Chapter 5: Assessment for Risk in Logistics Infrastructure Projects Using Analytic Network Process

5.1 Introduction

Air logistics infrastructure projects are time-sensitive, and capital intensive that involves high capital commitments and are of long duration. Such kind of projects is susceptible to risks. Risk management is a prerequisite for any sort of project being carried out. The broad heading of risk management is inclusive of assessing risks, identifying risks, mitigating risks and controlling risks. Risk management is an organized procedure for optimizing positive features and curtailing features that may have adverse effects on the objectives of the project. Numerous events with potential risks may occur in a mega-project development which may affect the success of the project. There are ample cases of ambiguity in infrastructure construction projects, comprising of performance of construction party, availability of resources, third-party involvement, not adherence to contractual obligations and environmental circumstances. As an outcome, projects of infrastructure construction face obstacles that push the project beyond the deadline and compromise on the quality of the project. Considering the unique characteristics of construction projects, over-running the schedule and cost is a common phenomenon. Thus, it is essential to apply risk assessment for cost estimation and scheduling infrastructure construction projects. From the process of start to end, especially for the mega-project development, the process of construction is complicated and comprises of numerous uncertainties that adversely affect the project (Van de Graaf and Sovacool, 2014; Renuka et al., 2014; Brookes, 2015; Mentis, 2015).

Wu et al. (2018) proposed a risk management framework to control risks for electric vehicle charging infrastructure. First, the authors provided a comprehensive risk index system using Delphi method. Next, a three-dimensional model encompassing probability, losses and uncontrollability involved for risk assessment in which Analytic Hierarchy Process is used for weight determination and grey fuzzy method is employed for assessment. Khodeir & Nabawy (2019) identified vital threats arising from the internal and external environment of stakeholder's organization during the construction of infrastructure. The methodology used in their research includes a literature review of infrastructure challenges, followed by identification and classification of risk factors using risk breakdown structure.

Furthermore, a checklist analysis of critical risks was performed. The 'Cairo Festival City" project was analyzed as a case study of an infrastructure project. Li et al. (2019) have provided a holistic risk assessment framework with five resolution phases to deal with preliminary preparation, information processing, interdependent effect analysis, risk aggregation, and risk rating. Subsequently, a fuzzy hybrid method is proposed based on extending and integrating the decision-making trial and evaluation laboratory (DEMATEL), two-additive Choquet integral (TACI), and fuzzy reasoning. The method is used to clarify the risk profile of the construction projects, and the risk sources and risk controllability are further diagnosed to support risk treatment.

There is an availability of a plethora of unconventional methods for risk assessment of projects, for example, Analytic Hierarchical Process (AHP), Analytic Network Process (ANP), Structural Equation Modeling (SEM), DEMATEL, fault tree, fish-bone, fuzzy logic, Monte Carlo simulation (MCS) (Wang et al., 2006), and failure mode and effect analysis (FMEA). These are predisposed to subjective criticism; however, they may not be the best methods to create awareness about risk in projects. The drawbacks of AHP and DEMATEL are that they fail to delineate the causal relationships of risks involved in a project, which is an essential step in risk assessment. Risk identification and assessment are two essential steps that determine the framework for the selection of suitable risk mitigation strategies. In most research papers, these steps are not adequately addressed and/or being somewhat compromised due to difficulty in data collection through subject matter experts involved in such projects.

In this research, first, the risk sources have been identified through literature, and experts' opinion, essential documents of previous and currently ongoing mega-projects under construction as well as risk factors were grouped into clusters. Secondly, for calculating the Risk Priority Indexes (RPIs), an Analytic Network Process (ANP) model is designed. The ANP model considers the interdependencies among risk variables, so it is superior to the Analytic Hierarchy Process (AHP). The Risk management aspect is well investigated in software projects, but there are very limited studies in the field of infrastructure project risk management. The main objective of this research paper is to develop a ranking system for risk variables of infrastructure projects. The models developed herein are applied to recognize key areas of risk to examine their magnitude of impact on primary objectives, which are cost, quality and time.

5.2 Literature Review

Literature review outlined in this section is aimed at providing foundational and state of the art grounds on risk identification, classification and management of infrastructure mega-projects. The transportation infrastructure is a vital component of sustainable development and economy for any country. The transportation infrastructure includes various modes – rail transportation, road transportation, air transportation and sea or maritime transportation. In this research, air transportation has been considered, which is vital for economic and social growth. Air transport infrastructure has to be in place well in advance to fetch and address air travel demand, which is continuously increasing every year; be it on the passenger side or for cargo (Wilke et al., 2014). There are increasing complexities and risk in transportation infrastructure projects, especially in construction project management which is very critical. Several researchers have gradually realized the increased significance in the diagnosis of projects' the value of risk measurement, specifically in the area of mega construction projects (Frizelle and Gregory, 2000; Chryssolouris et al., 1994; Baccarini, 1996) which helps in determining of the project’s success.

A study by Fallahnejad (2013) identified common factors responsible for the risks of these projects. They are payment and financial problems, poor site management, improper planning, shortage of equipment and materials, insufficient experience, and other factors like natural disasters such as earthquake and floods (Boateng et al., 2012). A study by Flyvbjerg (2009) found the most pertinent issue to be cost overruns by examining 258 transport projects as the sample for their study. In contrast, Yang and Wei (2010) accompanied time and cost overruns with construction delays and concluded it as a universal phenomenon. Oey & Nofrimurti (2018) studied warehousing infrastructure for consumer good company in Indonesia. The company used to distribute to various small and medium enterprises and company used to implement lean warehousing practices. The authors developed a risk assessment model for warehousing infrastructure.

