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# A Generic Conceptual Model for Risk Analysis in a Multi-agent Based Collaborative Design Environment

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**Abstract**
This paper presents a generic conceptual model of risk evaluation in order to manage the risk through related constraints and variables under a multi-agent collaborative design environment. Initially, a hierarchy constraint network is developed to mapping constraints and variables. Then, an effective approximation technique named Risk Assessment Matrix is adopted to evaluate risk level and rank priority after probability quantification and consequence validation. Additionally, an Intelligent Data based Reasoning Methodology is expanded to deal with risk mitigation by combining inductive learning methods and reasoning consistency algorithms with feasible solution strategies. Finally, two empirical studies were conducted to validate the effectiveness and feasibility of the conceptual model.

**Keywords**:
Conceptual Model, Risk, Collaborative Design

## 1 INTRODUCTION

Risk-based design is attracting significant attention in designing large scale products, such as airplane and ship. In conventional risk-based design projects, many risk assessment approaches have been developed in terms of design process and activities [1]. Through these approaches it is easy for designers to determine risk sources and anticipate their consequences after quantifying their probabilities. Global collaboration is a mainstream to distribute product design activities by using up-to-date design tool and technology. However, although this collaborative design is awarding but it involves more uncertainties due to complicating factors [2]. These factors are not only related to multidisciplinary tasks and enormous resources, but also concerned coordination, negotiation and decision authorities within multi-agent interactions. The complexity and associated risks in planning and managing such large scale projects are increased by the need to integrate the functions of both technical and social teams that may be distributed across geographical regions with diverse languages and culture [3].

Despite the importance of risk management given to collaborative design in a few literatures, the subject area continues to suffer from three interrelated problems: lack of risk constraints and variables with regard to an integrated conceptual model for a multi-agent based collaborative design environment; and uncertainty determination relating to how to quantify these constraints and variables in the existing literatures of research; and lack of the appropriate mitigation method for the feasible solution.

This paper presents a constraint-based generic conceptual model of risk evaluation (GCMRE) specifically designed in response to these problems, explicating the processes by which involvement and risk perceptions are caused and influence one another as well as subsequent consequences. The conceptual model identifies three distinct dimensions of risk constraints, and relates these to the relevant variables under a distributed collaborative design environment. Additionally, the validation of the conceptual model is discussed by using two empirical studies.

This study is established on a novel generic conceptual model (GCMRE) which initially maps constraints and variables by using a hierarchy constraint network and then, utilizing an effective approximation technique named Risk Assessment Matrix (RAM) to evaluate risk level and rank priority after probability quantification and consequence validation. The effectiveness of the model aiming for risk management in concurrent engineering (CE) projects is determined by the degree of data sharing and reuse, as well as the available support for decision making processes within the projects [3, 4, 5].The core of the study is an Intelligent Data-based Reasoning Methodology (IDRM) which is expanded to deal with risk mitigation by combining the inductive learning method and the reasoning consistency algorithm with feasible solution strategy. Consequently, the novel model will not only facilitate the decision making from a risk perspective but also emphasize on the data retrieving, storing, sharing and updating.

## 2 A GENERIC CONCEPTUAL MODEL OF RISK EVALUATION (GCMRE)

Under a concurrent multi-agent collaborative design environment, advanced technologies in computer networks have enabled collaborative designers more effectively to collaborate and integrate with a wide range of design agents and resources. Computer Supported Cooperative Work (CSCW) provides a design research area concerned with multi-agent interaction under multidisciplinary task dependencies supported by computer and web networks.

Collaborative design has typically multiple functional perspectives that address interrelated aspects of a distributed product design involving communication and negotiation among engineering agents. Owing to distinct domain perspectives, discipline knowledge and

