International Journal of Quality & Reliability Management

Modelling critical risk factors for Indian construction project using Interpretive Ranking Process (IRP) and System Dynamics (SD)

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Abstract

Purpose: This study employs an integrated approach of Interpretive Ranking Process (IRP) and System Dynamics (SD) for modeling the key risk factors for a typical construction project.

Design/methodology/approach: The risk parameters and performance measures applicable in the construction industry have been identified through extensive literature review and discussions with experts from construction industry. Based on the literature review, a questionnaire was designed and 64 responses were considered. The list of 20 risk parameters and 32 performance measures relevant for a construction industry is reduced to five risk parameters and five performance measures using factor analysis. IRP modeling is employed to examine the contextual relationships among risk parameters and to rank them with respect to performance measure factors. Subsequently, the results of IRP model were utilized as inputs to system dynamics (SD) analysis. The SD analysis is conducted for two models namely Risk Factor Model (RFM) and Risk Varisable Model (RVM) to understand the impact of interventions offered by project management team on risk reduction and mitigation.

Findings: The developed IRP model shows that the risk factor dimension 'construction management' has a high likeliness to occur during the construction phase.

Research limitations/implications: The research demonstrates an application of proposed approach for a typical construction environment and hence the results cannot be generalized.

Originality/value: This research addresses real life complexities in construction project by modelling critical risk parameters using an integrate approach of Interpretive Ranking Process (IRP) and System Dynamics (SD). The proposed approach would facilitate project managers to devise appropriate risk mitigation strategies for a construction project.

Keywords: Project management; Risks parameters; Factor analysis; Interpretive ranking process (IRP); Simulation; Systems Dynamics; Performance measures.

Paper type: Research paper

1. Introduction

India is witnessing a sustained growth in infrastructure build up. The construction industry has seen a strong growth with large spending on housing, road, ports, water supply, rail transport and airport development. While the construction sector's growth has fallen as compared to the pre-2008 period, it has picked up in the recent past. The strive for quality is a major concern for all sectors of the national economy, including construction (Pheng and Tan, 1996). Rapid economic development has increased the demand for the construction of public and private infrastructure and facilities in India has resulted in the undertaking of numerous infrastructure projects. These infrastructure projects involve a large number of complications (complex activities) right from the planning to termination phase (Kuo and

Lu, 2013). Construction industry is usually a riskier act as compared to other business activities because of the involvement of large number of complexities. Furthermore, each project is unique and often incorporated with new techniques and procedures. The primary requirement of any project (construction in this case) is to meet the three basic demands namely cost, time and quality as specified by the customer. While achieving these targets, the project faces a large number of risks which can be related to budget overrun, schedule overrun, financial losses, environmental damage and sometimes loss of life (Christian and Hachey, 1995). Therefore the project can be successful positively or negatively. In order to add value to the project, the risk management procedure should be adopted to improve the efficiency and project deliverables. Thus risk management can be said to be the study and analysis of co-ordinated activities under study and to arrive at a conclusion at the most significant factors affecting the project performance. Figure 1 reports the percentage of risk occurrences in construction management.

"Take in Figure 1"

The discipline of project risk management has developed over the recent decades as an important part of project management (Olsson, 2008). Nasir et al. (2003) stated that risk assessment for construction projects need special attention. High quality and safety of large scale construction projects can be guaranteed by risk assessment techniques. As the projects' processes are becoming more complex, the methodologies involved are relatively new for risk-sensitive projects. In addition to this, where objective information such as probabilistic data is not available, subjective judgemental data comes into play.

Raz et al. (2002) described that "We define project risks as undesired events that may cause delays, excessive spending, unsatisfactory project results, safety or environmental hazards and in some cases, even total failure". Uncertainty, complexity, urgency, lack of resources or other constraints like skills, policies, etc. are some of the major sources of risks. While risks cannot be avoided, however, risk management techniques for project plans, mechanisms and putting some extra resources and back-up plans can certainly be implemented if something goes wrong. Chapman (1997) defines risk as the potential for complexity and hurdle in completion of a project.

The literature covers broader spectrum of many ranking and decision-making tools, but there is lack of evidence of applications of Interpretive ranking process (IRP), specifically for modeling risks for infrastructure project. The strength of this technique lies in integrating analytical logic of the rational choice process and decision-making with intuitive process at the elemental level. This method has been developed to overcome the shortcomings of the existing ranking methods and tools (Haleem et al., 2012). IRP may be applied to rank relevant factors in the light of their performance outcomes as against ISM (Interpretive structural modeling), which limits itself to consider interaction among those factors only (Haleem et al. 2012). This study is an attempt to apply IRP for ranking the risk factors with reference to expected performance measures towards controlling the scope and performance of the construction project. As an extension, the results of IRP were utilized for system dynamics (SD) modeling to understand the sensitivity of various risk factors with respect to project team intervention in reducing or mitigating the risks.

The remainder of the paper is structured as follows. Section 2 provides a literature review on risk in project environment. Section 3 presents the research methodology. Section 4 demonstrates an application of Interpretive Ranking Process for modelling the risks in construction project. Section 5 deals with system dynamics simulation. Section 6 reports sensitivity analysis. Finally, Section 7 concludes with key managerial insights and scope for future work.

2. Literature review

Karimazari et al. (2011) found the existing approaches for risk management and summarized into a four phase process for effective project risk management, i.e., identifying, assessing, responding and monitoring and/or reviewing risks. Olsson (2008) reported a conceptual framework for managing risks in a multi-project environment. Zwikael et al. (2014) proposed a robust theoretical framework of impact of planning on project success. Patel (2013) figured out that time constraint, cost management and managerial experience are critical for identifying the level of risks in a construction project. Besner and Hobbs (2012) calculated the variability between the use of risk management practice and the uncertainty level in the project and found out that the uncertainty level decreases with increase in the use of risk management techniques. Loosemore (2010), in his research work, stated the use of multimedia technology in reducing risks by using the collective knowledge of various stakeholders across the firm. Terje (2011) showed that a supportive uncertainty management culture is characterized by positive attitude, commitment of time and resources, openness and respect, understanding of uncertainty management, uncertainty of management applied into daily work, senior managers asking for and using uncertainty information, active uncertainty management, a focus on opportunities and goals, responsibility allocation, accepted and operationalized policies and terminology, and a holistic uncertainty view.

Chapman and Ward (2004) explained the meaning of 'risk efficiency' in project management by providing risk analysis approach and finally concluded that best project management practices cannot be delivered only through guidelines. Thus, we can see that risk management identifies the relevant negative properties that go unseen during the project management phase. Risk identification refers to the obtaining of the risk parameters that have or are likely to affect the project in a negative way. Risk identification is an important step in risk assessment process and detailed research work regarding the identification of risk parameters has been done.

Risk Parameters

Zou et al. (2007) evaluated construction projects in China and classified risks of construction projects in five groups; namely, cost, time, quality, environment, and safety. Shen et al. (2011) classified identified risks of construction projects in six major groups according to the risks' nature. The six groups are financial risks, legal risks, management risks, market risks, policy risks, and technical risks. Chapman (1997) divided risks into four subsets viz environment, clients, industry, and project. Dias and Iannaou (1995) classified the origin and sources of construction risks in 10 groups, namely, country, unexpected accidents, physical, financial, construction, benefits, advance, logistics and procurement, extension, and operational risks. Flanagan and Norman (1993) presented three ways to classify the risks using the combination of theory and work breakdown structure arrangement. The three ways are identification of risks outcomes, identification of risk types, and identification risks influences.

Risk Factors

Going further, various risk factors have also been designed by various authors and are cited by various researchers. Wang and Yuan (2011) categorized risks into appropriate factors such as decision making, engineering experience, completeness of information, professional knowledge, scope of the activity, economy and social experience, technical aspects, decision goal achievement efficiency. Zavadskas et al. (2010); Zayed et al. (2008); Bunni (2003), on the other hand, classified the risk factors into political, economic, social, climate, time, quality, cost, resources, team members, and project location. Iyer and Jha (2005), in their work on risk analysis, have considered factors such as auditors, design, competition, project nature, and climate as risk factors. Zeng and Smith (2007) have analysed the risk factors into project manager's commitment, management support, coordination between stakeholders and owners, supervision of activities, and climate. Renuka et al.(2014) classified risk factors as scope and design changes, site conditions, rules and regulation, funds availability, managerial skills, resource availability, weather, clearance approvals, safety and delays.