Lo et al. (2006) discovered the manpower problem, insufficient work knowledge, poor communication, and natural ground conditions to be risks related to delays among Hong Kongs' construction project. Ali-Mohammed (2010) found factors behind Bahrain's' bridge and highway mega-projects success to be utility diversion, traffic congestion, environmental considerations, existing services locations' accuracy, fees for consultant's supervision, and land acquisition. Cavalieri et al. (2019) employed data of road transport infrastructure projects during the periods of 2000 to 2013 in Italy. Authors applied risk management during the entire project life cycle and analyzed each life stage on the project delays and cost overruns (Ke et al. 2010). The study by the (Ke et al. 2010) showed that Italy road PPP projects suffer from cost overruns during execution phase.

Decision support systems and models of MCDM (Multi-Criteria Decision Making) have been used for assessing the risk in infrastructure projects. A study by Hsu and Liou (2013) examined the airline industry in terms of outsourcing provider for risk consideration and anticipated a hybrid MCDM based on Analytic network process (ANP) and decision-making trial and evaluation laboratory (DEMATEL). A study in the Cape Town city used the Analytic Hierarchy Process (AHP) for investigating the development of a potential multi-airport (Zietsman & Vanderschuren, 2014). Pineda et al. (2018) came out with an evaluation model development prioritizing the relative weights regarding the factors for purchase intentions of low-cost carriers among the current and potential customers. Papadimitriou et al. (2019) reviewed the infrastructure risk very specific to the effect of these risk factors on road safety. Three safety parameters viz. crash risk, probability of crashes and the severity of crashes were used by the authors. A decision support systems was developed for the better road safety.

A study by Delbari et al. (2016) recommended a two-stage process for improving so that evaluating the indicating parameters for competitiveness and full-service airlines drivers using AHP (quantitative stage) and Delphi (qualitative stage). The Taiwanese airline industry was also studied for improvement in the criteria for service quality of the airline by applying a combination of ANP and DEMATEL (Chen, 2016). A study by Rezaei et al. (2017) examined three Key Performance Indicators (KPIs), i.e. Loading time, cost and quality for identifying the best configuration bundling between selected outstations for freight supply and Schiphol airports' KLM hub using BWM (Best Worst Method). Li et al. (2017) evaluated the quality of in-flight service by using a three-stage model based on the 2-tuple fuzzy linguistic and fuzzy analytic hierarchy process (FAHP) method. A study by Chang et al. (2015) investigated the SMS (safety management system) performance using a two-stage method wherein first method included determining and to rank the elements and components of SMS using ANP and the second method included assessing and ranking their performance.

A model was designed by Hu and Hsiao (2016) for assessing the quality of risk. This model measured the quality of risk for the services in airlines. Kano model, satisfaction, and importance degree were integrated into the model. Rezaee & Yousefi (2018) identified significant modules influencing the operational safety of the airport. Da Cunha et al. (2017) evaluated small size airports for the levels of risks in consideration to the small to medium airports context. Kivila et al. (2017) studied the process of identifying the significant sustainable project management practices. The study was carried out on large tunnel project involving a large number of stakeholders. The results of the study concluded that different control practices are used at all project life cycles to implement sustainability indicators during project execution.

Safety evaluation models were studied by Netjasov and Janic (2008). Four types of models were investigated, i.e., third-party risk, human factor error, collision risk, and operations for air traffic management/control and aircraft causal. Kim and Yang (2012) investigated the frequency of risk for hazards linked to runway incursion of Gimpo International Airport. Analytic hierarchy process (AHP) was used to find out the weights, and fifteen risks were verified for causing runway incursion. Further step included performing a fault tree analysis. In runway incursions, a study by Chang and Wong (2012) revealed the risk factors of human about the pilots. Wilke et al. (2014) suggested a unified model for a complete assessment of risk. Firstly, triangulation was attained in the development of the process model. Secondly, a database set comprising of twelve databases were combined for determining the causal factors.

Edinburgh Tram Network project data was collected, the study modelled risks analytically by adopting an innovative approach with a combination of new Risk Priority Index and Analytic Network Process (ANP). This approach delivers a collaborative direction to the developers in prioritizing the risks athwart the supply network of the project and for the performance of mega-projects, initiating the appropriate strategies for mitigation in lieu of time consequences and cost significance of STEEP risks. Besides these researches, ANP is used in solving a wide array of problems related to MCDM. Some latest ANP applications include decision analysis and risk assessment (Ergu et al., 2014); levelling and resource allocation (Cannemi et al., 2014); resource allocation (Liang and Wey, 2013); location analysis (Yeh and Huang, 2014); decision making for outsourcing (Tjader et al., 2014). ANP, an extension of AHP, is the primary method for the current study. This method permits the determination of the project systems' complexity and complex systems' analysis (Saaty, 2000).

5.2.1 Risk identification and classification

The risk management process application entails an understanding of risk, that differs by situational context and specific application. Risks can significantly impact each phase of project life cycle from the conceptual design to the closure stage (Flyvbjerg, B. 2014). Cclassification of risk is an integral part of the identification of risk. There are several classification methods used earlier and are also currently being used, which broadly categorize risks under various categories. These include

- Bruzelius, Flyvbjerg, and Rothengatter (2002) suggested a general sorting for identification phase: a) Cost risk – operation, maintenance, construction; b) Demand risk – traffic revenues and forecast; c) Financial market risk – interest rates for the future; and d) Political risk – PPP investments, regulation.

- Bing et al. (2005) suggested a discrepancy among micro and macro risk levels. Micro risk levels comprise of stakeholder relationships risks that are shaped through the purchase process of construction items because of the inherent differences among the private and public sectors in the management of the contract, macro risk levels represent exogenous risks.
- Westney and Dodson (2006) and Rolstadås and Johansen (2008) recommended alternative risk groups. Authors differentiated between contextual risk (allied with projects' external circumstances) and strategic risk (improper decisions implementation, the dearth of responsiveness to changes in the industry, potential influence on capital or earnings from opposing business decisions, that might impact the work scope and organizations' performance.
- Krane, Olsson, and Rolstadås (2012) provided risk classification as per decision making hierarchy levels in projects i. e. the strategic level, the policy level and operational level. (restricted to projects' direct results and with the operational objectives of the project).