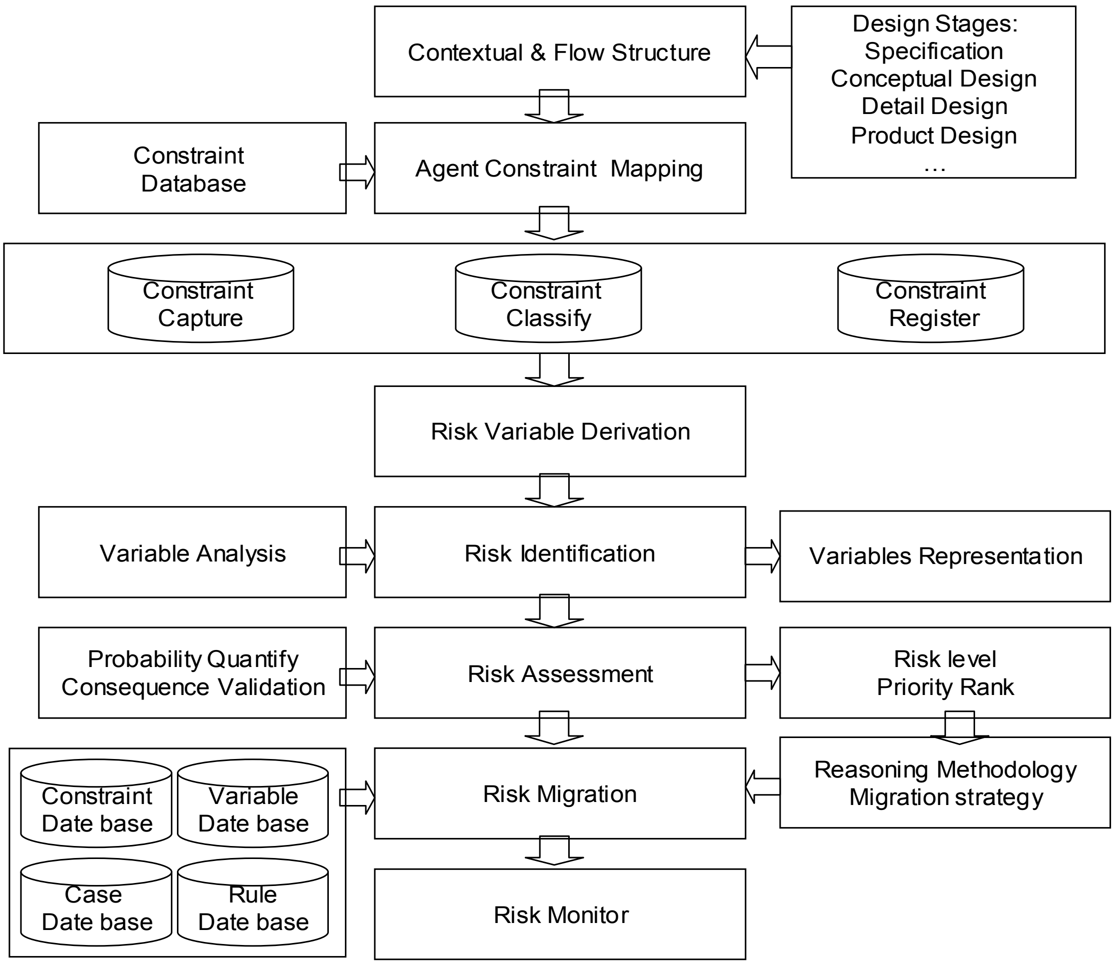


Figure 1: Architecture of GCMRE for Collaborative Design .

evaluation standards in a collaborative design system, collaborative risk evaluation is critical and needs to be further considered. GCMRE is designed as a generic conceptual risk evaluation model in a web-based multi-agent collaborative design environment. The aim of GCMRE is to support a distributed collaborative design through global collaboration from the risk perspective. Figure 1 shows the generic conceptual model and is briefly illustrated below.

### 2.1 Contextual and Flow Structure

The contextual and flow structure is established as a VB module and interacts with customer-based GUI interface. In order to structure the contextual information and model the flow related to different design phases, i.e. conceptual design, preliminary design, detail design, manufacturing and assembling, a database is built.

### 2.2 Constraint Mapping

Constraint mapping is a technique which can manage the uncertainty, constraint relationships and all of the objects related to the constraints in a concurrent and collaborative multidisciplinary design project [2, 6]. In collaborative design, there are many restrictions among multiple design agents, including task based design criteria, design rules, design resources and the up-to-date design techniques. These restrictions under concurrent engineering (CE) can be characterized as constraints, and those classified constraints in the process of collaborative design can form a constraint network or database [2]. From the point view of risk, a constraint must have relationships with risk variables. The emergence of risk variables will result in straight constraint violation, thus the risk variables can be derived and identified by using the constraint mapping.

The constraint mapping can check whether or not the collaborative design result satisfies the whole constraint network by constraint propagation, if not, there must be risk variables that exist, and then we must track them and register the constraints. There are three ways to input constraints by capturing, classifying and registering.

In order to accelerate the constraint mapping, a hierarchical constraint network technique is used in this study. The constraint can be generalized into three levels as shown in Fig.2: task-dependence level, actor-interaction level and resource-integration level.

Task-dependence level constraints represent constraints of the schedule, product quality, time and so on. The actor-interaction level constraints describe the design constraint of various design actors, which link communication, negotiation decision-making, etc. Resource-integration level constraints represent restrictions on knowledge, technology; design material, funding, human resources, etc. For example, in the conceptual design phase, the task-dependence level constraints are the most important factor and the task-dependence level constraint network is propagated first to derive and identify risk variables. With the design goes further, the actor-interaction level constraint is more concerned about, and the constraint network of this level has the priority of detection. At the stage of detail design phase, we need to check the resource-integrated level constraints. Thus, with the help of the hierarchy constraint network, risk variables could be identified promptly.