Performance measures

''Performance measurement is the heart of ceaseless improvement. As a general rule, benchmarking is the next step to improve contractors' efficiency and effectiveness of products and processes'' (Luu et al., 2008). Performance measures are the parameters on which the comparison of other parameters are based upon (Yu *et al*., 2007) .The various key performance indicators referred by various authors used in various countries are given in Table 1. Performance measures help the mangers in developing the direction, tracking the speed of the organisation, compiling the data measures for measuring the performance of project (Cox *et al*., 2003).

"Take in Table 1"

Here, risk parameters, risk factors and performance measures in the construction industry have been analysed through numerous techniques which shed light on the risk behaviour during the project management phase. The various risk assessment techniques used by various researchers in construction industry are shown in Table 2.

"Take in Table 2"

3. Research Methodology

An extensive literature review led to the identification of 20 risk parameters and 32 performance measures relevant for an infrastructure project. Survey method was used to obtain the importance of these parameters and measures. Factor analysis was used to reduce the risk parameters and performance measures. IRP technique has been applied for ranking the risk parameters with reference to performance measures. Subsequently, the outcomes of IRP model are utilized for a system dynamics based simulation and sensitivity analysis. The research methodology employing an integrated approach of IRM and system dynamics based simulation is presented in Figure 2.

"Take in Figure 2"

Questionnaire-based survey

The questionnaire was developed by studying the exhaustive literature. Based upon the risk parameters and performance measures identified through literature, the research questionnaire was designed. The respondents, which typically included the site experts, project managers, engineers, architects, consultants were asked to assess the risk parameters on a five-point Likert scale (where 1=will not occur at all, 2=somewhat likely, 3=likely, 4=more likely, 5=always occur). Similarly, performance measures were also assessed on a five-point Likert scale (1 = not at all significant, 2 = a little bit, 3 = to some degree, 4 = relatively significant and 5 = the most significant). The questionnaire was developed taking into account experts' opinion.

Data collection

The study has focused on one large-scale construction organization and the potential respondents were selected based on their number of years of experience (more than five years) and exposure to various risk-critical construction activities. Anticipating the difficulties associated with the mail surveys and the possibility of respondents misunderstanding the questionnaire items, convenience sampling method was used through interviewing various experts which are a part of the case study undertaken. This research was conducted between December 2014 and January 2015 at the construction site itself. Convenience sampling is a non-probability sampling technique where subjects are selected because of their convenient accessibility and proximity to the researcher. A questionnaire sheet was developed containing the risk parameters and performance measures and was distributed to the members working on the site. The profile of the respondents included Executive engineer (One), Site engineers (Five), Site supervisors (Fourteen), and workers (Fifty Eight) with more than five years of experience. We have also reviewed the past records and site logbook to understand the relevance and importance of various risks involved in the construction industry. This has helped to reduce the perception bias and select the most appropriate risk parameters and performance measures for the purpose of analysis. Before administering the questionnaire, researcher sought the opinion of Executive engineer and experienced people of the case organization on relevance of the key risk parameters and performance measured included in the questionnaire. In order to facilitate the workers, where necessary, the questionnaire was explained in a local language and data was collected on one to one basis. We have checked the returned questionnaires for its completeness and questionnaires having less than 70% complete information were not considered for the purpose of analysis. Finally, a total of 64 questionnaire responses were accepted.

Data Analysis and results

The respondents assessed the survey on a Likert scale. The means and standard deviations of risk factor and performance measures were calculated and are described in Table 3 and Table 4 respectively.

"Take in Table 3"

"Take in Table 4"

Factor analysis

Data reduction and summarisation is the ultimate aim of factor analysis, keeping in mind that the information is condensed from a large number of initial variables into a smaller set of new amalgamated dimensions (here, risk parameters) with minimum loss of information (Doloi et al., 2012). In this study, factor analysis is used for two purposes namely identification of risk parameters and performance dimensions. The risk parameters are extracted based upon the principal components analysis with varimax rotation. The Bartlett's test of sphericity and the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy were employed to test the appropriateness of the data for factor analysis. The collected data were analysed using statistical software – SPSS Version 20. Both factor analysis and reliability testing were carried out on to rank the risk parameters using the IRP technique. The test results showed KMO value of 0.575 for risk parameters which is just above acceptable value of 0.5. Low value of KMO can be justified with the reason that the sampling adequacy is not met adequately. The questionnaire was distributed to 64 respondents whereas the variables in the data sheet were 20. Bartlett's test of sphericity is also significant ($p<0.01$). Cronbach's alpha value was found to be 0.711(minimum value=0.7) after eliminating 3 parameters, namely 'increase in labour salaries', material damage' and 'high competition in bids'. Factor loading of greater than 0.4 were taken into consideration. Five risk parameters have been extracted which cover 70.27% of the total variance and were extracted and grouped into 5 dimensions (Engineering design, Construction management, Social and Economic, Physical and Logistics).The various risk dimensions along with their parameters are described in Table 5.

"Take in Table 5"

For performance measures, both factor analysis and reliability testing were carried out. 5 factors were extracted through the factor analysis which covered 69.69% of the total variance. KMO value of 0.516 was obtained. The suggested value is 0.5 or greater. The low value of KMO is justified with small sample size of 64. Bartlett's test of sphericity is also significant (<0.05). Factor loadings of greater than 0.4 were used to classify the performance measures into performance factors. Measure "main water use' was eliminated by the software and the Cronbach's alpha value was obtained as 0.758(minimum=0.7). The various performance dimensions along with their factors are shown in Table 6. The scree plots for risk parameters and performance measures are presented in Figure 3.

"Take in Table 6"

"Take in Figure 3"

4. Interpretive ranking model

Combination of intuitive process and rational thinking is the main strength of IRP technique, instead of using each mechanism individually. The IRP is based on paired comparison approach which minimises rational overload on human thinking. It uses interpretative matrix as a basic tool and comparisons among parameters in the matrix. The traditional AHP's drawback that the interpretation of experts' judgments remains opaque to the implementer is overcome in this method as the experts here are supposed to spell out the interpretive logic for dominance of one element over the other for each paired comparison. Furthermore, extent of dominance is not required by IRP. It also makes an internal validity check via the vector logic of the dominance relationships in the form of a dominance system graph. IRP is a novel ranking tool that can be applied to rank relevant factors in the light of their performance outcomes as against interpretive structural modeling (ISM), which limits itself to consider the factors only. IRP uses two sets of variables, i.e. one set of variables that are to be ranked and the other set of reference variables that provide the basis for ranking (Luthra et al., 2014). In this study, 5 risk dimensions and 5 expected performance measures identified based on the survey and using factor analysis are considered for IRP modeling. The steps of IRP employed for a typical case organization and related results are as follows:

Step 1: **Elements of suggested CSFs and expected performances**

5 risk dimensions and 5 performance dimensions have been extracted using factor analysis as seen in Table 5 and Table 6 respectively.

Step 2: **Development of Cross-Interaction matrix**

A cross-interaction matrix represents the relationship between each risk dimension and performance measure in this matrix, '1' representing a presence of relationship between the pair of variables and '0' representing its absence. Based on above mentioned logic, a cross-interaction matrix in a form of binary matrix has been developed and presented in Table 7.

"Take in Table 7"

Step 3: **Interpretation of interactions**

The interpretations of the various risk dimensions with each performance measure are interpreted in the matrix. The matrix is shown in Table 8.

"Take in Table 8"

Step 4: **Pair-wise comparisons**

The information in the interpretation matrix is used to compare the risk parameters with reference to reference variables (here, performance measures) in a pair-wise manner, one by one. For example, risk dimension R1 dominates R2 with respect to performance measures P4 and P5. This process is repeated for the entire matrix and the dominating pair-wise interaction matrix is shown in Table 9.