The following section provides a risks review in infrastructure projects discussed in the literature:

Design Risk - Design risk related to the design/ planning phase of the mega-project like project control scope, contract formation, bid cancellation (of pre-investment non-recovery risk costs, pre-investment risk), land use and, feasibility analysis, acquisition risk (availability of site risk), and delivery method (Callegari et al., 2018).

Legal and Political Risk– These risks derive from the change in the country's governing policy under which the mega-project is undertaken. For instance, change in government regulations, political actors, cancellation of a concession and authorization criteria are involved (Owens et al., 2012; Giezen, 2012).

Operation and Maintenance Risk – These risks relate to the operational phase which influences the operator incompetence, unnecessary high operations costs, operation quality or capacity, economic viability issues and poor construction quality (Gil, Miozzo, and Massini, 2012; de Sousa Júnior and Reid, 2010; Brady and Davies, 2010).

Construction Risk– These risks are highly substantial in any mega-projects' life cycle. The occurrence of these risks happens in any mega-projects' phase but usually occurs in the phase of construction. Schedule delays in the project and/or cost escalation (or cost overruns), construction errors, coordination problems, an accident during construction, inappropriate design, failing in complying to the agreed standards of quality and unexpected technical difficulties are the consequences observed out of these risks (Vit 2011; Santoso, Ogunlana, and Minato, 2003; Giezen, 2012).

Financial Risk

a. **High Leverage Risk**– It wields influence on the solvency of mega-project, as the basis of, liquidity problems like shortages in funds availability, credit constraints, exchange/interest rate risks, and credit downgrading or high leverage (Severance, 2009 and Owens et al., 2012).

b. **Economic Risk** - Economic risks relate towards investment to the economic structure or overall mega-project, like residual transfer value, projects' inappropriate metrics. Economic risk pertains to asset's residual value less than the expected value. Due to economic factors, if infrastructure assets lose value causes risks to Infra projects.

Customer Risk (Demand Risk) - It relates to the sales level within the mega-projects where during the operational phase charges are paid by the users.

Contractual Risk - These risks comprise those which arise from the contracts' renegotiation, like problems caused by vagueness and imprecision of the contract and midstream change in the scope of the project (Dettman et al., 2010).

Labor Risk - These risks are associated with workers and consist of accident cost, language difficulties, cultural differences and training. The rising of these risks can happen at any mega-projects' stage but happens, especially throughout the construction operational phases (Wang et al., 2010).

Force Majeure Risk - This risk comprises of extreme weather conditions, natural disasters, war, the case of a natural collapse or terrorism (El-Sabek, 2018).

This is the procedure wherein companies regularly deliver the risks accompanied to their activities. The risk management focus is to evaluate substantial risks in order to implement appropriate risk responses for achieving the maximum and sustainable value from the organizations' activities. Management of risk improves knowledge of the prospective aspects which influence any organization. Regardless of the approaching of age of management of risk as a business, Arrow, (2008); Baker et al. (1999), created this "no global (risk management of the project) industrial standard exists".

5.2.2 Proposed risk classification

It can be observed from the earlier discussions in the literature that there is no unique homogeneous classification available, to consider all the possible risks, primarily associated with logistics infrastructure projects, the following broad classification is proposed comprising of nine broad categories and five subcategories.

1. Design Risk
2. Legal and Political Risk
3. Operation and Maintenance Risk
4. Construction Risk
5. Financial Risk
    a. High Leverage Risk
    b. Economic Risk
6. Customer Risk
    a. Demand Risk
    b. Social Impact Risk
    c. Environmental Risk
7. Contractual Risk
8. Labor Risk
9. Force Majeure Risk

