Chapter 7: Critical Success Factors Modelling for Infrastructure Projects Using Bayesian Belief Network

7.1 Introduction

Complexities and uncertainties are highly prevalent in large infrastructure construction projects. Too great interfaces (Osipova and Eriksson, 2013), less previous experience (Tang et al., 2006), along with different kind of stakeholders (Olander and Landin, 2005) can add more uncertainties to managing risks on these projects. Infrastructure projects, generally struggle with the variety of risks associated with different stages of decision making process and every infrastructure projects present unique situations of occurrence of risks. Some of the risks are very specific to infrastructure projects like the number of approvals and delays due to long planning cycle. This factor establishes the need to investigate risk management in Infrastructure projects. It becomes vital for infrastructure project managers to manage risk appropriately, but literature in infrastructure project risk management mostly addresses the issues related to risk assessment. Though there exist several studies on risk assessment in infrastructure projects, research lacks the studies dealing with enabling factors or risk management strategies used by the project sponsors or managers. Turner (2009) highlighted that the essence of project management is risk management. Project risk management is a central approach that increases the chance of project success. Many authors have found that project change during project implementation is one of the most common causes of delays (Assaf and Al-Hejji, 2006; Han et al., 2009). Different authors have focused on investigating the leading causes of project delays. Authors have attempted to assess the criticality of risks in different kind of projects. It becomes imperative also to study the critical success factors so that risk management can be implemented efficiently. A relationship-oriented perspective has been put forth to deal with risk management, especially in large infrastructure projects (Tsamboulas et al., 2013; Ward and Chapman, 2008).

Many studies have advocated control-focused project management practices, such as strict planning and monitoring of change orders to reduce its effects and improve performance (Doloi et al., 2011; Giezen, 2012; Menches et al., 2008). De Man and Roijakkers (2009) examined how the governance structure of contractors and sub-contractors in the construction sector could balance control and trust in dealing with such risks. Osipova and Eriksson (2011) empirically explored the effects of cooperative procurement on the management of risks in construction projects. Osipova and Eriksson (2013) encouraged academics and practitioners to reflect further on how to combine different management systems to achieve successful joint risk management. Even though some studies on risk mitigation factors and success factors of infrastructure projects have been done, authors have talked about the critical success factors for projects in general (Cooke-Davies, 2002; Chan, et al. 2004; Lin Moe and Pathranarakul, 2006; Phogat and Singh, 2013; Badewi, 2016). Studies are more focused on IT and software projects and few on Construction projects. The literature lacks in terms of modeling of critical success factors in infrastructure projects. They also do not emphasize how these critical success factors affect project objectives. This research aims to identify the critical success factors in large infrastructure projects and assess their effects on these objectives.

This paper draws information and inspiration from the literature of risk management of the different type of projects, which are mostly very general. This research develops a quantitative model to assess the impact of risk enabling factors for a given infrastructure project along with their critical scores. Though it may not include an exhaustive list of all elements, it has attempted to take in all relevant factors so that model becomes comprehensive enough. Bayesian Belief Network (BBN) model has been used to derive causal relationships among risk management factors effectively. BBN's are probability-based models which give better results in the presence of new evidence. They are very powerful for making inferences and drawing conclusions based on the available information (Jensen, 1996). It is a practical tool which can accommodate both historical data and expert's judgment. Due to data not available of projects, appropriate data has been majorly sourced from experts opinion. The unique contribution of this research is to assess risk enabling factors in infrastructure projects using a Bayesian belief network modeling framework. The use of the BBN model gives interesting insights into the effect of various risk enabling factors (referred to as critical success factors) on identified objectives of the project. Depending on their scores obtained from the analysis, these factors can be prioritized to satisfy the overall goals of the projects.

The chapter is structured into multiple sections: The next section deals with the extensive literature review on the topic. Section 3 describes the research methodology explaining about the Bayesian Belief Network model along with all essential steps in a systematic way. Section 4 includes the explanation of different elements associated with the proposed model, along with their inter-relationship for a given infrastructure project. The next section presents data analysis whereas 'Research finding and model validation' section presents the research finding and validation of results. Finally, the study has been concluded in section 'Managerial Implications'.

7.2 Literature Review

Uncertainty and risk are two different concepts but are commonly used interchangeably. It is evident from this definition that uncertainty gives rise to risk, and risk may lead to losses. This concept is consistent with the Software Engineering Institute (SEI), which have defined risk as to the possibility of suffering loss (Royer et al.,2000).

For quantitative measurements, Risk (R) = Pi x Ii where Pi is the probability of the ith event, and Ii is the impact of the ith event. For qualitative measurements, a probability and impact matrix concept be used. Managers tend to prefer qualitative or verbal characterizations of risks rather than probabilistic descriptions because of the skepticism that a single number cannot accurately represent the broad dimensionality of the risk (Bannerman, 2008). A risk can have multiple causes and multiple impacts. In other words, a risk may occur due to another risk which might have happened at different stages of the decision-making process. Thus, risk inter-relationships can be understood using a network or graph-theoretic model treating risk as nodes, edges as causal relationships, and the edge weights as strength of the relationship. This concept helps in understanding each risk in a better way and in turn, helps in re-evaluating risks and risk priorities (Fang and Marle, 2012). However, the network might become much more complicated if the data size of the project is significant. Table 7.1 lists the classification of risks associated with different projects, as suggested by various authors. Risk management is indispensable as 'unmanaged or unmitigated risks are one of the primary causes of project failure' (Royer, 2000). Studies have indicated that even if only 5% of the total project budget is spent on risk management, the success rate of a project increases by 50–70% (DeDolph, 2003). Unfortunately, it is neglected by many organizations because of various reasons (viz., intangible risk management benefits, busy schedule of project teams, incentives linked to problem solving rather than prevention and mitigation needs etc.) (DeDolph, 2003). The main focus of risk management in projects is usually planning and controlling of uncertainty (Lee et al., 2007). Moreover, risk assessment is done for specific technical aspects rather than focusing on risks that impact the success of a project (Lee et al., 2007). Table 7.1 portrays various risk factors to classify risks associated with different research studies as proposed by various authors.