"Take in Table 9"

Step 5: **Development of dominance matrix**

The dominating interactions have been summarised in the form of a matrix called dominance matrix, which gives the number of cases in which one ranking variables dominates or is dominated by other ranking variable. The net dominance for a ranking variable i.e. action is computed as (D – B), where D represents the total no. of cases where these ranking variable(s) dominate all other ranking variables and B represents the total number of cases in which a particular ranking variable is dominated by all other ranking variables. The actions are then ranked based on their net positive dominance values. A summarised dominance matrix indicating the ranking of all CSFs is provided in Table 10.

"Take in Table 10"

Step 6: **Interpretive Ranking Model**

Interpretive ranking model is a diagrammatical representation of the derived final ranks of the ranking variables. The developed IRP model is shown in Figure 4. This figure helps in interpreting how each risk factor influences various performances areas. The arrows in the diagram represent the reference variable(s) in which cases a particular ranking variable is dominating the other ranking variables. For example, the arrow from R5 to R1 demonstrates that R5 dominates R1 for performance P1, P2 and P3. Likewise, arrow from R1 to R5 demonstrates that R5 is dominated by R1 for performance P4 and P5. For all the risk parameters, the number of risk parameters dominating and the ones being dominated are shown within brackets. Also, the numbers dominating and number being dominated are displayed in brackets for all actions. For example, for risk factor R5, the numbers of dominating and dominated risk parameters are shown as (10, 8).

"Take in Figure 4"

The interpretive ranking model suggests that the risk dimension 'Construction Management' has the highest rank which implies that the construction company should take appropriate actions in their execution stage so that associated risks such as 'poor construction plan', 'inefficient experience and skill in construction workers', 'poor labour productivity' and 'unstable supply of critical construction materials' can be minimized. The order of risk dimension is as follows Construction Management > Physical > Logistics > Engineering Design > Social Economic. Hence, appropriate actions need to be taken by the project managers during the execution stage of the project.

5. System dynamics model

System dynamics (SD) is a proven effective method for modeling and analysing complex, dynamic and nonlinearly interacting variables and is adopted in this study as the tool to simulate the assessment process of risk assessment (Sterman, 2001). The method was introduced in the form of a computer simulation model by Forrester (Forrester, 1971). Li et al. (2016) have employed SD modelling for transportation risk management in chemical supply chain. In an another application in the domain of risk management, Wilson (2007) has analysed the impact of transportation disruption on supply chain performance to compare a traditional supply chain and a vendor management inventory system. SD modelling is appropriate for conducting simulation processes and has two major features in allowing for changes in variables over time, and secondly, feedback (the transmission and receipt of information). This approach connects four elements as a system namely state variables (Stock), flow function (Flow), auxiliary variables (Convertor), and streamline (Connector), with decision-making feedback loops. Typically, SD modelling is a five-step procedure to formulate a model (Yuan, 2012). This includes:

Step 1 *Causal Loop Diagram*: It combines all the data by converting the complexities into simpler cause-effect diagram.

Step 2 *Stock-Flow Diagram*: It is the result of causal loop diagram and built in professional software.

Step 3 *Confidence Building*: This is done before the model is adopted for quantitative analysis. Coyle (Coyle, 1996) has suggested few steps for the same.

Step 4 *Base run simulation*: Helps understand the system ''as-is'', while scenario analysis offers insights into management measures that would potentially improve the current behaviour of the system.

Step 5 *Sensitivity analysis*: The parameters are varied in magnitude for studying the changes occurring in the system.

The literature reports select applications of system dynamics modelling for analysing construction risks. A summary of selected contributions is cited in Table 11. The management efficiency rate considered in this research is assumed to be equal to the risk rate occurring in the construction projects. These rates can be implemented in the system dynamics model for risk transfer rate (Anees et al., 2013). Figure 6 shows the rate at which risks occur and that the average value comes out to be 4.667 per cent. Keeping this in mind, there is no model developed for assessing risk on a magnitude level and also with respect to the presence of risk parameters.

"Take in Table 11"

The data collected through questionnaire and results obtained from IRP modeling were utilized for conducting the SD simulation. The entire analysis includes constructing, validating, and simulating the two models (risk factor value model and risk variable model) using Vensim PLE software. The outcomes of complete analysis for both the models are presented in Figure 5 (Part A: Vensim PLE model; Part B: Extreme behaviour test; Part C: Results). Subsequently a sensitivity analysis is carried out for both the models. The two models tested are based on the following assumptions.

"Take in Figure 5"

1. The factor with the highest rank was taken weight equal to 1/15 since the rate of reduction of the factor was the least while the factor with the lowest rank was taken weight equal to 5/15 since the rate of reduction of the factor was the highest.
2. Initial values of each of the risk factor were taken as the mean obtained during the data survey process.

3. The risk factor value was taken as the average of all the risk factor values combined together.
4. The risk transfer rates were used in the risk variable model based on literature review (Anees et al., 2013).
5. Incoming risks are the risks which are present at the initial stages of the project (Cauchemez et al., 2004). Instantaneous risks are the risks which are detected at any given point of time (Cauchemez et al., 2004).
6. The management efficiency is assumed to be equal to the risk occurrence rate i.e. when the risk occurs the management team is informed about the former's appearance and acts accordingly.

The risk factor value model (RFM) has been built through the following steps in Vensim PLE software:

1. Each risk dimension has been simulated with its corresponding risk variables.
2. The risk reduction rate has been used as per the ranking obtained in the IRM process. The factor with the highest rank i.e. 'construction management' is assigned a weight of 1/15 and the factor with the lowest rank i.e. 'social and economic' is assigned a weight of 5/15. The other parameters such as physical, logistics, and engineering design are assigned the weights 2/15, 3/15 and 4/15 respectively.
3. The risk factor value depends on 5 risk parameters namely the R1: "engineering design", R2: "construction management", R3: "social and economic" R4: "physical" R5: "logistic" (Figure 5, part: A).
4. Each individual risk parameters is further caused by its own risk variables. For example, risk factor "engineering design" is caused by "inappropriate design", "design drawing error", "Conflicting interfaces work items", "construction management technique". Similar procedure is followed for other risk parameters and their variables.
5. Risk reduction rates have been used for individual parameters. For example, w1 is used for "inappropriate design"; w2 is used for 'inappropriate design"; and so on. The notations have been shown in Table 12.
6. For the risk factor value weight of 4.667% was used (Anees et al., 2013).
7. Initial values were used which were obtained through the questionnaire survey where response was achieved on a Likert scale.
8. The values of each dimension and risk factor were equal to the product of risk reduction rate (weight) and the risk value.
9. Average values were used to calculate the risk factor value. The final model is named as risk factor model (RFM).

"Take in Table 12"

Similarly, the risks variable model presented in Figure 4 has been built on the following steps:

1. Incoming risks are the risks which are present at the initial stage of the project management phase and the management team knows its presence but has not affected the project. In other words, the risks have not occurred as till date.
2. Instantaneous risks are the risks which arise when the risks affects the project. These risks appear during the project management phase. These risks are seen as those that have affected the project in some way either to affect the cost, schedule or the quality structure of the project.
3. Incoming risks are transferred into instantaneous risks through the risk occurrence rate i.e. as the project proceeds.
4. Instantaneous risks are transferred through the management efficiency rate and are dumped into the sump i.e. these risks are converted into opportunities.
5. Initial value of incoming risks is 17, the reason being that 17 risk variables have been detected in the initial stages from Table 6.
6. Initial value of instantaneous risks is 0, the reason being that no risk has yet emerged in the project management phase (Cauchemez et al., 2004).
7. Risk transfer rate of 4.667% has been taken as feedback for the simulation.
8. The final model for risk variable has been presented in Figure 5.

Both the models are validated based on five tests. This includes boundary test (all the risk parameters are taken into account), structure verification (all the parameters have been acknowledged through literature review), dimensional consistency (the parameters are dimensionless with only a magnitude value) and extreme conditions – Part B (Figure 5) (the model is tested under conditions of 0% and 100% transfer rate. 0% indicates that no risk reduction occurs or the management team fails to act completely whereas 100% indicates that the team has acted out of its best potential).