The conceptual framework used for ANP modeling is shown below in Fig. 5.1

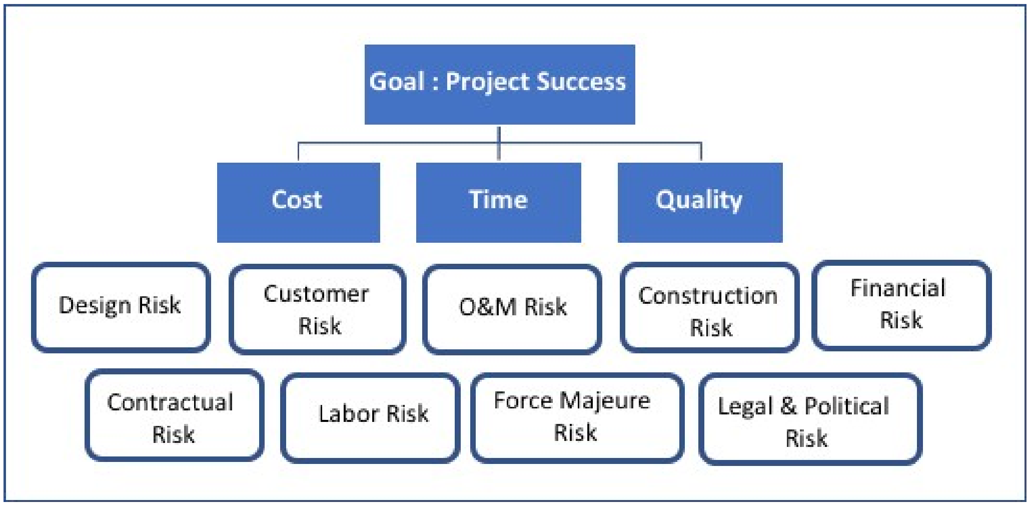

Fig. 5. 1 Conceptual ANP framework for infrastructure project risk management

5.2.3 Making decisions using Analytic Network Process

Such a process involves numerous decision alternatives or options based on a comparison of various criteria and choosing the appropriate or best option based on mathematical reasoning (Hwang & Yoon, 2012). Some methods are PROMETHEE (Brans and Vincke, 1985), ANP (Saaty, 1996), best-worst method (Rezaei, 2015, 2016), AHP (Saaty, 1990, 2008), TOPSIS (Opricovic and Tzeng, 2004) and ELECTRE (Roy, 1991). Phogat and Singh (2013) applied five multi-criteria decision making (MCDM) techniques to select suitable equipment used for hilly road construction, which is very challenging due to involvement of complex processes involving reconnaissance and survey to fix the alignment, formation and construction works of various layers of pavement. They examined the applicability of Analytic Hierarchy Process (AHP), Simple Additive Weights Method (SAW), Distance-Based Method (DBM), Elimination Et Choice Translating Reality (ELECTRE) and Preference Ranking Organization Method (PROMETHEE) methods as prospective decision-aid tools to select appropriate management tool. Gothwal & Raj (2019) used multi-criteria decision-making approaches, Analytic Network Process (ANP) and Analytic Hierarchy Process (AHP) techniques for prioritization of alternatives. For this purpose, the authors used an analysis of factors affecting the manufacturing system and to find out the best manufacturing system.

Generally, methods for Multi-Criteria Decision Making (MCDM) model are extensively applied in selecting problems with a limited amount of choices together several criteria. By incorporating numerous expert's judgment and keeping into account the criteria of quantitative and qualitative, and the selection of preset choices.

The techniques of MCDM are undertaken for measuring the degree of project's risk, and taking corrective or/and preventive actions which will lead to balancing or/and preventing the risks, permitting project managers in the implementation of response to risk plans for reducing, avoiding or/and accepting the risk of the projects. This technique considers the criteria for time, cost and quality, which represents the Project management's Iron Triangle (Atkinson, 1999). ANP has been used for risk assessment for various kind of projects. In research by Boateng et al. (2017) considered the construction project risk and STEEP (macro averment risks). ANP is among the complex and advances MCDM methods. This method works between the network's elements by supporting the feedback and dependencies. Hence, making ANP as one of the most vital and appropriate methods in the decision-making fields, that are categorized by the prevailing dependencies regarding the elements of lower or higher level.

5.2.4 Why use ANP over AHP

AHP is a hierarchy-based model where the goal, criteria, sub-criteria and ultimately alternatives are modelled in a top-down approach powered with the pair-wise comparison. AHP technique, however, has limitations where goal and criteria have interdependencies. In such cases, ANP is more reliable and provides desired decision-making support based on systematic and reliable analysis.

In a hierarchy based AHP approach, the effect on the alternatives and criteria dependency and further criteria affects goal. AHP does not consider or is not effective where criteria affect alternatives; the criterion has interdependencies and/ or alternatives dependency on one another.

The complex decisions involve network model with feedback and dependence that advances the urgencies consequent of judgements and styles for accurate prediction. The network of ANP permits interdependency (feedback, external dependence, and inner dependence) with decision clusters and also among the same cluster elements (Saaty, 2000, 2005). ANP is superior techniques than AHP for qualitative risk data, as described in Fig. 5.2, ANP has been adopted for handling feedbacks and interdependencies that are present into the complex system.

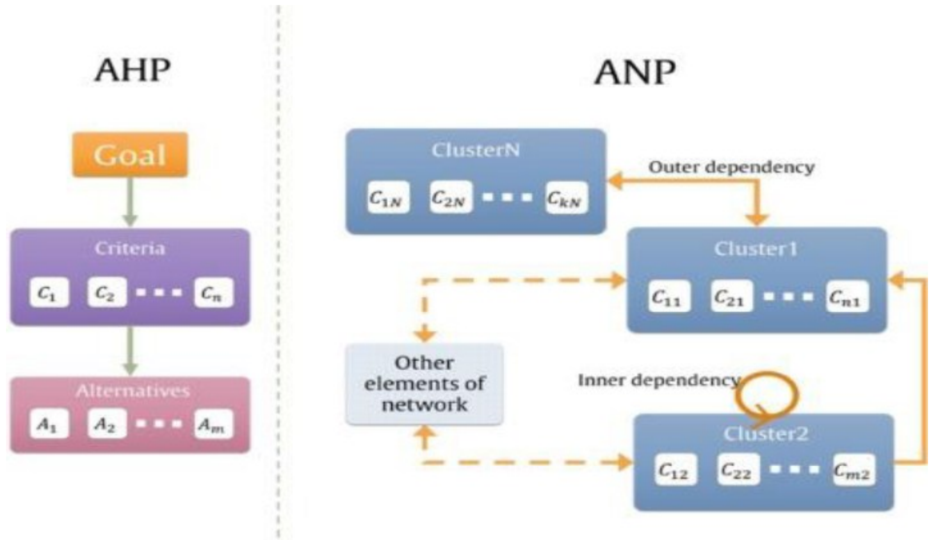

Fig. 5. 2 AHP vs ANP

The main steps followed in ANP are:

- First, the risk factors affecting the project are identified and are classified according to an objective criterion.
- All the factors are then arranged in a hierarchical tree structure with categories of risk in the intermediate level and lowest level having the factors of risk.
- Each level elements are compared pair-wise from a scale of 1 to 9 about its standing in producing the under-consideration decisions. Meaning of rating is as follows: 1 denotes equal preference, 3 is for moderate preference, 5 for strong preference, 7 denotes very strong preference, and 9 represents extreme preference. In case the manager feels that the importance lies in between the given preferences, he or she can use the middle values of 2, 4, 6 and 8. For example, if a factor is more than just strongly preferred but not so much as to be very strongly preferred, it can

be rated as 6. These preferences are better captured in the form of a comparison matrix.

- The upper half values denote its reciprocal values that are diagonal of the matrix values. Hence, the stakeholders need to fill only the lower half triangle of the matrix.
- The consistency ratio of the resultant matrix is calculated, and this should be less than 0.1 as per consistency criteria suggested by Saaty's (1989). If this does not happen, then the recollection of data is to be done until that matrix turns out to be consistent.
- Then the element's relative weights for every level about the adjacent upper-level elements are calculated as the normalized eigenvector components associates to the comparison matrix's largest eigenvalue.
- The Supermatrix is constructed. For obtaining priorities globally in a system having influences interdependently, columns are used for entering the local priority vectors. These local priority matrices are positioned as a segment in a supermatrix based on influence flow from cluster to cluster or within the cluster.
- Super matrix is converted into a limit matrix by converging Supermatrix to the power of 2k+1, where k is an arbitrarily high number. The priorities in the limit matrix denote the final weights of risk factors.