Table 7. 1 Various risk factors given by different authors.

References	**Categories of Risks**
Winston, (2006)	Internal, External, Project, Technical
DCITA, (2003)	Project Management, Health and Safety, Project Outcomes, Operational Management, Natural Disaster, Financial, Commercial, Personnel
Lee et al., (2007)	Market, Social, Policy, Technology, Legal risks
Assaf and Al-Hejji, (2006)	Process related risks, Owner related, Contractor related risk

References	Categories of Risks
MRC, (2004)	Feasibility, Reputation, Finance and Ethics
Day, (2010)	Financial, Market, Economical, Environmental, Technological, Political
Cannemi et al., (2014), Tjader et al., (2014)	Resource Allocation, Decision related risks, Outsourcing risks
Boateng, et al. (2015)	Disasters, Disruption Risks, Delays

The risk management system is defined as an efficient tool to manage all risk categories in an integrated manner (Cooper et al., 2005). It can be an effective management response to dynamic business environment and facilitate the acceleration of technological development. This system measures and manages all kind of risks associated with the business systematically, irrespective of their types and nature. A critical aspect of the performance of the risk management system is effective and efficient mitigation of risks. As inappropriate risk response process wastes time and organizational resources, the targets on risk mitigation will also become meaningless (Basova and Mitselsky, 2011). A project manager is not only responsible for time, cost and quality management, but also for integration, scope, human resource, communication, risk and procurement management, which makes him or her the most responsible person for project success. As achieving project objectives is the most important goal, it is vital not only to understand the success factors of a project but also investigate how these factors interact with each other and affect the project objectives.

The success factors of a project are interlinked. Time and cost of a project can have interlinkages because longer duration might be needed to carry out extra work or required to be solved due to unexpected problems. A longer duration than the stipulated one may also lead to increased risk of not meeting the objectives.

Control-focused project management approach has been used successfully by many project professionals (Doloi et al., 2011; Giezen, 2012; Menches et al., 2008). However, increase in project complexity due to long duration and a large number of stakeholders, the project management ability of a project manager to control different aspects of his/her project may reduce significantly (Gransberg et al., 2013). Collaboration among key project actors and stakeholders is essential for the success of a project (Mu et al., 2011). Gustavsson and Hallin, (2014) concluded that adaptation of milestones of a project and its objectives to fit changes in project scope and content due to unexpected and/or changed circumstances is a crucial determinant for project success. Organizational complexity involves contextual aspects of the project, such as numbers of people and stakeholders involved, and their interactions (Maylor et al., 2008), as well as the diversity and complexity of project tasks and objectives (Vidal and Marle, 2008). In publicly procured projects, the external context and stakeholders are especially important because "the structure of participating stakeholders may lead to increased complexity" (Geraldi et al. 2011). Reve and Levitt (1984) defined a principal-agent relationship as a professional relationship between the client and the third party consultant to manage construction works taken by the contractors. By incorporating relational risks into a project governance structure, risks of conflict and interactions of human factors, (e.g. bounded rationality and other moral risks) can be better understood, predicted and planned effectively. Good communications of risks are also of paramount importance (Atkin and Skimore, 2008). Through proper governance structures, motivation and morale of the all project team members can be maintained, and project stakeholders are informed about the status of different stages of the project. The infrastructure projects, including public and private construction projects (residential, industrial, utilities, etc.) are of significant importance for their sponsor. The application of systematic cost estimation methods has not been introduced efficiently except for some cases that may present particularities (e.g. public-private partnership projects).

Moreover, risk reserves are determined either on an empirical basis or in a regulatory manner by taking into consideration fixed amounts that correspond to a certain percentage of the overall budget (Touran, 2003). Wibowo et al.

(2012) provided methods for quantifying payments of guarantees to protect project sponsors from sky-rocketing costs of acquiring land, delays in scheduled toll adjustment, and compensation payments. This practice is applicable in case of nationalization of events looking forward to considerable investments in infrastructure from private investors and have been focusing on the development of tools and activities to attract more investments through PPP format.

Management activities in a construction project can be handled effectively if construction companies explore the critical success factors (CSFs) which are responsible for improving the performance of projects. Many efforts have been made to address these issues using different types of resources planning tools(Cheng, et al., 2014; Leyman and Vanhoucke, 2016; Mohammadipour and Sadjadi, 2016). Such tools can prepare a proper ordering schedule for different types of resources (e.g. materials, manpower, project cost and duration, etc.), especially for construction projects (Sarker et al., 2012). Furthermore, it should be noted that simultaneous consideration of the project scheduling and material ordering can improve the total costs of a project. Some of the researchers have developed optimization and heuristics-based scheduling algorithms for project management. Schmitt and Faaland (2004) proposed a heuristic algorithm for scheduling of a recurrent construction project aiming to maximize the net present value of the cash flows. Dodin and Elimam (2001) developed a model by considering the crashing possibility of activity, rewards for early completion, and materials quantity discounts.

Insight into the works carried out by various researchers on the assessment of risk enabling factors of infrastructure projects are given below in table 7.2

Table 7. 2 Critical Success factors in infrastructure projects

References	Critical Success Factors used by the research
Chan, et al. (2004)	Adequate support, Mutual trust, Long term commitment, Effective Communication, Efficient coordination, Productive conflict resolution
Li, et al. (2005); Jefferies et al. (2002);	Strong private consortium; Appropriate risk allocation and risk sharing; Commitment/responsibility of public/private sectors; Thorough and realistic cost/benefit assessment; Project technical feasibility; Transparency in the procurement process; Good governance; Favorable legal framework Bennett; Political support; Government involvement by providing guarantees; Stable macro-economic environment; Well-organized public agency; Shared authority between public and private sectors; Competitive procurement process
Qiao et al. (2001)	Preliminary Qualification Evaluation Phase; Tendering Phase, Concession Award, Construction Phase, Operation Phase, Transfer Phase
Nguyen, et al. (2004)	Comfort, Competence, Commitment and Communication
Atkin and Skimore (2008)	Identifying and understanding stakeholders concerns, Assessing stakeholders attributes
Guo, et al. (2014)	Governance related factors, Relationship related factors
Xenidis and Stavrakas (2013)	Appropriate budget allocation, Adjusting budgets based on risk assessment
Sarkar, et al. (2012)	Schedule planning, use of project management tools/techniques