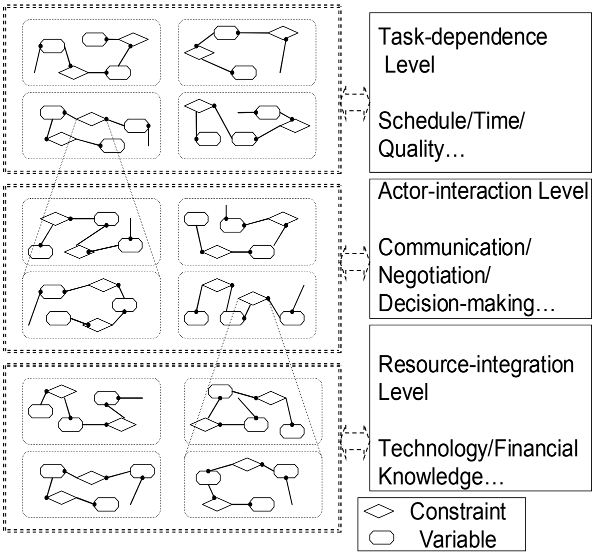


Figure 2: Hierarchy of GCMRE Constraint Mapping .

### 2.3 Risk Identification

Risk variables are derived based on constraint mapping and classified by using some traditional techniques such as Failure mode and effect analyses, Fault-tree analysis, problem reports and records tracking technique etc. There are two relationships among risk variables: independent and dependent. In this study, each risk variable is assigned a unique risk identification number as a reference in order to aid with communication and tracking during the whole risk evaluation process. A comprehensive questionnaire needs to be carried out to gather the general and sufficient risk information. As shown in Table 1, a list of formal risk variable representation with corresponding attributes is created and will be input into the risk variable database. These risk variables also can be inherited in later iteration. The risk variable database is a bank that store and list the risk description and other basic information about each risk variable. The database of risk variables are a good source of lessons learned and useful for identifying risks in the future.

Table 1. Risk Attribute for Collaborative Conceptual Design.

| Constraint | Risk Variable | Probability | Consequence | Risk level | Rank Priority |
|---|---|---|---|---|---|
| XXXX | XXXX | Level | Level | Number | Number |
| ... | ... | ... | ... | ... | ... |

### 2.4 Risk Assessment

After identifying risk variables, a Risk Assessment Matrix (RAM) technique is used for assigning a risk level and a rank priority relating to probability quantification and consequence validation. Since a risk variable is associated with its probability and consequence, some literatures [1, 3, 7] suggest ranking them into several levels in order to quantify or validate them.

In GCMRE, the RAM is adopted by a $3 \times 3$ Risk Assessment Matrix as show in Figure 3 [7]. The probability for each risk variables is assessed as high (H), medium (M), or low (L) according to pre-specified criteria, while the consequence here is addressed as severe (SE), moderate (MO) and Minimal (MI). Through calculation of the magnitude of probability and consequence, a risk level is validated. The risk level is an assigned value from 1 to 9 that indicates how magnitude risk is associated with the overall risk variables. The overall risk level is determined by the lowest value within all risk variables. For example, assuming a knowledge risk probability is quantified as Low (L) while its consequence is validated as Severe(S), the knowledge risk level is equal to 5 in terms of Risk Assessment Matrix Method. So to others risk variables. Considering a cost level risk which is assigned 2, it is the lowest value among all risk variables, the overall risk level is equal to 2 [Figure 3].

| Consequence Validation | Probability Quantify: High (H) | Medium (M) | Low (L) |
|---|---|---|---|
| Severe (S) | 1 | 2 | 5 |
| Moderate (MO) | 3 | 4 | 7 |
| Minimal (MI) | 6 | 8 | 9 |

Risk level calculation:

Knowledge risk level = 5
Technical risk level = 7
Cost risk level = 2
Time risk level =4

Overall risk level =2 (lowest number)

Figure 3. Risk Assessment Matrix Method

Finally, a rank priority is identified in order to decide the sequence of prompted disposal. The high rank priority indicates high significance of risk variables needing to be resolved by choosing an optimum mitigation strategy.

### 2.5 Risk Mitigation

To eliminate a risk variable by mitigation requires feasible a mitigation strategy and sufficient resources to execute the risk mitigation plan [7]. All mitigation strategies can be generated by iterative processes or inherited experience [3]. By combining inductive learning methods and reasoning consistency algorithms, a flow chart of Intelligent Data-based Reasoning Methodology (IDRM) is presented in Figure 4.