Figure 5 (Part B) extreme behaviour test for RFM shows that when the risk reduction rate is 0%, the Likert scale does not decrease at all (shown by topmost line in the range of 5 on Likert scale) indicating that risks occur every time. On the other hand, when the rate is 100%, the Likert scale decreases at a much faster rate (shown by decreasing-trend line) and approaches 0 value on Likert scale concluding that the risks have been prevented from occurring at the initial stage itself. Similarly, Figure 5 (Part B) extreme behaviour test for RVM shows that when the management efficiency is 0% i.e. when the team fails to act completely the instantaneous risk variables go on increasing in number at a tremendous faster rate (shown by increasing-trend line) whereas when the management efficiency is 100% i.e. when the team converts all risks into opportunities, the instantaneous risk variables decrease at a much faster rate (shown by decreasing-trend line).

Figure 5 (Part C), result of the risk factor model (simulated with average risk reduction value of 4.667%) shows that the risk factor value goes on reducing with respect to time. This can be verified by the actions taken by the management team towards risk mitigation. Similarly, the results of simulation for instantaneous risks are presented in Figure 5 (Part C). The rates have been assumed as average of 4.667% taken from literature review.

The analysis carried out for both RFM and RVM models had led to select critical observation such as:

1. The risk factor value goes on decreasing with value starting from 5 on a Likert scale.
2. This shows that the team has achieved in reducing the risks.
3. The number of incoming risks goes on decreasing over a period of time indicating that the needful actions have been taken by the management team.
4. This is verified from the fact that the amount of risk and the degree of uncertainty decreases over a period of time and as the project gets completed in any project, the same being the highest in the initial stage.
5. Furthermore, the instantaneous risks i.e. the risks which appear as the project proceeds go on increasing. This can be verified from the fact that constant changes occur due to stakeholder influence, client changes and other risks which are mentioned in the IRP model.
6. However, as the management team recognises that the risks have appeared, management efficiency comes into action and due to appropriate actions taken the risk variables are reduced.

6. Sensitivity Analysis

Sensitivity analysis is used to determine how 'sensitive' a model is to the changes in the values of the parameters of the model and to the changes in the structure of the model (Yuan, 2012). By using sensitivity analysis, we can further analyse various responses and so their effect on the whole project. The current models have been based upon the risk transfer rates and the management efficiency rates. By varying these rates (Anees et al., 2013), the study of the behaviour of the risk factor and the risk variables (both the incoming as well as the instantaneous variables) can be studied for the mentioned period of time. The outcomes of sensitivity analysis for both the models RFM and RVM are presented in Figure 6. It includes Part A: Sensitivity Analysis for factor values, Part B: Sensitivity analysis for risk variables (Part B1: Incoming variables and Part B2: Instantaneous variables).

The risk factor value depends upon the risk transfer rate. The different risk rates indicate the occurrence of the risks in the project. This, in turn, depicts the actions taken by the management level to reduce the risks. Rates of 5%, 7.5% and 12.5% were used into the function box of the Vensim PLE software. The graph in Figure 6 (Part A) shows that higher the risk rate, the more informed is the management team and hence better actions are taken to reduce the risk happenings. This can be seen from the fact that the higher the risk rate, the more quickly it gets reduced to 0 value. The lines approaching zero at infinity state the fact that some risks are prevalent in the project management phase.

Similarly, the risk variables have been simulated with risk transfer rates of 5%, 7.5% and 10%. These rates too depict the behaviour of the management efficiency. The higher the risk transfer rate, the quickly the risks are transferred and the management team responses early. Figure 6 (Part B) shows the sensitivity analysis performed for the risk variables.

The graph in Figure 6 (Part B1) is for incoming risk variables shows that the higher the risk occurrence rate, the management team is informed earlier and hence the number of risk variables goes on decreasing at a much faster rate. The graph in Figure 5 (Part B2) is for instantaneous risk variables which indicate two things: (1) initially when the risk occurrence rate is high, the number of risk variables goes on increasing. This can be verified from the data that the average of the risk occurrence rate increases. (2) When the team is informed about the risks that have occurred, the team acts quickly to reduce the parameters which is shown by the declining trend.

7. Conclusions, managerial implications and scope for future work

This study has employed a novel approach based on Interpretive Ranking Process and System Dynamics for analysing the risks parameters for a construction project. In our study, twenty risks parameters (Table 4) and thirty two expected performance measures (Table 5) for an infrastructure project were identified through extensive literature review. These risks parameters have been validated through pretesting of questionnaire among selected experts from a typical construction industry. A detailed survey was carried out to observe the importance of identified risk parameters and expected performance measures.

Since number of risk parameters and expected performance measures identified from literature review are large in number, factor analysis technique has been utilised to reduce the number of risk parameters and expected performance measures. The analysis reduces the number of risk parameters to five (Table 6), namely engineering design, construction management, social and economic physical logistics. Similarly, four expected performance measures namely: financial, internal business, customer, environment, learning (Table 7) have been extracted from factor analysis.

These reduced five risks parameters and performance measure dimensions have been used as input for development of IRP-based model. This study is an attempt to extend IRP's application to rank risk parameters with respect to performance measures to for a typical construction project in India. The interpretive ranking model suggests that the risk dimension 'Construction Management' has the highest rank which implies that the construction company should take appropriate actions in their execution stage so that associated risks such as 'poor construction plan', 'inefficient experience and skill in construction workers', 'poor labour productivity' and 'unstable supply of critical construction materials' can be minimized.

'Construction Management' risk dimension consists of parameters namely inappropriate design and poor engineering, Design Drawing errors, Conflicting interfaces work items and Poor construction plan (technical). 'Inappropriate design and poor engineering' factor can be brought into light by the design team during the planning phase so that no hitches occur during the implementation stage to the project managers. Same is the case with the 'Design Drawing Error' where the design team needs to practice special precaution and rectify and correct the errors for future. 'Conflicting interfaces work items' and 'Poor construction plan' are the parameters which demands the development of a detailed role-responsibility structure based on WBS and a strong execution plan.

Simulation was carried out for the risk dimensions along with their respective risk variables and combined into a magnitude called as the Risk Factor Value. The weights of risk reduction rate were used through literature review. The model showed that the risk factor value goes on decreasing with time and also with the increase in the risk reduction weight. The second model consisted of the risk variables consisting of the incoming and the instantaneous variables. The incoming risk variables tend to decrease with time whereas the instantaneous variables increase with time for a certain period until the management team is informed and then gradually decreases through the period. For the validity of the system dynamics approach, both the models were passed through a series of tests concluding that the models can be accepted in the study of other industrial as well as academic sectors.

India's rapid economic growth over the last decade has placed tremendous stress on its limited infrastructure. The sector has received growing attention from the government and the public, bringing the shortage of infrastructure to the fore. Fulfilling India's aggressive economic growth aspirations would be seriously challenged due to this shortage. The country needs to urgently accelerate the conceptualisation and implementation of all its infrastructure development to enable planned growth. Trends during the first two years of the Eleventh Plan have raised doubts over whether India will be able to realise its ambitious infrastructure plans. Issues that plague the sector include a shortfall in awarding projects as per plan, inefficient project execution and constrained capital flows to the sector. Here the performance measures play a very important role in assessing the ranking of the risks associated with a typical infrastructure project.

In today's business world, the competition among the construction businesses is quite high. The construction managers are facing numerous challenges to achieve a right balance between time, cost and performance. Many of these challenges are a direct result of construction operations, while others are a result of indirect, peripheral activities. A surprising number of challenges are not construction issues but must be addressed and managed by the construction manager (CM) to ensure project success. Some of the construction issues include workforce considerations, safety, time constraints, and the changing nature of the work. Non-construction challenges that CMs face that are part of the business landscape include legal issues, government regulations, environmental concerns, and socio-political pressures. It is critical that the CM understands the demanding realities that he or she faces in the planning and control of construction operations. Understanding interrelationships among risks parameters and ranking based on various performance measures will help construction manager to increase awareness on possible problems in executing a project and lead them to balance T-C-P (time-cost-performance) trade-offs.