7.3 Research Methodology

7.3.1 Bayesian Belief Network

Bayesian Belief Network (BBN) can represent probabilistic cause and effect relationships in the form of Directed Acyclic Graphs (DAGs). The nodes represent random variables having some probability distribution and the directed edges represent causal relationships. A conditional probability table is associated with each node having a parent node. Bayes' theorem is the basis of this model which can be expressed as given in equation (7.1).

$$P\ (X|Y) = P\ (Y|X) * P(X) / P(Y) \qquad \text{--- (7.1)}$$

where

P(X|Y) is the posterior probability that event X occurring, given that event Y occurs; P(X) and P(Y) are the prior probability of the occurrence of X and Y, respectively;. P(Y|X) is the conditional probability that event Y occurring, given that event X occurs. Thus, using this, the likelihood of the occurrence of a particular state of a random variable can be predicted in a more accurate manner provided that its causal random variables have taken a particular state.

BBN's can be used in both ways: 1) top to bottom, used as predictive modelling, and 2) bottom to top, used as a diagnostic tool. That is, one can move not only from causes to consequences but also can calculate the probabilities of occurrence of different causes which might have led to these consequences. BBN's are used for the analysis of data and expert knowledge, especially in fields that are fraught with uncertainty, as they make it possible to treat uncertainty explicitly. They are also used to create "expert systems" that include expert knowledge about a complicated domain such as medicine and medical research. For causal modeling, BBN is the best fit methodology. In this research, an attempt has been made to study the effect of various level of risk enabling factors on project objectives.

BBN's are also useful in handling cases where some data entries are missing or not unavailable. The expert judgments can be easily incorporated under such conditions. BBN has certain limitations also which include its inability to model cyclic dependencies, large data requirements for assessing conditional probabilities and limited performance when it comes to high dimensional data. The task of forming a BBN model can be broken down into two steps- 1) Parameter learning which is quantitative and 2) Structured learning i.e. qualitative.

Parameter Learning (Quantitative): This involves determining the probability distribution for each node given in the BBN framework. The probabilities can be objective (derived from data) or subjective (derived from expert judgment). Objective probabilities can be estimated through maximum likelihood estimator method, and/or maximum posterior estimate etc. Subjective probabilities can be determined through surveys, interviews, and likewise. The knowledge derived from the previous two sources can be combined using adjusted weighting algorithm (Woodberry, 2005). This method is most commonly used when the number of parameters in the BBN is greater than the available data. A sample BBN network is shown in Fig. 7.1.

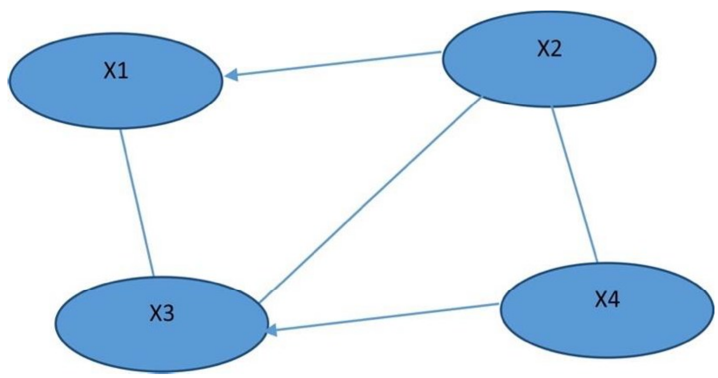

Fig. 7. 1 Sample Bayesian Network diagram

Structured Learning (Qualitative): This includes creating a directed acyclic graph, identifying variables and identifying the relationship between them. This analysis can be done by using data. Other alternatives include literature review, experimental observations, and input from field experts. Data-driven approaches include looking for the location of all possible structures and using the score function to evaluate the benefits of each structure. The highest scoring structure is then selected. This method is extensive in case the search is too exhaustive. Another method is a data-driven approach considering constraint-based aspects. In this method, an edge is established between the two nodes in case the statistical test value of the conditional independence test exceeds the predefined threshold. This method however yields less reliable results when there are smaller number of data points. Mixed models have recently been developed that combine the previous two methods. Fig. 7. 2 shows an example of a directed acyclic graph, which is the basic data structure of a BBN model.

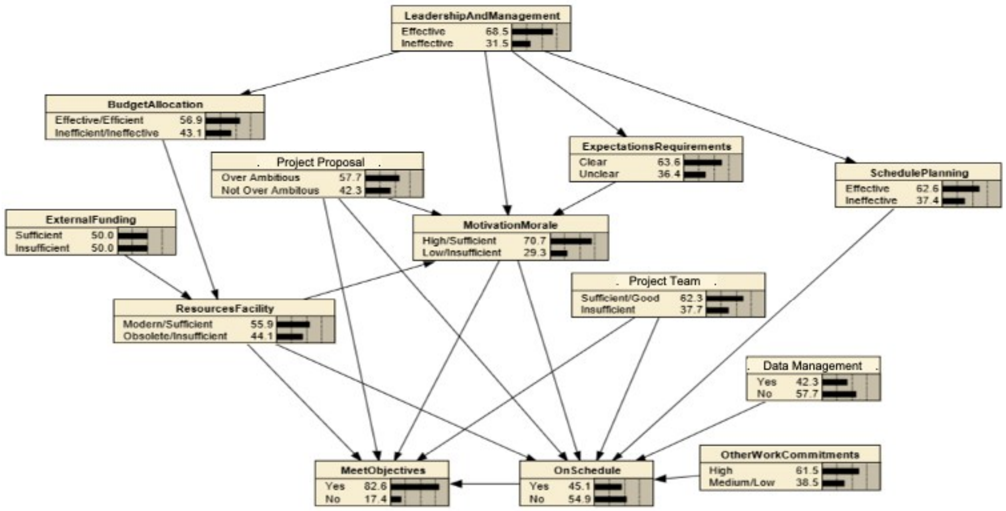

Fig. 7. 2 Interrelationship among critical success factors in Infrastructure project

Though BBN's were used initially only for discrete random variables, they have been applied successfully by incorporating continuous or hybrid domains with some restrictions on network structure and probability distributions (Langseth et al., 2009). If the restrictions make the model infeasible, then the continuous values can be discretized, which may generally lead to a loss of information.