In the proposed IDRM, following initial contextual and flow structure, two reasoning consistency algorithms are adopted as the IDRM methods first to match a series of given constraints and variables to rules or cases through database. The constraints and variables are collected as a set of data bank in the database by an iterative or inherited manner. There are three reasoning consistency algorithms related to distinct risk mitigation strategy respectively in IDRM: Rule-based Reasoning Consistency algorithm (RRC), Case-based Reasoning Consistency algorithm (CRC) and constraint or variable relaxation consistency algorithm.

If the proposed IDRM could handle the risk constraint and variable properly, Rule-based Reasoning Consistency algorithm or Case-based Reasoning Consistency algorithm would be called to deal with the risk by matched rules or cases; else risk constraints and variables would be transported to a constraint or variable relaxation consistency algorithm. A corresponding rule-based or case-based mitigation strategy would be implemented appropriately if matching successful. After the risk mitigation solving completely, rules or cases inherited during the IDRM process would be added to the rule or case database by inductive leaning method ultimately.

### 2.6 Risk Monitor

To keep a continual flow of risk evaluation, it is critical to monitor risk status with accurate tracking and recording. Some practical techniques are implementing in practice. Generally risk monitor is applied to chase case and update database and provides the GCMRE further information in the future.

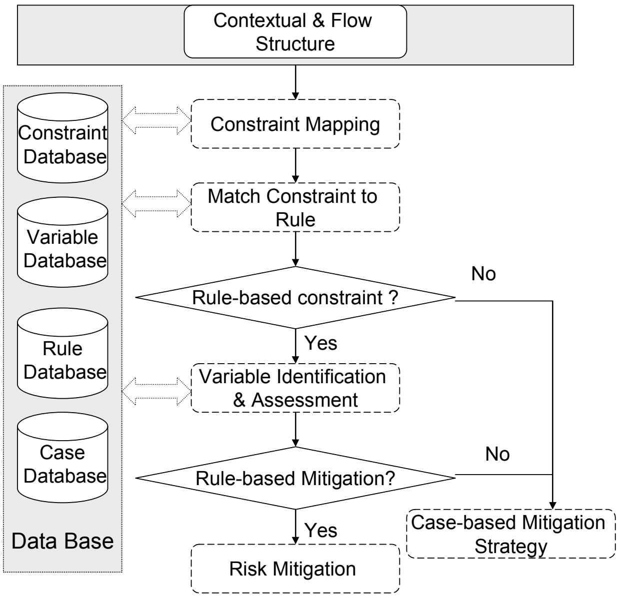


Fig 4: Intelligent Data-based Reasoning Methodology (IDRM) .

## 3 VALIDATION

Two deep industrial field studies were conducted in order to test and validate the effectiveness and feasibility of the proposed conceptual model in two design business companies within UK. One is ACDP in Berkshire, an integrated leading building services engineering consultancy with a wealth of experience and expertise within collaborative design; the other is Industrial Design Human Factor (IDEF) department in Xerox Corporation (Welwyn Garden City, UK). Most projets from ACDP are small and short-term based and with less collaboration due to limited agents and resources. While collaborative projects from Xerox are large-scale and long-term based which involved more multidisciplinary agents, complicated tasks and collaborative resources.

Initially, industrial interviews and questionnaire surveys were conducted in two companies with 30 design staffs each from various levels. They are all with wealth experiences in collaborative design as industrial designers, design managers, product engineers and project managers etc.

During the two-month industrial field study, interviews, questionnaires and field observation were employed in the two companies in order to find out if the proposed generic conceptual model can support or enhance risk evaluation under the multi-agent collaborative design environment. The authors have participated in one design project at each company. In terms of the collaborative design practice and observation of the whole collaborative design activities, process and management, the authors believe that the proposed model is appropriate for their agent-based collaborative design projects. And this conclusion was validated objectively by most involved multidisciplinary collaborative designers through face-to-face industrial interviews.

As for the questionnaire surveys, there were 67 responses and 78% of the interviewees believed the proposed generic conceptual model was effective and feasible in collaborative risk evaluation which could be implemented in various industrial organizations.

They also recommended that the model should be further developed and evaluated to include more details about how to link constrains and variables with industrial practice.

## 4 CONCLUSION

This paper presents a constraint-based generic conceptual model of risk evaluation (GCMRE) in order to manage the risk through related constraints and variables under the multi-agent collaborative design environment.

A hierarchy constraint network is developed to mapping constraints and variables. Then, an effective approximation technique named Risk Assessment Matrix (RAM) is adopted to evaluate risk level and rank priority after probability quantification and consequence validation. Additionally, the Intelligent Data-based Reasoning Methodology (IDRM) is expanded to deal with risk mitigation by combining inductive learning methods and reasoning consistency algorithms with feasible solution strategies. Finally, two empirical studies were conducted to validate the effectiveness and feasibility of the conceptual model.

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