This research has demonstrated an application of IRP for a typical construction project. However, it is to be noted that the performance measures need not be the same at every project site. The measures can change from project to project and hence a careful consideration is required while extracting the risk parameters and performance measures from the given list of 20 risks parameters and 32 performance measures.

IRP methodology used in this work is based on interpretive and judgmental processes and may at times be highly subjective. The results may not be free from bias due to interpretive and judgmental elements involved in the decision-making process. The number of the experts nominated was also small and could be increased to get wider and deeper insights into the problem situation. IRP usually treats all the criteria equally ignoring their relative importance. However, this limitation can be overcome by assigning ordinal weights to various criteria and carrying out sensitivity analysis. But this may complicate the process to some extent and would require justification for the weights assigned. It is difficult to interpret a matrix of size beyond 10x10 as the number of paired comparisons would increase exponentially, and thus, only modest-sized problems can be effectively handled with this process. The model is also based on the opinion of experts which may vary from field to field. As a future scope, this technique can also be used in other industry for ranking the risk parameters accordingly.

In addition, following can be considered as some of the opportunities for extending the present work.

1. The results of the risk factor rankings obtained can be verified by other methods like Fuzzy Logic or Bayesian Belief Networks. IRM process is based on interpretive approach of the user, whereas Fuzzy Logic and BBN use the probabilistic approach. Comparison of the results between each other can give better insights in the application of each of the methods.
2. A regression model can be developed for the risk factor value dependent on various risk variables showing the behaviour of the same and can be compared with the simulated value.
3. The risk reduction weights have been adopted from the literature review. An exact calculation of these weights using the secondary literature and exerts opinion for a typical case organization can help to improve the accuracy and relevance of the results.
4. The study can be further extended and supported by various other simulation models including the cost and the schedule structure of the project.

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Table 1: Research on Performance Indicators

Author	Country	Performance indicator	
Horta et al. (2009)	Portugal	1. Productivity 2. Customer satisfaction 3. Predictability	4. Safety 5. Profitability 6. Growth
Wang and Yuan (2011)	USA	1. Profitability 2. Market shear 3. Return on capital 4.Quality 5. Cash flow	6. Internal business 7. Reliability 8. Innovation and learning 9. Customer focus
Nudurupati et al. (2007)	UK	1. Quality 2. Safety 3. Clients satisfaction 4. Time	5. Employee satisfaction 6. Cost 7. Environment impact
Yu et al. (2007)	Korea	1. Profitability 2. Development 3. Growth 4. Technological capability 5. Stability	6. Business efficiency 7. Customer satisfaction 8. Informatization 9. Market share 10. Organization competency
Ramirez et al. (2004)	Chile	1. Safety 2. Training 3. Productivity 4. Planning effectiveness	5. Quality 6. Cost variation 7. Efficiency of labour 8. Schedule variation

Table 2: Various Risk Assessment Techniques implemented

Technique	Author (with year)	Description of the technique
Bayesian Belief Network	Baloi and Price (2003), Nasir et al. (2003), Ahmed et al. (2005)	It is based on subjective probability and takes into account all the available information
Factor Analysis	Iyer and Jha (2005)	It is used for condensing the information into factors with little loss in the data
Fuzzy Techniques	Nieto-Morote and Ruz-Vila (2011), Ahmed et al. (2005), Zeng et al. (2007)	It is based on the reasoning by human mind to find an approximate but not an exact solution
Program Evaluation and Review Technique (PERT)	Mulholland and Christian J. (1999), Nasir et al. (2003)	It is used to statistically estimate the amount of time for uncertain tasks
Decision Making Matrix	Zeng et al. (2007)	It combines the chance and occurrence of an event as a product to quantify risks.
Interpretive Structure Modeling	Jha and Devaya (2008)	It is a computer-assisted learning process with which groups can structure complex issues to form interpretable patterns
Interpretive Ranking process	-----------------------	It uses both the intuitive and rational process to rank items

Table 3: Results of Survey assessing risks on Likert Scale

S. No.	Risk variable	Mean	Standard Deviation
1.	Poor construction plan(technical)	2.438	0.560
2.	Unstable supply of critical construction materials	2.094	0.583
3.	Inaccurate project program	1.500	0.504
4.	Increase in prices of materials	2.813	0.531
5.	Design Drawing errors	1.906	0.811
6.	Inappropriate design and poor engineering	1.844	0.672
7.	Material Theft	1.219	0.417
8.	Equipment theft	1.469	0.712
9.	Increase in labour salaries	2.688	0.588
10.	Material Damage	2.479	0.908
11.	Inefficient experience and skill in construction workers	2.469	0.616
12.	Conflicting interfaces work items	2.688	0.467
13.	High competition in bids	2.250	0.713
14.	Poor Construction Plan(managerial)	2.625	0.826
15.	Poor labour productivity	2.250	0.797
16.	Consultant cost for studies	2.688	0.588
17.	Undefined scope of working	1.344	0.541
18.	Funds Availability	2.313	0.588
19.	Equipment Damage	2.844	1.237
20.	Poor Communication between home and field offices	2.094	1.318

Table 4: Results of Survey assessing performance measures on Likert Scale

S. No.	Performance measures	Mean	Standard Deviation
1	Successful tenders rate	4.625	0.488
2	Labour efficiency	4.188	0.990
3	Resource management	3.750	0.976
4	Impact on society	2.094	0.583
5	Value of money	3.000	0.356
6	Competitive price	3.906	0.921
7	Safety	3.656	0.781
8	Productivity	2.688	0.732
9	Growth	3.969	0.816
10	Effectiveness of planning	4.688	0.467
11	Technological capability	1.438	0.500
12	Partnership and suppliers	3.344	0.781
13	Profitability	3.688	0.924
14	Policy or law of government	4.313	0.852
15	Business efficiency	4.219	1.061
16	Innovation	3.063	0.664
17	Informatization	3.438	0.833
18	Empowered work force	1.563	0.794
19	Financial stability	3.844	0.979
20	External customer satisfaction	4.219	0.417
21	Quality of service and work	4.063	1.006
22	Main water use	3.313	0.687
23	Continuous improvement	3.219	0.654
24	Interest cover	2.875	0.604
25	Competitors	2.906	0.526
26	Impact on biodiversity	3.563	1.067
27	Cash flow	3.094	0.811
28	Waste	2.406	0.660
29	Managers competency	3.938	0.941
30	Energy use	2.563	1.097
31	Human resource training and development	1.500	0.667
32	Defects	2.313	1.139

Table 5: Risk dimensions used for IRP modeling

Dimension	Risk Factors
R1:ENGINEERING DESIGN	Inappropriate design and poor engineering, Design Drawing errors, Conflicting interfaces work items, Poor construction plan(technical)
R2: CONSTRUCTION MANAGEMENT	Poor Construction Plan (managerial), Inefficient experience and skill in construction workers, Poor labour productivity, Unstable supply of critical construction materials
R3: SOCIAL AND ECONOMIC	Increase in prices of materials, Funds Availability, Consultant cost for studies, Consultant cost for studies
R4: PHYSICAL	Equipment theft, Material Damage, Material Theft
R5: LOGISTICS	Undefined scope of working, Inaccurate project program, Poor Communication between home and field offices

Table 6: Performance dimensions used for IRP modeling

Dimensions	Performance Measures
P1:FINANCIAL	Profitability, Growth, Financial stability, Cash flow, Interest cover
P2:INTERNAL BUSINESS	Safety, Business efficiency, Effectiveness of planning, Labour efficiency, Successful tenders rate, Managers competency, Innovation, Resource management, Technological capability
P3:CUSTOMER	Quality of service and work, Value of money, Competitive price
P4:ENVIRONMENT	Policy or law of government, Competitors, Impact on society, Impact on biodiversity
P5:LEARNING	Continuous improvement, Human resource training and development, Informatization