5.2.5 ANP Modeling of a Mega Air Logistics Construction Project

ANP model has been applied on an air logistics infrastructure facility at an Airport project in India. It is assumed that the duration of the project is approximately two years, and it is being constructed in an isolated area where a nearby village has to be displaced. The project aims at catering to the increasing air traffic demand. Hence, the customer demands could significantly influence the financial success of the Airport project (thus, the customer risk is high).

The risk priority index (RPI) value specifies the magnitude of influence of risk upon the project's success and is calculated in percentage terms. It is an advanced innovative technique employed in this study to rank the impact of risks identified relating to the project objectives. The RPI can be used as an indication to appeal the interest of a developer to know risks that would have the largest influence on objectives of the project. Higher the RPI, greater is the probability of risk related to the project. Drawing from the ANP Network models is illustrated in Fig. 5.3. The pair-wise evaluation matrices were formed for each element of risk based on their influence on the objectives of the project (time, quality and cost). The following framework was deployed to construct the ANP model and compute the respective Supermatrix (Fig 5.3).

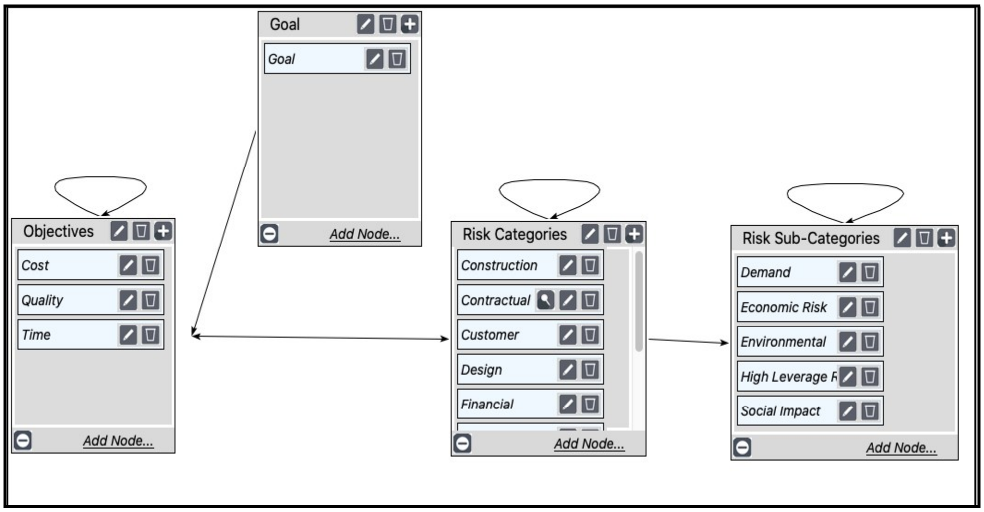

Fig. 5. 3 ANP Model Structured in Super Decision Software

5.2.6 Data Collection Steps

1) The data for paired comparison was collected by taking opinions of from 12 subject matter experts working in the infrastructure field.
2) The aggregated pairwise comparison matrices were computed by taking mean score from all the respondents.
3) The means were taken to assess the risk influence level on the three project objectives clusters.
4) This is essential to form a ground for translating inputs from a large pool of participants and convert the risk variables into one score to meet the prerequisites of ANP in order to line up risks via constructing the hierarchical structure of risks.
5) All the pair-wise comparisons thus made are converted into respective comparison matrices.

6) The single score values were then put into a multiple measures software, named as Super Decision to examine the correlations between option and criterion.
7) A priority risk or numerical weight is inferred for every component in the hierarchy, permitting various components for comparison with one another practically and continuously.
8) Limit Matrix is calculated from weighted Super Matrix
9) Lastly, the priority of risk is inferred for each decision alternative

Stepwise process is mentioned as below-

1. **Identification of Goal, Project Objectives, Risk Categories, Sub-Categories -> Design a Analytic network** (basis inputs from Experts) ->
2. **For each cluster and parent variable** identified carry out a Paired Comparison seeking Scores from Experts (on Saaty Score 1-9) -> Calculate **Weighted Pairwise comparison** by dividing each entry of column with sum of respective column -> Calculate Local Priority Vectors (Average of respective row weighted scores) -> Calculate **Pairwise matrix [A] x Priority Vector (wi)** -> Calculate λ = [A]x[wi]/ [wi] -> Calculate λmax (Average λi) -> Calculate Consistency Index= λmax -n/ (n-1) -> RI from Saaty's recommended table of RI -> Calculate Consistency Ratio = CI/ RI.
   In case CR <=0 , the consistency of the pairwise comparion is good, else have to again obtain the data.
3. Calculate **Priority Vector for each pairwise comparison**.
4. **Priority vector for each pairwise comparison** mapped in **Super Matrix** containing all parent and child nodes.
5. **Weighted Super Matrix** by dividing each column entry by the sum of respective column entries
6. Calculating **Limit Matrix** by multiplying Super Matrix by itself 'x' no. of times. In the research problem 'x' considered as 3.
7. **Relative Priority Matrix -** For Risk factors considered Avg. of each row calculated multiplied by 10 to give easy readability of Priority vectors (Relative Priority Matrix). This give Ideal Priorities for respective risk categories.

8. **Normalized Priority Matrix -** Calculated by dividing each entry by the sum of RPI Matrix column.

5.2.7 The Control Hierarchy and Pair-wise Comparison

To perform the pair-wise comparison and assign different nodes in different clusters, their relative priorities concerning each other. The following pair-wise matrices were used. The following pair-wise comparison matrix in Table 5.1 gives us relative priorities concerning construction. Similarly, the other priority matrices used in the ANP model are in Tables 5.2 to 5.9.