7.3.2 Selecting query variables

The query variable is the variable used by the BBN model to accurately predict the likelihood of its various states whenever new evidence is available. BBN can be used to determine which variables have a greater impact on query variables using sensitivity analysis. In this study, the main risk factors that can be used as a query variable are given below:

i. *Risk of not meeting the set objectives*: whether or not the project achieves specific project results, is primarily what distinguishes a successful project from a failed plan.

ii. *Risk of not completing the project within the stipulated timeframe*: a time frame is specified for each project. Timely completion of the project is of concern, as it is widely accepted in the project management literature that projects completed over time are more likely to achieve their objectives within a given budget.

7.3.3 Selection of Risk enabling factors

Literature in risk management of infrastructure projects is limited. Moreover, this available literature is general for all type of projects and does not focus specifically on the particular area of the project. The steps followed to get the most relevant risk enabling factors are:

i. Critical success factors (CSF) in infrastructure projects identified by different authors (Campbell and Schofield, 2006) are given in Table 7.3.
ii. Elimination of irrelevant risk enabling factors or CSF not affecting the selected query variables-
    a. Critical Success Factors relating to project sustainability and ethical code of practice
    b. Critical Success Factors relating to the respective organization and users
iii. consultation with infrastructure professionals to get their feedback for shortlisting the factors.

7.3.4 Determining BBN structure for risks

The structure study has been carried out through a literature review for the following reasons:

- The number of nodes is relatively small, which is 13. Hence, the task of defining the network was not complex.

- Unavailability of data for which machine learning or optimization algorithms could be applied for auto-generation of the network structure.

The basic methodology (Literature review and expert opinions) was applied to determine the variables for each risk enabling factor, which directly influences it and is influenced by it. Implementation of Bayesian belief networks (BBN) modeling requires risk factor identification and then establishing a relationship among them. The initial stage in the BBN model development is structural development and evaluation, which on the first iteration will produce an unparameterized causal network. This phase of model development can be undertaken via a knowledge or data-based approach. Knowledge-based model development is done through expert elicitation of parameters. The risk enabling factors were identified using literature review, and then the prepared list was sent to the experts for validation. Questionnaire for the structural development was based on a literature review, and two senior-level managers were consulted who confirmed the list of enabling risk factors. For the qualitative study, validation of the risk factor enabling factor was ensured through extensive literature review and subject matter experts (SME) opinions. Once, the relevant variables were identified, then experts were asked to draw linkages among various risk factors used in the study. For establishing a structural relationship among variables, Delphi method was used. Once opinions of experts converged on a particular structure, it was taken for further evaluation. The experts were project sponsors, project managers and contractor/subcontractors. For the structural model development, six experts were interviewed through Delphi method. These experts were from all domains of the infrastructure project and having 15-20 years of experience. Delphi method is a scientific method ensuring the elimination of subjectivity in estimation through the iterative process. The selection of subject matter expert has followed the Delphi method guidelines and included a sufficient number of experts for drawing a structural model.

In the second step, the parameterization of the model was done. Prior to parameterization, all variables were discretized into states. For continuous variables, states were further discretized into sub-ranges. Wherever possible, states were established using recognized classifications, management thresholds or guidelines. If these guidelines were not available, sub-ranges were specified with the guidance of the experts. The number of 'states' or 'classes' assigned to each variable were not pre-determined but evaluated and assigned on an individual basis. In the next step, expert elicitation is applied to the whole Conditional Probability Tables (CPT), rather than individual parameters. For parent nodes, prior probabilities were elicited, and for child nodes, CPT was elicited with respect to each possible state.

7.3.5 Obtaining the probability tables

The probabilities were obtained by surveying infrastructure professionals. A questionnaire was sent to infrastructure professionals working in various public and private projects. The respondents were asked to exercise their judgment using perception, beliefs and experience about the likelihood of the selected risk enabling factors in light of causal relational manner. Thus, the probabilities obtained were subjective rather than objective. Survey method was chosen because learning probabilities from a data-driven approach would require data of an extremely large number of different infrastructure professionals in various projects varying in the occurrence of the factors. The method adopted to elicit expert's judgment is described as follows:

i. Estimation of Prior probabilities: The characterization of the probabilities of all states of those nodes which do not have any parent node can be done directly or by pair-wise comparisons between the states. In the direct method, the probabilities for each state has been specified by the experts by taking into consideration that their sums become one. In pair-wise comparison method, experts are asked questions like “Out of these two states, which one is more likely and by how much?” which results in a ‘n x n’ matrix, where n is the number of states.

ii. The latter method may prove easy for the experts as they have to consider only two states at a time instead of n states. But the downside is that n x (n-1) / 2 entries need to be specified instead of n-1.
iii. The former method has been used in this work as there are only two states per node considered in the study, and hence the pair-wise comparison method provided no additional benefit. This resulted in a single probability which needed to be specified per node with no parent.
iv. Conditional probability estimation for single parent nodes: Probabilities for this type of nodes were also estimated using the direct method, which resulted in a single probability per state of the parent node.
v. Conditional probability estimation for multi-parent nodes: The respondents were asked to specify the probabilities for the states of this type of nodes for every combination of the states of the parent node due to the following reasons:
    a. Each combination of the states may result in a range of probabilities which may lead to visualize an insight into the spectrum of solutions. For example, if a node has five parents, and each parent has two states, then $2^5 = 32$ probabilities may exist.
    b. It would be challenging for respondents to accurately provide judgement for each combination of parent states, as many variables are involved.

