feasible case.

IX. CONCLUSION

There are many quantitative as well as qualitative models for risk analysis but as explained earlier, the implementation of these models in practice is restricted by the fact that the whole activity of risk management in construction is experience intensive. There is a need of integrating knowledge management and risk management tools to deal with this problem.

We suggested an IT-enabled solution to the risk management problem in construction supply chains. The paper discussed the framework of an integrated Decision Support System based on CBR. The DSS discussed here can be used in preventive as well as interceptive risk management. As the DSS can be used flexibly for various different projects, it ensures the return on investments. For the firms who undertake projects in a particular segment, this CBR system would bring enormous savings. While the framework of CBR system is discussed in detail, preparation for such a system using risk analysis tools is also illustrated. Finally, using a case, we illustrated the input-output sequence of user-system interface and a sample retrieved case of the case-base. This case explains how the proposed CBR system can be used in practice.

REFERENCES

[1] A. Aamodt and E. Plaza, "Case-based reasoning: Foundational issues, methodological variations, and system approaches," *Artificial Intelligence Communications*, IOS Press, vol. 7(1), pp. 39-59, 1994.

[2] J. F. Al-Bahar and K. C. Crandall, "Systematic risk management approach for construction projects**,"** *Journal of Construction Engineering and Management*, vol. 116 (3), pp. 533-546, Sept. 1990.

[3] D. Baloi and A. D. F. Price, "Modelling global risk factors affecting construction cost performance," International Journal of Project Management, vol. 21(4), pp. 261-269, May 2003.

[4] G. Briscoe, A. R. J. Dainty, and S. Millett, "Construction supply chain partnerships: skills knowledge and attitudinal requirements," *European Journal of Purchasing and Supply Management*, vol. 7 (4), pp. 243-255, Dec. 2001.

[5] A. R. J. Dainty, S. J. Millett, and G. H. Briscoe**, "**New Perspectives On Construction Supply Chain Integration," *Supply Chain Management: An international Journal*, vol. 6 (4), pp. 163-173, 2001.

[6] Ericsson, H. M. , "Managing construction supply chain by simulation," working paper, Helsinki University of Technology, Finland, 1999. Available: http://itc.scix.net/data/works/att/ecce-2001-8.content.pdf

[7] S. S. Hwang, T. Shin, and I Han, "CRAS-CBR: internal control risk assessment system using Case-Based Reasoning," *Expert Systems*, vol. 21 (1), pp. 22-33, Feb. 2003.

[8] C. Jung, I. Han, and B. Suh, "Risk analysis for electronic commerce using case-based reasoning," *International Journal of Intelligent Systems in Accounting, Finance and Management*, vol. 8, pp. 61-74, 1999.

[9] J. L. Kolodner, "Case-Based Reasoning," book, publisher: Morgan Kaufmann, Palo Alto, CA, 1993.

[10] N. D. Long, S. Ogunlana, T. Quang and K. C. Lam, "Large construction projects in developing countries: a case study from Vietnam," *International Journal of Project Management*, vol. 22 (7), pp. 553-561, Oct. 2004.

[11] B. Mulholland and J. Christian, "Risk assessment in construction schedules," *Journal of Construction Engineering and Management, ASCE*, vol. 125 (1), pp. 8-15, 1999.

[12] W. O'Brien, M. Fischer, and B. Akinci, "Importance of Site conditions and capacity allocation for construction cost and performance: A case study," in Tucker, S.N. (Ed.), *Proceedings of the Fifth Annual Conference of the International Group for Lean Construction*, Griffith University, Queensland, Australia. Available: http://www.iglc.net/conferences/1997/papers/OBRIEN.pdf

[13] W. J. O'Brien, "Construction supply chain management: a vision for advanced co-ordination, costing and control," *Proceedings of the Berkeley-Stanford Construction Engineering and Management*, Workshop*:* Defining a Research Agenda for AEC Process/Product Development in 2000 and Beyond, University of California, Berkeley, CA.

[14] W. O' Brien, "Enabling Technologies for Project Supply Chain Collaboration," *NSF/ICIS Infrastructure and Information Technology Workshop*, Arlington VA, 2001.

[15] J. H. M. Tah and V. Carr, "A proposal for construction project risk assessment using fuzzy logic," *Construction Management & Economics*, vol. 18, pp. 491-500, 2000.

[16] J. H. M. Tah and V. Carr, "Towards a framework for project risk knowledge management in the construction supply chain," *Advances in Engineering Software*, vol. 32 (10), pp. 835-846, Oct. 2001.

[17] J. Taylor and H. Bjornsson, "Construction supply chain improvements through internet pooled procurement," *Proceedings of IGLC-7*, Berkeley, CA, 207-217, July 1999.

[18] A. Wong and P. Fung, "Total quality management in the construction industry in Hong Kong: A supply chain management perspective," *Total Quality Management*, vol. 10(2), pp. 199-208, 1999.

[19] J. Yan, P. E. Chaudhry, and S. S. Chaudhri, "A model of a decision support system based on Case-Based Reasoning for third party logistics evaluation," *Expert Systems*, vol. 20 (4), pp. 196-207, Sept 2003.

[20] S. D. Zoysa, Y. Wand, and A.D. Russel, "Use of IT in managing environmental risks in construction projects," *ASCE conference proceedings,* 2005.