The above priority matrices tell us about the interdependent risk priorities, now establishing similar priority matrices between the objectives of the project, i.e. cost, time and quality is shown in the next part of this section. Further, the interdependencies amongst these three objectives will be shown. The following Tables 5.1, 5.2 and 5.3 is presenting the pair-wise comparison matrices of identified nine risk factors for three project objectives viz., cost, quality and time.

Table 5. 1 Pair-wise comparison for cost

COST	Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
Construction	1.00	3.00	6.00	2.00	2.00	6.00	3.00	3.00	2.70
Contractual	0.33	1.00	2.00	0.67	0.67	2.00	1.00	3.33	0.90
Customer	0.17	0.50	1.00	0.33	0.33	1.00	0.50	1.67	0.45
Design	0.50	1.50	3.00	1.00	1.00	3.00	1.50	5.00	1.35
Financial	0.50	1.50	3.00	1.00	1.00	3.00	1.50	5.00	1.35
Force Majeure	0.17	0.50	1.00	0.33	0.33	1.00	0.50	1.67	0.45
Labour	0.33	1.00	2.00	0.67	0.67	2.00	1.00	3.33	0.90
Legal	0.33	0.30	0.60	0.20	0.20	0.60	0.30	1.00	0.27
Operation	0.37	1.11	2.22	0.74	0.74	2.22	1.11	3.70	1.00

Table 5. 2 Weighted Pairwise comparison for cost

	Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation	Priority Vector
Construction	0.27	0.29	0.28	0.29	0.29	0.28	0.29	0.11	0.29	**0.27**
Contractual	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.10	**0.10**
Customer	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	**0.05**
Design	0.14	0.14	0.15	0.14	0.14	0.15	0.14	0.18	0.14	**0.15**
Financial	0.14	0.14	0.15	0.14	0.14	0.15	0.14	0.18	0.14	**0.15**
Force Majeure	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05	**0.05**
Labour	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.10	**0.10**
Legal	0.09	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	**0.04**
Operation	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.13	0.11	**0.11**

Priority vector of the above pair-wise comparison matrix is shown below, and CR is less than 0.10; hence decision matrix is consistent.

Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
0.27	0.10	0.05	0.15	0.15	0.05	0.10	0.04	**0.11**

Multiply Pairwise comparison matrix with Priority vector obtained above resulting into –

Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
2.43	0.90	0.45	1.35	1.35	0.45	0.90	0.33	1.00

λ = Priority / Local priority vector

λ_i = 2.43/ 0.27 = 9.14728; likewise λ value calculated for other entries. (n=9)

λ_{max} = Average λ value = 9.13434

CI = λ_{max} – n / (n-1) = 0.0167; n=9

Where λmax calculated by averaging the λ values of each row

RI value as per Saaty's recommended values-

RI	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

RI = 1.45 in this case

CR= CI/RI = 0.012 < 0.1 Hence, ok

The above priority matrix suggests the relative risk priorities of different parameters and describes how they influence the cost. Similarly, the other priority matrices have been obtained, which are given in Tables 5.2 to 5.7.

Table 5. 3 Pair-wise comparison for quality

QUALITY	Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
Construction	1.00	3.00	6.00	2.00	2.00	6.00	3.00	3.00	4.28
Contractual	0.30	1.00	2.00	0.67	0.67	2.00	1.00	3.33	1.43
Customer	0.17	0.50	1.00	0.33	0.33	1.00	0.50	1.67	0.71
Design	0.50	1.50	3.00	1.00	1.00	3.00	1.50	5.00	2.14
Financial	0.50	1.50	3.00	1.00	1.00	3.00	1.50	5.00	2.14
Force Majeure	0.17	0.50	1.00	0.33	0.33	1.00	0.50	1.67	0.71
Labour	0.33	1.00	2.00	0.67	0.67	2.00	1.00	3.33	1.43
Legal	0.10	0.30	0.60	0.20	0.20	0.60	0.30	1.00	0.43
Operation	0.23	0.70	1.40	0.47	0.47	1.40	0.70	2.33	1.00

Priority vector of the above pair-wise comparison matrix is shown below, and CR is less than 0.10; hence decision matrix is consistent.

Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
0.29	0.10	0.05	0.15	0.15	0.05	0.10	0.03	0.07
CR= CI/RI	CR= 0.066							

Table 5. 4 Pair-wise comparison for time

TIME	Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
Construction	1.00	3.00	6.00	2.00	2.00	6.00	3.00	3.00	4.28
Contractual	0.30	1.00	2.00	0.67	0.67	2.00	1.00	3.33	1.43
Customer	0.17	0.50	1.00	0.33	0.33	1.00	0.50	1.67	0.71
Design	0.50	1.50	3.00	1.00	1.00	3.00	1.50	5.00	2.14
Financial	0.50	1.50	3.00	1.00	1.00	3.00	1.50	5.00	2.14
Force Majeure	0.17	0.50	1.00	0.33	0.33	1.00	0.50	1.67	0.71
Labour	0.33	1.00	2.00	0.67	0.67	2.00	1.00	3.33	1.43
Legal	0.10	0.30	0.60	0.20	0.20	0.60	0.30	1.00	0.43
Operation	0.23	0.70	1.40	0.47	0.47	1.40	0.70	2.33	1.00

Priority vector of the above pair-wise comparison matrix is shown below, and CR is less than 0.10; hence decision matrix is consistent.

Construction	Contractual	Customer	Design	Financial	Force Majeure	Labour	Legal	Operation
0.29	0.10	0.05	0.15	0.15	0.05	0.10	0.03	0.07
CR= CI/RI	CR= 0.066							

Based on the score collected from the Pair-wise comparison for the project goals, the following Table 5.4 represents relative weights of the prime objectives of the project.