The probability elicitation methodology used in this research consisted of two steps. First, to ask the node's conditional probability on each of its parents. Then combine these probabilities to obtain the node's conditional probability on all of its parents. The combination step was achieved by using equation 7.2 (Kim and Pearl, 1983).

$$P(X \mid Y1, Y2, Y3 \ldots Yn) = \alpha P(X \mid Y1) * P(X \mid Y2) * P(X \mid Y3) \ldots P(X \mid Yn) \qquad \text{--- (7.2)}$$

where ‘α’ = normalization factor. Normalization factor ensures that for a given combination of the states of the parents, the sum of probabilities of all the states for a node equals 1.

7.4 Model Description

Fig. 7.2 shows the model which was developed using Netica tool (Netica, 2016) by following the project methodology described in the previous section. In this section, first, the model complexity is judged using various measures, and then the variables are described along with the justification for cause-effect relationships. Fig. 7.2 shows the relationship among different risk enabling factors in infrastructure projects.

7.4.1 Model complexity

An overly complex model may work poorly (Adkinson, 2009). Therefore, BBN modeling accuracy must be balanced with simplicity by trying to find a simplified model that yields acceptable results. Complexity measures can be used to compare alternative model structures and summarize the basic structure of the model. The simplest measure of the complexity of the BBN model is the number of nodes and edges. The model has 13 variables and 21 links.

Some other important data sets are related to the number of nodes and the conditional probabilities of the entire node network. In this model, all variables are considered as discrete, and only two number of states per variable has been taken to reduce the duration of survey length, which would otherwise result in not only low response rate by the respondents but also avoid engaging them with lesser time per question. Hence, the total number of states worked out is 26. The conditional probability number, excluding the nominal preceding probabilities, is 372, which is calculated using equation 7.3.

$$\sum_{i=1}^{V} \left[S \prod_{j=1}^{n} P_j \right] \qquad \text{--- (7.3)}$$

where

S = the number of states of the child node

P_j = denotes the number of states of the jth parent node

7.4.2 Network detailing – Nodes and Edges

Root Nodes: Critical Success factors (CSF) in infrastructure projects considered are shown in Table 7.3. These factors are not probabilistically affected by any CSF considered in the developed model. Thus, these variables are conditional independent of the other variables.

Table 7. 3 Root nodes of the proposed BBN model

Risk/ Risk Factor	Description
EF - External funding	It assesses whether the funds allocated by the sponsor are sufficient to obtain the most suitable and advanced software, hardware and other resources.
RP - Project proposal	It assesses whether the objectives of the project proposal can be classified as overly ambitious based on the difficulty in achieving the project objectives. The project may require high levels of innovation, new technology to be used, and / or the project may have high complexity, but the perceived benefit may be low.
OWC - Other Work Commitments	It assesses whether the cumulative commitment is greater than the project associated with the project team members. Other work adjustment commitments may include other projects and responsibilities that reduce the amount of time and attention a team member may have on a related project.
RT - Project Team	It measures the size of the project teams and whether they have the skills, experience, skills or knowledge needed to successfully complete the project

Risk/ Risk Factor	Description
DAM – Data Management	It assesses the need for reconstruction when there are no backups that can lead to loss of data storage devices and loss of storage devices.
LM - Leadership and Management	It assesses the commitment of the sponsor / manager and their experience and capabilities in effective monitoring, planning, managing projects and managing risks.

Nodes with parents:

Resources and Facility (RF): Whether the existing resources like software, hardware and the equipment available are modern and sufficient or not, depends partly on the finances allocated to the project. Some resources financed through the funds received from recent Infrastructure projects may prove to be useful. However, in some cases, the available resources may not be sufficient and may need to be enhanced through the funding received. Despite receiving sufficient funding, the poor budget allocation may lead to fewer funds allocated to the most critical equipment.

Budget Allocation (BA): The planning of the allocation of funds is carried out by the project sponsor, and its effectiveness depends primarily on his/her experience and management skills. This planning is effectively done by ensuring enough funds for the most critical resources and keeping contingency funds.

Clarity on Scope, Objectives, Requirements and Expectations, (EROS): The project sponsor is responsible for communicating the scope and requirements of the project to the project team. It is his responsibility to ensure transparency and make sure that every project team member knows what is expected from him and does not have any doubts or confusion regarding his expectations.

Schedule Planning (SP): Deciding the order of tasks and how much time to allocate on each task is primarily done by the project sponsor and project manager. This planning is efficiently done by setting milestones, ensuring proper time management so that enough time is allocated to the most critical tasks. It must also be ensured that critical tasks are performed when the work commitments of the project team are low, and enough margin of time is allocated to deal with contingencies. Thus, whether the planning is efficient or not depends primarily on the project manager's experience and management skills.

Motivation and Morale (MM): Projects with high morale take the initiative and develop a work environment which fosters high morale in other Projects. This ensures better coordination and motivation. People with high motivation tend to work harder and for longer hours. Leaders and managers in any team have the capacity to create a favorable environment for high motivation and morale by providing regular feedback and guidance, giving sufficient autonomy and flexibility and ensuring good communication and coordination within the team members. How clearly defined the objectives and targets are and whether one knows what is expected of him can also affect one's morale and motivation as the person who is not sure of how his work will impact the whole project, in general, may feel the work he is doing is not important. How challenging but realistic the defined objectives in the Project proposal are, also affects motivation because when a person can perceive the feeling of achievement when he fulfils the goals, he tends to put efforts towards its attainment. The previous two arguments are consistent with goal setting theory of motivation (Locke and Latham, 1990). Availability of modern and appropriate resources and the facility can affect morale as its absence can lead to frustration due to the hindrance caused in the way of achieving goals.