Table 7: Cross Interaction Matrix

		Performance measures				
		P1	**P2**	**P3**	**P4**	**P5**
Risk factors	**R1**	0	0	1	1	1
	R2	1	1	1	0	1
	R3	1	1	0	1	1
	R4	1	1	0	0	0
	R5	1	1	1	0	1

Table 8: Interpretation of Cross-interaction matrix

Risks ↓ Performance →	P1	P2	P3	P4	P5
R1	-----	-----	Engineering design has direct implications on the customer satisfaction	Engineering design directly affects the environment	Learning is achieved through engineering design
R2	-----	Internal business is affected through construction management	Customer satisfaction is increased through proper construction management techniques	-----	Construction management leads to successful learning
R3	Financial measure is related through social economic factor	The firm is responsible for socio-economic factors	-----	Environment is largely responsible for socio-economic factors	Learning has direct implications through socio-economy impact
R4	Physical aspects determine the assets and hence the financial position	Internal business is determined through physical assets	-----	-----	------
R5	Logistics control the financial part of the firm	Construction management is required for proper logistics	Customer is affected through logistic planning	-	-

Table 9: Dominating interaction matrix for managing risks in infrastructure project

Dominating	R1	R2	R3	R4	R5
R1	--	P4,P5	P1,P2,P3,P5	P4,P5	P4,P5
R2	P1,P2,P3	--	P1,P2,P3,P5	P1,P2	P1,P5
R3	P4	P4	--	P4	P4,P5
R4	P1,P2,P3	P3	P1,P2,P3	--	P2,P4,P5
R5	P1,P2,P3	P2,P3	P1,P2,P3	P1,P3	--

Table 30: Dominance matrix for managing risks in infrastructure project

Dominating Being dominated	R1	R2	R3	R4	R5	No. of cases dominating(D)	Net Dominance D-B	Rank Dominating
R1	1	2	4	2	2	11	0	**IV**
R2	3	--	4	2	2	11	5	**I**
R3	1	1	--	1	2	5	-9	**V**
R4	3	1	3	--	3	10	3	**II**
R5	3	2	3	2	--	10	1	**III**
Number of cases being dominated (B)	11	6	14	7	9	46/46		

Table 11: Work on System Dynamics in construction sector

Author	Contribution/Focus	Select research directions
Shin et al. (2014)	The author has created System Dynamics model to study the behaviour of workers to construction risks	The extension can be done for analysing other risk parameters
Zhang et al. (2014)	Prototype model for developing sustainability of construction projects	Simulation results can be used further for assessing dynamic impact on construction risks
Anees et al. (2013)	The author has shown the rate of risks occurring in the construction phase with respect to management efficiency	These rates can be incorporated in the risk transfer rate considering them as management efficiency
Nasirzadeh et al. (2008)	Various construction risks were used to simulate with respect to one factor using fuzzy techniques	A crisp value of risk factor can be simulated in future

Table 12: Table showing the notations for Risk Factor Value Model (RFM)

Notation		Description
w1, Rate1	:	inappropriate design and poor engineering weight and rate
w2, Rate2	:	design drawing errors weight and rate
w3, Rate3	:	conflicting interfaces weight and rate
w4, Rate4	:	construction management(technical) weight and rate
w5, Rate5	:	increased prices weight and rate
w6, Rate6	:	funds availability weight and rate
w7, Rate7	:	construction cost weight and rate
w8, Rate8	:	equipment theft weight and rate
w9, Rate9	:	material damage weight and rate
w10, Rate10	:	material theft weight and rate
w11, Rate11	:	undefined scope weight and rate
w12, Rate12	:	inaccurate project program weight and rate
w13, Rate13	:	poor communication weight and rate
w14, Rate14	:	poor construction plan (managerial) weight and rate
w15, Rate15	:	inefficient experience weight and rate
w16, Rate16	:	poor labour productivity weight and rate
w17, Rate17	:	unstable supply of sources weight and rate
w01, Rate01	:	engineering design weight and rate
w02, Rate02	:	social and economic weight and rate
w03, Rate03	:	physical weight and rate
w04, Rate04	:	logistic weight and rate
w05, Rate05	:	construction management and rate