Table 5. 5 Pair-wise comparison of objectives

Objectives	**Cost**	**Quality**	**Time**	**Priority vector**
Cost	1	6.082	2.466	0.636
Quality	0.1644	1	0.405	0.104
Time	0.405	2.466	1	0.258

Similarly, for the Customer risk factor relative weights to sub-criteria are shown in the following matrix in Table 5.5 to 5.7 as follows:

Table 5. 6 Pair-wise comparison for demand risk

Demand Risk	Environment Risk	Social Impact Risk	Priority Vector
Environment Risk	1	0.5	0.33
Social Impact Risk	2	1	0.67

Table 5. 7 Pair-wise comparison for environmental risk

Environment Risk	Demand Risk	Social Impact Risk	Priority Vector
Demand Risk	1	0.5	0.33
Social Impact Risk	2	1	0.67

Table 5. 8 Pair-wise comparison for social impact risk

Social Impact Risk	Demand Risk	Environment Risk	Priority Vector
Demand Risk	1	1.5	0.59
Environment Risk	0.67	1	0.41

The weighted Supermatrix was obtained after entering all the data in Super decision software, as shown in Fig. 5.4.

Table 5. 9 The weighted Super Matrix

Super Decisions Main Window: Untitled.sdmod: Weighted Super Matrix

	Constru~	Contrac~	Customer	Design	Financi~	Force M~	Labour	Legal	Operati~	Cost	Quality	Time	Goal	Demand ~	Economi~	Environ~	High Le~	Socia
Constru~	0.00000	0.05357	0.07207	0.10000	0.01361	0.04546	0.10204	0.04167	0.07401	0.19210	0.20000	0.20000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Contrac~	0.08000	0.00000	0.05405	0.08000	0.05442	0.09091	0.06122	0.10417	0.03701	0.06403	0.06667	0.06667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Customer	0.04000	0.03571	0.00000	0.08000	0.04082	0.02273	0.02041	0.02083	0.05551	0.03202	0.03333	0.03333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Design	0.10000	0.08929	0.01802	0.00000	0.01361	0.02273	0.05102	0.08333	0.09252	0.09605	0.10000	0.10000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Financi~	0.08000	0.07143	0.01802	0.04000	0.00000	0.11364	0.06122	0.10417	0.09252	0.09605	0.10000	0.10000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Force M~	0.02000	0.05357	0.09009	0.02000	0.04082	0.00000	0.02041	0.02083	0.03701	0.03202	0.03333	0.03333	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Labour	0.06000	0.07143	0.01802	0.06000	0.06803	0.09091	0.00000	0.02083	0.05551	0.06403	0.06667	0.06667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Legal	0.04000	0.05357	0.05405	0.08000	0.06803	0.04546	0.08163	0.00000	0.05591	0.01921	0.02000	0.02000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Operati~	0.08000	0.07143	0.00901	0.04000	0.03401	0.06818	0.10204	0.10417	0.00000	0.07115	0.04667	0.04667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Cost	0.16667	0.16667	0.11111	0.16667	0.11111	0.16667	0.16667	0.16667	0.16667	0.00000	0.16667	0.16667	0.63698	0.00000	0.00000	0.00000	0.00000	0.00
Quality	0.16667	0.16667	0.11111	0.16667	0.11111	0.16667	0.16667	0.16667	0.16667	0.16667	0.00000	0.16667	0.10473	0.00000	0.00000	0.00000	0.00000	0.00
Time	0.16667	0.16667	0.11111	0.16667	0.11111	0.16667	0.16667	0.16667	0.16667	0.16667	0.16667	0.00000	0.25829	0.00000	0.00000	0.00000	0.00000	0.00
Goal	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00
Demand ~	0.00000	0.00000	0.11111	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.33333	0.00000	0.50
Economi~	0.00000	0.00000	0.00000	0.00000	0.16667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00
Environ~	0.00000	0.00000	0.11111	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.33333	0.00000	0.00000	0.00000	0.50
High Le~	0.00000	0.00000	0.00000	0.00000	0.16667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00
Social ~	0.00000	0.00000	0.11111	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.66667	0.00000	0.66667	0.00000	0.00

The limit matrix thus worked from the weighted Super matrix is as shown below.

Table 5. 10 The Limit Matrix

LIMIT MATRIXç	Construction	Contractual	Customer	Design	Financial	Forced Majeure	Labour	Legal	Operational	Cost	Quality	Time	Goal	Demand	Economy	Environment	High Leverage	Social
Construction	0.132	0.128	0.080	0.123	0.087	0.125	0.121	0.126	0.125	0.097	0.095	0.095	0.195	0.000	0.000	0.000	0.000	0.000
Contractual	0.060	0.068	0.045	0.063	0.043	0.059	0.064	0.057	0.067	0.064	0.064	0.064	0.065	0.000	0.000	0.000	0.000	0.000
Customer	0.038	0.036	0.022	0.031	0.020	0.035	0.037	0.039	0.035	0.039	0.038	0.038	0.032	0.000	0.000	0.000	0.000	0.000
Design	0.073	0.072	0.053	0.082	0.053	0.079	0.083	0.076	0.071	0.072	0.071	0.071	0.097	0.000	0.000	0.000	0.000	0.000
Financial	0.077	0.080	0.061	0.082	0.058	0.077	0.085	0.077	0.076	0.074	0.072	0.072	0.097	0.000	0.000	0.000	0.000	0.000
Forced Majeure	0.035	0.031	0.018	0.036	0.022	0.035	0.033	0.035	0.033	0.031	0.031	0.031	0.032	0.000	0.000	0.000	0.000	0.000
Labour	0.058	0.057	0.042	0.054	0.035	0.056	0.060	0.063	0.057	0.058	0.058	0.058	0.065	0.000	0.000	0.000	0.000	0.000
Legal	0.040	0.038	0.021	0.033	0.023	0.039	0.033	0.040	0.038	0.044	0.044	0.044	0.019	0.000	0.000	0.000	0.000	0.000
Operational	0.052	0.055	0.043	0.059	0.041	0.057	0.054	0.049	0.057	0.054	0.059	0.059	0.062	0.000	0.000	0.000	0.000	0.000
Cost	0.132	0.133	0.092	0.132	0.090	0.131	0.134	0.132	0.131	0.160	0.131	0.131	0.061	0.000	0.000	0.000	0.000	0.000
Quality	0.132	0.133	0.092	0.132	0.090	0.131	0.134	0.132	0.131	0.132	0.159	0.131	0.149	0.000	0.000	0.000	0.000	0.000
Time	0.132	0.133	0.092	0.132	0.090	0.131	0.134	0.132	0.131	0.132	0.131	0.159	0.124	0.000	0.000	0.000	0.000	0.000
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Demand	0.004	0.004	0.093	0.009	0.005	0.003	0.002	0.002	0.006	0.004	0.004	0.004	0.000	0.444	0.000	0.333	0.000	0.167
Economy	0.013	0.012	0.003	0.007	0.167	0.019	0.010	0.017	0.015	0.016	0.017	0.017	0.000	0.000	1.000	0.000	0.000	0.000
Environment	0.004	0.004	0.093	0.009	0.005	0.003	0.002	0.002	0.006	0.004	0.004	0.004	0.000	0.333	0.000	0.444	0.000	0.167
High Leverage	0.013	0.012	0.003	0.007	0.167	0.019	0.010	0.017	0.015	0.016	0.017	0.017	0.000	0.000	0.000	0.000	1.000	0.000
Social	0.004	0.004	0.148	0.009	0.005	0.003	0.002	0.002	0.006	0.004	0.004	0.004	0.000	0.222	0.000	0.222	0.000	0.667