7.5 Data Analysis

After filling in the probabilities and compiling the BBN model, we get the total probabilities of the query variables, as shown in Table 7.4. In the general scenario, where we are not sure about whether any of the causal risk enabling factors are high or low, we can see that the model shows high confidence in predicting that there is a low risk of the project not achieving its objectives. This can be attributed to the fact that infrastructure projects achieve results. Infrastructure projects are the public goods, and they are constructed for the wellbeing of the society, so ultimately, these projects meet the objectives, but the probability of completing these projects is not high. Infrastructure projects get delayed due to various risk factors. Generally, management used to keep enabling factors into consideration to fulfil objectives of the projects but not the schedule. Table 7.4 presents the outcome variable's probability for two states.

Table 7. 4 Infrastructure projects query variable probability

Outcome	Yes	No
The project does not achieve objectives	82.6	17.4
The project does not complete in time	45.1	54.9

Sensitivity analysis is useful in determining the relative importance of causal variables in terms of its effect on the target variable. This helps the manager to focus on risk management efforts on the most critical risk factors. Two types of sensitivity analysis can be performed under the BBN modeling framework:

i. Analysis of the sensitivity to the results of observing the difference in the posterior distribution of the node under different conditions. We can infer on how the results from other nodes affect our confidence in a particular node. Sensitivity can be measured using entropy and reciprocal information. Entropy is a measure of the randomness of a variable, based on its probability distribution. As observed from Equation (7.4), each state has an equal probability variable that has the highest entropy of all the probability distributions of the same states.

$$H(X) = -\sum_{x \notin X} P(x) \log P(x) \quad \text{--- (7.4)}$$

Mutual information is a measure of the effect of one variable over another. In Equation (7.5), I (X, Y) is the correlation between X and Y, and shows how independent is the joint probability of X and Y. Therefore, the greater the interaction information, the greater the sensitivity.

$$I(X,Y) = H(X) - H(X|Y) \quad \text{--- (7.5)}$$

Table 7.5 and Table 7.6 shows a typical output of sensitivity analysis. The risk enabling factors are listed in descending order of their sensitivity score.

ii. Sensitivity to parameters is monitored by variation in the query node by changing the parameters of each query node. This is a time-consuming task for complex BBNs. To evaluate the sensitivity to the parameters, the variance reduction method was used to detect the change in the variability of the investigated variable by the change in the parameters. This creates a lot of scenarios for comprehensive analysis. If there are two states of four variables, there are sixteen scenarios. For BBN modeling, sensitivity to the results gives more sensible results.

In this section, only sensitivity to the results is concentrated, and tornado charts are used to graphically visualize the effects of sensitivity to the findings in Figs. 7.3 to 7.6. Tornado charts are listed vertically with data categories. Tornado charts use the critical success factors of variables in order of their effectiveness. The sensitivity of the causal variable to the target variable is displayed by the length of the horizontal bar. Tables 7.5 and 7.6 show the correlation between risk enabling factors and outcome variables (achieving project objectives and schedule). Mutual information is provided in the second row of Tables 7.5 and 7.6 between the two variables (in this case the risk factor and the resulting variable respectively). Higher scores indicate greater dependence between variables.

Table 7. 5 Sensitivity analysis risk of not achieving Project objectives

Risk/ Risk factors	**Mutual Information**
Meet Objectives	0.6676
Motivation and Morale	0.1006

Risk/ Risk factors	Mutual Information
Schedule Planning	0.0788
Resources and Facility	0.0616
RFP Soundness	0.0451
Project Team	0.0407
Leadership and Management	0.0145
Clarity of Expectations/ Requirements/ Objectives	0.0132
Budget Allocation	0.0059
External Funding	0.0047
Other Work Commitments	0.0004
Data Lost	0.0002

Table 7. 6 Sensitivity analysis for on-schedule

Risk/Risk factors	Mutual Information
Meet Objectives	0.9931
Motivation and Morale	0.0871
Schedule Planning	0.0790
Resources and Facility	0.0788
RFP Soundness	0.0519
Project Team	0.0351
Leadership and Management	0.0335
Clarity of Expectations/ Requirements/ Objectives	0.0330

Risk/Risk factors	Mutual Information
Budget Allocation	0.0299
External Funding	0.0151
Other Work Commitments	0.0056
Data Lost	0.0021

Results in Tables 7.5 and 7.6 show the effect of each risk enabling factor, one factor at a time and one query variable (outcome variable). Mutual information score indicates that the sensitivity means that two variables share more information and have more dependency. In another way, this also indicates the relative importance of the factors.

Based on the results presented in Tables 7.5 and 7.6, some key findings from the sensitivity analysis are given below:

- Low motivation is the most critical risk that can lead to schedule risk and the risk of not achieving goals. Therefore, project leaders must be looked after.

  The project team's morale is high when budget planning is adequate to ensure resources and facilities are adequate; Assessments, needs, objectives and scope are clear to avoid confusion through proper and regular communication with project team members;
- Good coordination and communication among project team members provides timely guidance and feedback to ensure high motivation.
- Proper budgetary allocation is more important than the inefficiency of the fund. This shows that it is more important to use funds efficiently as compared to receive large amounts of funds. Moreover, there is little emphasis on the two risk factors.
- In case the project is not completed within the stipulated time, it is less likely to achieve its goals.

- The second important factor in completing the project on time is proper scheduling. Its importance can be mainly attributed to critical bad scheduling may not provide enough time for most complex tasks and improper schedule may not be plan for contingencies and unforeseen circumstances.

  Tornado Figs. 7.3 to 7.6 show the sensitivity analysis for query variable 'not achieving the objectives' and 'on schedule' is high and low, respectively. Figs. 7.3 to 7.6 indicates the different interpretation of sensitivity analysis.

  Tables 7.5 and 7.6 show that mutual information between each risk enabling factor and the infrastructure project's goals. Mutual information quantifies the information shared between two variables. Such information becomes useful to correlate the importance of both the variables and reduces the uncertainty between them. Both Tables 7.5 and 7.6 show that if project manager knows about the morale and motivation of his/her team, he/she can predict the achievement of project goals in a better way.