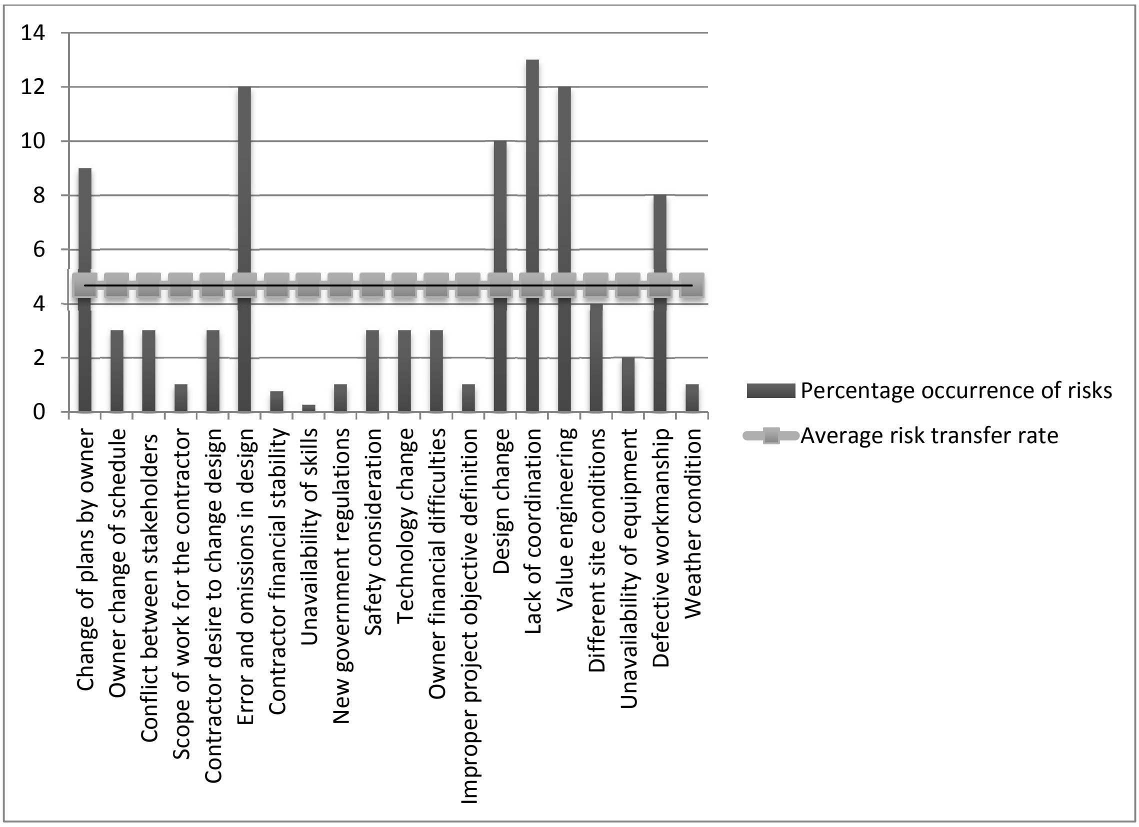


Figure 1: Percentage of risk occurrences in construction management

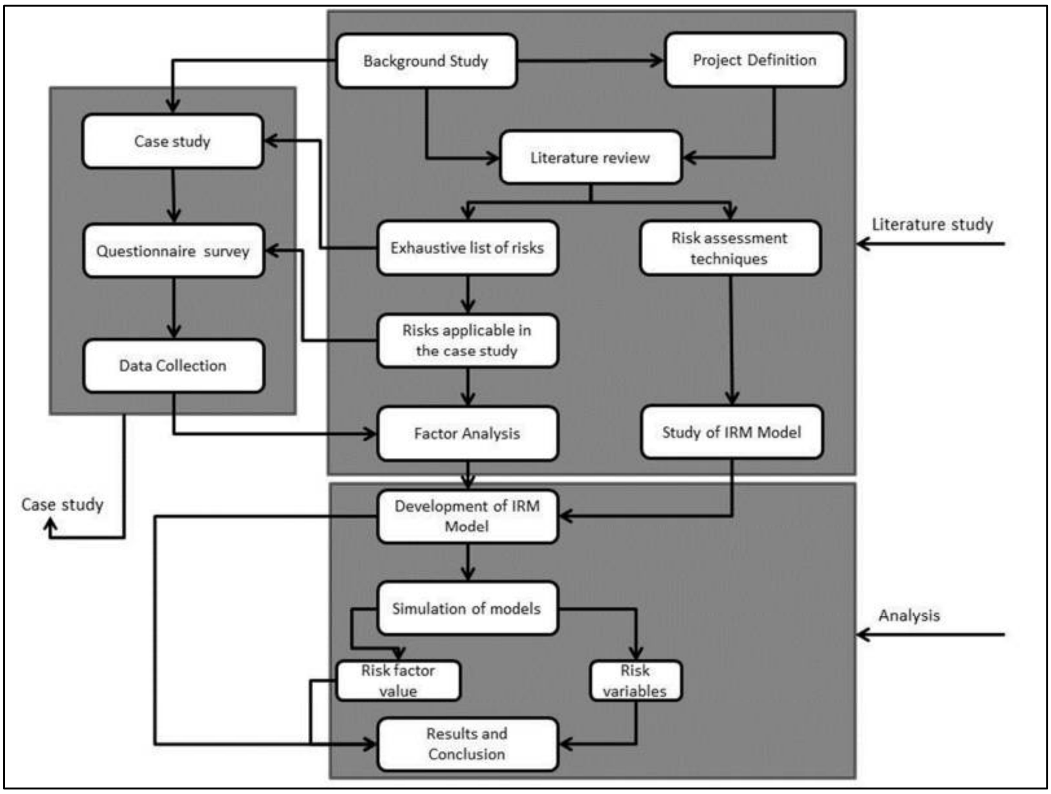


Figure 2: Research Methodology

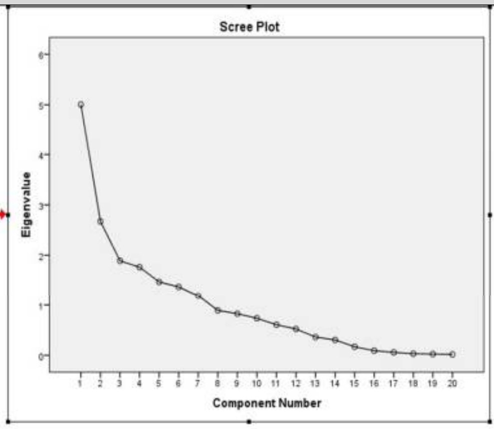
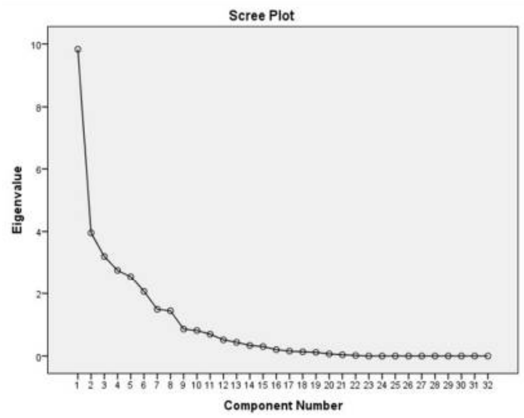
Scree Plot for risk Variables	Scree Plot for performance measures
	

Figure 3: Scree plots for risk variables and performance measures

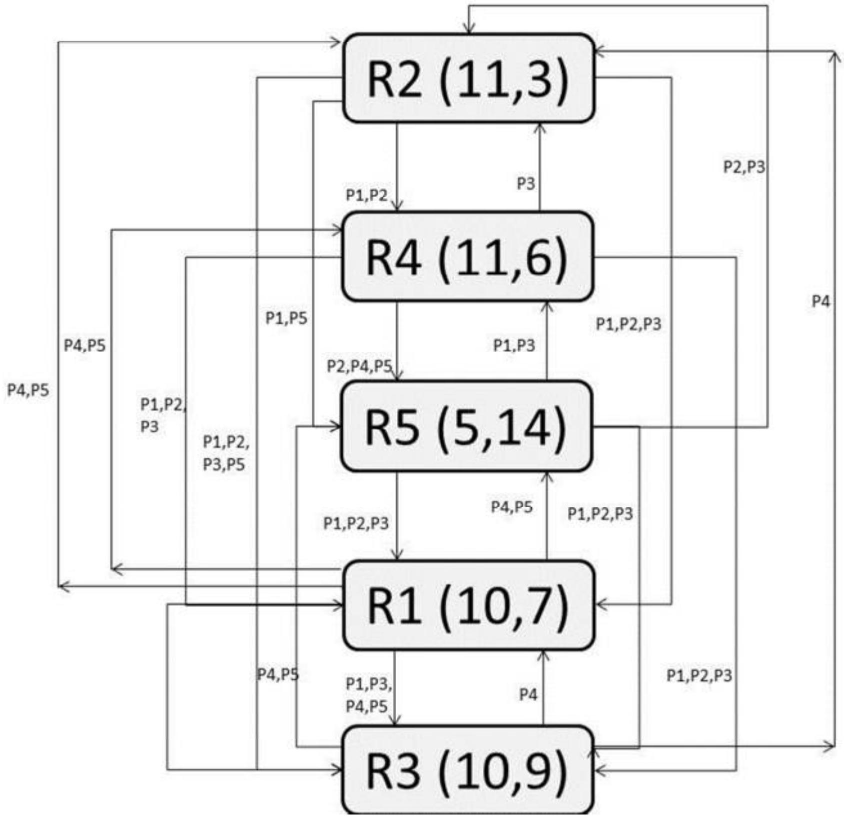
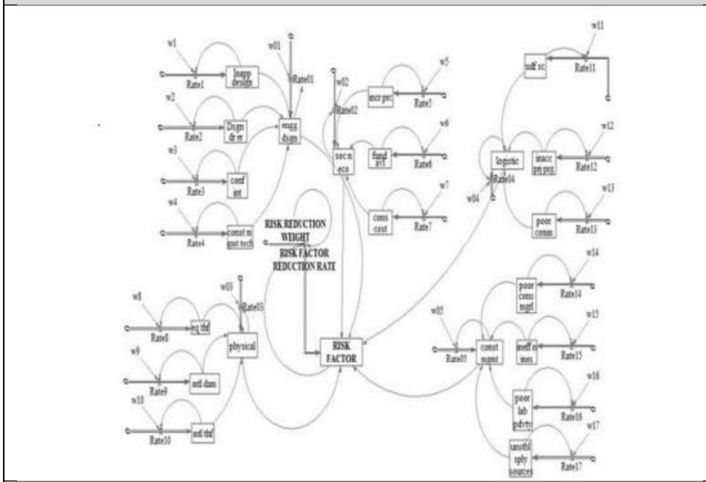
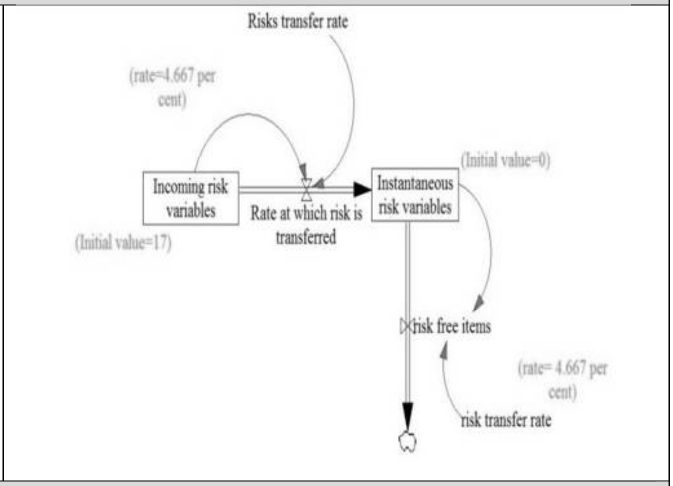


Figure 4: Interpretive ranking model of risk dimensions with respect to performance measures