Priorities are then worked out from limit matrix for all the risk categories as shown in Fig. 5.8.

5.3 Data analysis and Results

Once all data is collected, the priority matrices were used to get the priority index. After entering all the above data in Super Decision software and running the simulation, the priority weights were determined. The limit matrix for the 9 risk categories provided the Ideal value by calculating their average values from the limit matrix as shown in Table 5.8.

Table 5. 11 Risk Priority Index (RPI)

Risk Classes	Ideal Value	Normalized Value	Rank
Construction	**1**	**0.20**	**1**
Contractual	0.56	0.11	4
Customer	0.32	0.07	8
Design	0.66	0.13	3
Financial	**0.68**	**0.14**	**2**
Force Majeure	0.29	0.059	9
Labor	0.51	0.10	5
Legal	0.35	0.073	7
Operation	0.50	0.10	6

Risk priority index data has been taken from the super decision matrix, as shown in Table 5.8. The ideals values are taken directly from the ANP analysis, and these values have been converted into normal values by dividing each ideal value by the sum of all the ideal values i.e. 4.87. Thus, the ranks of the risk factors in infrastructure projects are obtained. The RPI's established in this study can be formulated to prioritize mega-projects from the perspective of risk management in the process of construction contingent on the placement of other aspects. Taking an example, previously noted risks in this context are considered as risks for a developer to measure on lines of the cost, quality and time of the project, the RPI's in this context act as catalysts to denote values to prioritize these risks. A higher RPI indicates higher risk in the project. Therefore, the risk of construction is placed on top priority as it holds the highest percentage of RPI (20.4%) as displayed in Table 5.8. Effects of risks on the cost, quality and time of the project could be evaluated in the order, based on influence as follows: Construction risk, Financial risks, Design risks, Contractual risks, Labor risks and so on.

Subsequently, the developer of the mega-project has the plasticity to re-group apt risks under every cluster of risks identified based on geographical placement and project being implemented. The RPI's entice the attention of the developer to probable risks that possess the highest degree of influence on the objectives of the project and deliberate upon suitable procedures of risk management.

5.4 Conclusion

The results of this study indicate that a developer trailing mega-projects is required to assess financial and construction risks in the construction stage of the life cycle of the project, inferring from the results of the Risk priority index (RPI's). Moreover, the interactions among risks in upcoming social, political and economic conditions of a developed country may serve as critical aspects to deal with for project developers. Hence, the model in this study can be applied to a company's decision on managing risks based on the influence of risk on the performance of the project. Contrary to the findings that proprietors and developers are required to be active for deploying operative measures to manage the growing encounters faced in the mega-project construction process.

Deficiency in quality follows the progression of construction, tailed by technical, social, political and environmental risks. For managers who tackle project related issues within inadequate resources, this calls for a need to investigate the management of inter-relationship amongst the risks for safeguarding efficient reactions for addressing issues faced in the work settings. In the process of attempting to control risks at multiple levels, the project management and risk assessment team is for the stages in the life cycle of the project. Risks of distinct kinds often require distinct forms of control and mitigation. The model tested in this paper dwells upon organizational decisions often discussed by employees and committees may have a conflict of interests pertaining to the priority of objectives. It is, therefore, difficult to compile information from top management about pair-wise assessment.

5.5 Limitations and Future Scope of research

This research considers the expert data to prioritize the risk factors in infrastructure projects. One of the limitations is that there may exist biases in data collection through expert opinion. Though a scientific method of data collection has been followed, if experts are changed, then there is a possibility of change in data. For example, this data was collected for Indian infrastructure projects, so the change in project selection of some other countries will affect the ranking of risk factors.

This research used the analytic network process method that considers the interaction of risk factors. This research may be extended, considering the simulation methods with appropriate probability distributions of each risk factor. Further, the effect of mitigation strategies can also be considered and incorporated in the model.

In the next chapter 6, financial risk model is developed to further understand the dependency of financial risk on other internal and external factors. Though the ANP model risk priority ranked construction risk as top risk and then the second significant risk was a financial risk. We took the financial risk to understand them better because construction risk has been well researched in literature, and it's related to the project manager and project team. One important stakeholder is the project sponsor, and his perspective is also essential in risk modelling. From a sponsor's perspective, we took a financial risk for further model development.

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