  On the other hand, sensitivity analysis results show the exact change in the outcome variables with respect to change in its parent nodes. Fig. 7.3 shows sensitivity analysis results for the query variable; not achieving the objectives is high.

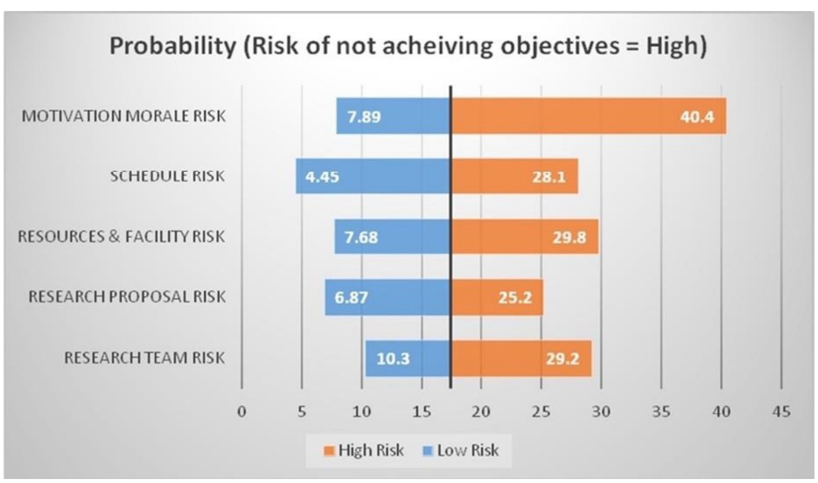

Fig. 7. 3 Sensitivity analysis for query variable not achieving the objectives

Fig. 7. 3 shows when the probability of risk not achieving objectives is high (set to occur at 100%), then simultaneously, the probability of motivation and morale is high is 40.4%.

When the probability of risk to not achieving objectives is high, then the probability of motivation and morale being low is 7.89%. Next Fig. 7. 4 shows sensitivity analysis for query variable on schedule is high.

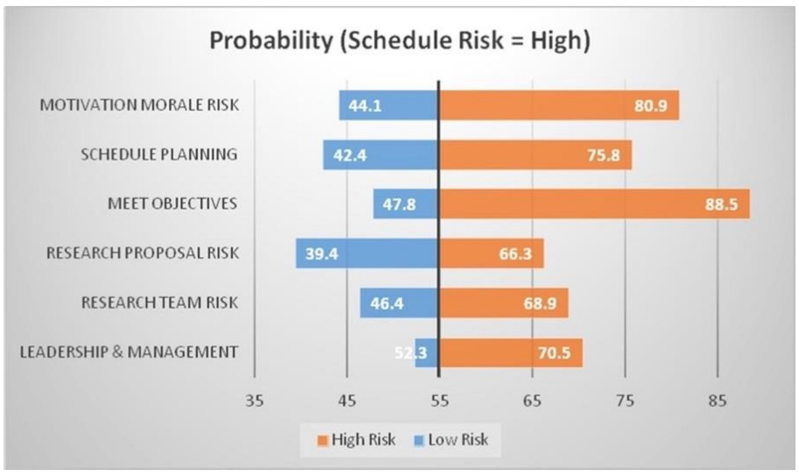

Fig. 7. 4 Sensitivity analysis for query variable on-schedule

Fig. 7. 4 shows when the probability of risk of on-schedule is high (set to occur at 100 %), then simultaneously, the probability of motivation and morale is high is 80.9%. When the probability of risk to on-schedule is high, then the probability of motivation and morale being low is 44.1%. Similarly, the other important factor is schedule planning and its probability of being high stands at 75.8 %.

Next Fig. 7. 5 shows sensitivity analysis for query variable not achieving the objectives is low.

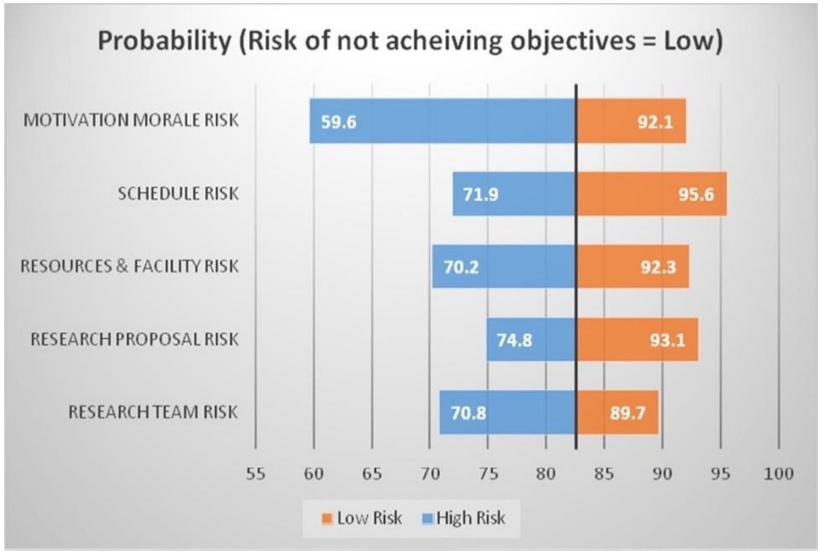

Fig. 7. 5 Sensitivity analysis for query variable not achieving the objectives

Fig. 7. 5 shows when the probability of risk not achieving objectives is low (set to occur at 0%), then simultaneously, the probability of motivation and morale is high is 95.6%. When the probability of risk to not achieving objectives is low, then the probability of motivation and morale being low is 59.6%. This result further corroborates the finding obtained through Fig. 7. 3. Below Fig. 7.6 shows sensitivity analysis for query variable on-schedule is low.