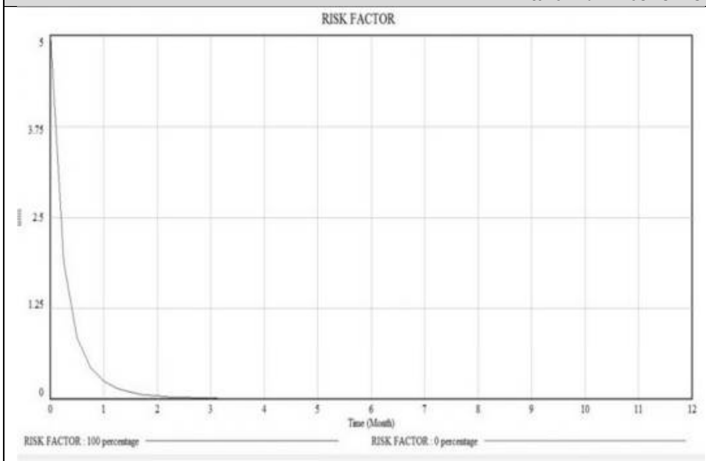
Risk Factor Model (RFM)	Risk Variable Model (RVM)

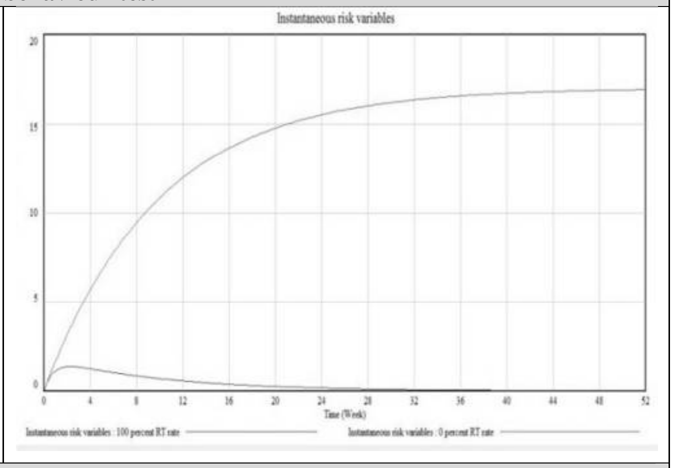
Part A: RFM an RVM models in Vensim PLE software



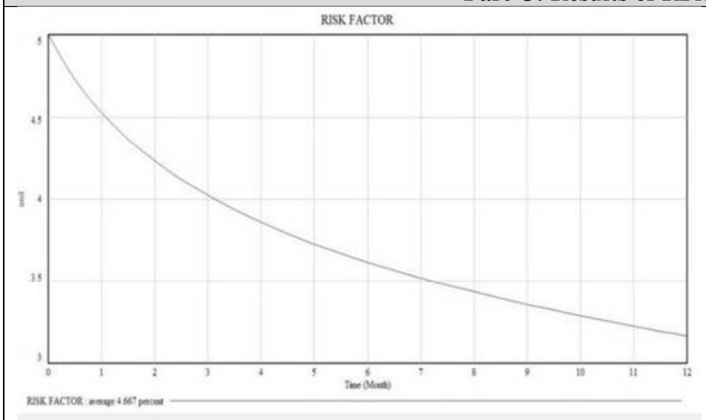


Part B: Extereme behaviour test





Part C: Results of RFM and RVM models



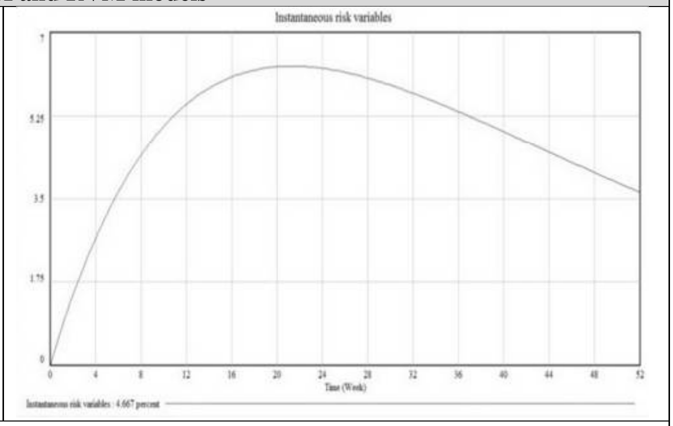
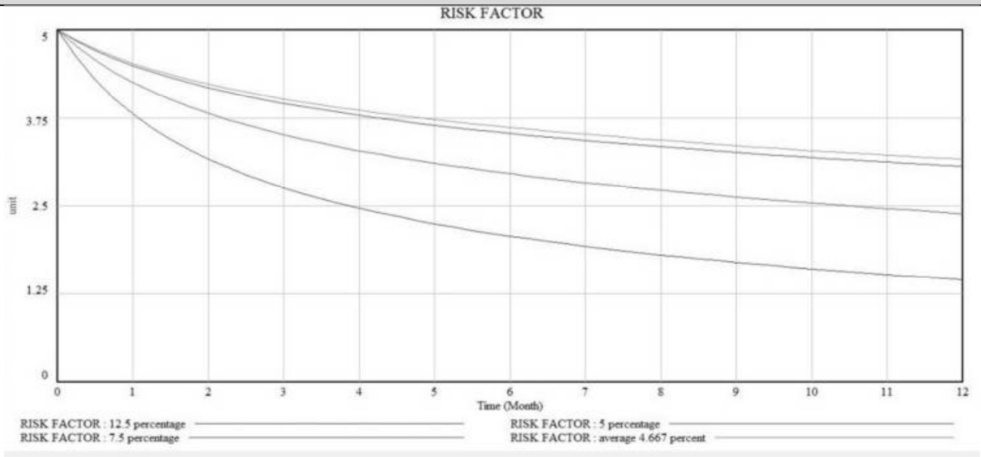


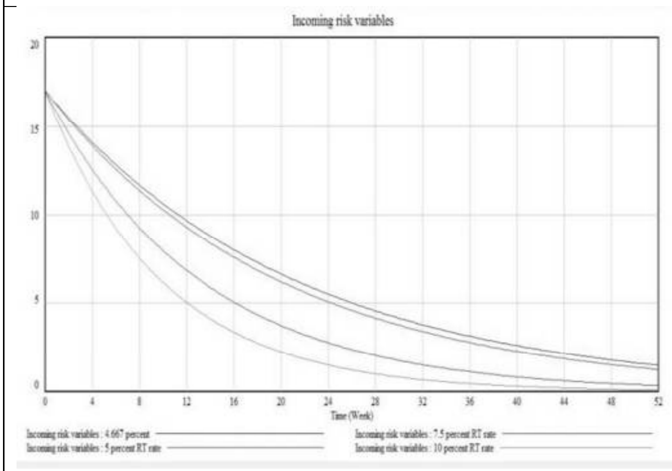
Figure 5: Vensim PLE software results (risk factor and risk Variable models, extreme test, and results)

Part A: Sensitivity Analyses for Risk Factor Value



Part B: Sensitivity Analyses for Risk Variables

Part B1: Incoming risk variables



Part B2: Instantenous risk variables

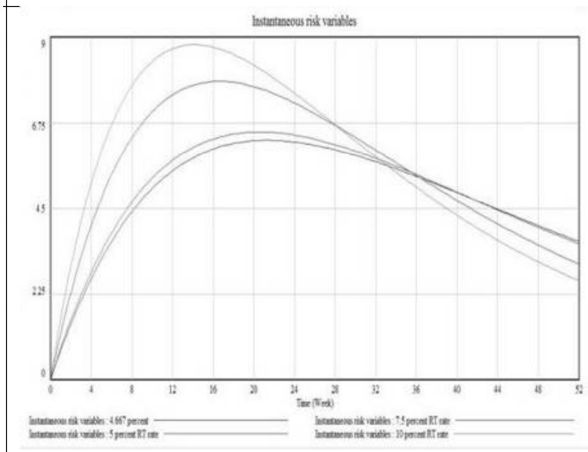


Figure 6: Results of sensitivity analysis