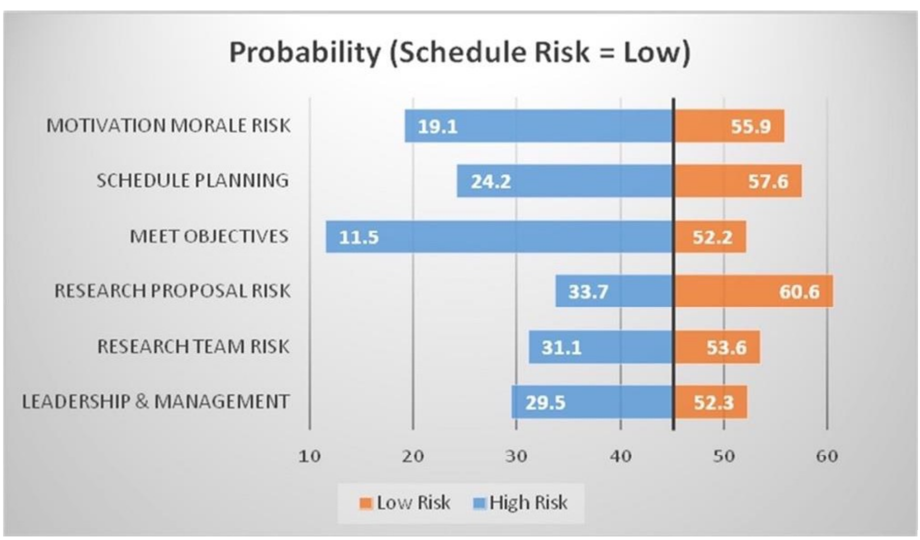

Fig. 7. 6 Sensitivity analysis for query variable on-schedule

Fig. 7. 6 shows when the probability of risk of on-schedule is low (set to occur at 0%), then simultaneously, the probability of motivation and morale is high is 55.9%. When the probability of risk to on-schedule is low, then the probability of motivation and morale being low is 19.1%. Similarly, the other important factor is schedule planning and its probability of being high stands at 57.6 %

7.6 Study findings and validation

7.6.1 Study findings

In this research, a model is being proposed to assess the effect of critical success factors on project objectives. BBN model developed in this research presents the current state of critical success factors in infrastructure projects, which show that morale and schedule planning of projects are most prevalent with both are more than 50% level. Tornado charts indicate the criticality of the risk enabling factors. These two factors importance were corroborated by Johnsen and Veen (2013) that highlighted the importance of critical information and morale of employees for the success of projects. Murugesan (2012) also pointed out that leadership role is the motivation of team members and team members emulate the leader and are highly motivated to achieve set goals and do not worry about a group or individual goals. Findings of this research also establish that the most vital factors in infrastructure project risk management are motivation and morale. Highly motivated people take more accountability and do not hesitate to share the negative information (risk) to the leadership. If risk information is detected early, it saves costs as well explores better plans for risk management. Other enablers are also ineffective in the range of 29.3% to 43.1%. The sensitivity analysis findings represent the relative importance of the critical success factors (CSF) in infrastructure projects. Team morale or motivation is most critical for the success of infrastructure projects. The proposed model portrays the practical relevance to project managers in terms of identifying the level of CSF and explores how the selected levels affect project objectives.

7.6.2 Validation

Due to the absence of data on real projects, the model prediction performance cannot be measured. Thus, to validate the model, the subjective route has been adopted rather than an objective one, as the model was presented to the subject experts to get their constructive feedback. The experts chosen for model validation were the senior managers/leaders working for important infrastructure projects. Several questions on the proposed model in this research were asked to subject matter experts (SME). The questions were on relevance, practicality, and usefulness. Three subject matter experts working as project managers in large infrastructure projects gave their consensus on all three dimensions of model validation. The consensus was that most of the relevant risk enabling factors were considered and cause-effect relationships represented the real phenomenon. The only limitation was that the number of states was low, that is a middle ground option should have been there. This positive feedback was achieved by making alternative models in the early stage and choosing the one who had the most agreements of the experts.

7.7 Managerial Implications

Sensitivity analysis results in present insightful findings. Through this analysis, we can draw inferences about the various risk enabling factors' (CSF) importance and their criticality. Tornado graph 7.3 and 7.6 show the effects of risk enabling factors on infrastructure project objectives. It is evident from the graph that the particular infrastructure project, morale and motivation are more prevalent for the goal of the cost attainment as well as project being on-schedule. Similarly, most of enabling factors are present in infrastructure projects to some extent, some are at high levels, and some are at low levels. This also enables the infrastructure project professionals in updating the effect of risk enabling factors on infrastructure project goals, whenever new information is arrived at about the level of CSFs. Based on this, the effective infrastructure project risk mitigation strategies could be implemented with the cooperation of all stakeholders in the infrastructure project. The proposed

BBN risk assessment exercise should be carried out from time to time as an infrastructure project's duration is large. This research is one of the unique efforts in terms of proposing and building a model that combines the subjective and objective factors in a probabilistic manner. If objective data is not available, prior and conditional probability may be determined using SMEs.

7.8 Conclusion

In this chapter, critical success factor modeling has been proposed for infrastructure projects using the BBN approach. This BBN model can be used to get a better idea of how likely the attainment of project objectives within the stipulated time is, in light of new evidence so that corrective measures can be taken in a timely manner. The critical success factor selection for the model and the establishment of the relationships between them was made through literature review and expert interviews. The probability tables were formed using the judgments of infrastructure projects. Scenario analysis justified the usage of critical success factor modeling as a higher probability of success was demonstrated in favorable conditions. Sensitivity analysis was carried out, which resulted in the relative importance of various critical success factors in affecting the project success. One of the important finding pertaining to infrastructure projects states that morale and motivation is a highly important factor. Infrastructure projects lack the motivation in project team due to the complex interfaces and a large number of stakeholder involvement. This information will prove useful for government and project leaders to prioritize their risk management efforts effectively. The model received positive feedback from project professionals but could be made more useful for the practical purpose by incorporating more states per variable. This research provides a unique approach to understand the interrelationship among the major risk factors and the analysis demonstrates that proposed methodology can help the managers to the effect of changes in risk factors on achieving the project objectives.