Hierarchical Structuring of PPP Risks Using Interpretative Structural Modeling

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Abstract: Project risk management emphasizes the need to rank and prioritize risks in a project to focus the risk management efforts. This risk prioritization is of special significance in public-private partnership (PPP) projects, since project success depends upon the efficient allocation of risks to the party who can best manage it. Previous studies on risk identification and assessment of PPP project risks have only produced an unstructured list of such risks and prioritizing them on the basis of probability and impact. This paper suggests the use of interpretative structural modeling (ISM) to prepare a hierarchical structure as well as the interrelationships of these risks that would enable decision makers to take appropriate steps. MICMAC (*matrice d'impacts croises-multiplication appliqué a un classemen*) analysis is also done to determine the dependency and driving power of the risks. ISM, along with MICMAC analysis, provides a useful hierarchy of risks whose individual relationships are unambiguous but whose group relationships are too complex to organize intuitively and can help practitioners better understand risk dependencies and prioritize risk-mitigation efforts. This study identified 17 risks encountered during the development phase of PPP projects in Indian road sector and found that fourteen risks were weak drivers and weak dependents. Delay in financial closure, cost overrun risk, and time overrun risk have been found to have the highest dependence on other risks. The analysis can be extended by practitioners for risk analysis in other infrastructures such as railways, seaports, airports etc.

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Introduction

Due to the enormous capital investments required for restoring and expanding the crumbling public infrastructure, coupled with the need to contain the fiscal deficit, the governments world over are entering into partnership with private sector for making provision of public goods and services. Public-private partnership (PPP) has been widely recognized as an innovative institutional mechanism to leverage the private sector's efficiencies in public services. It enables a win-win situation for all stakeholders and blend public objectives with marketability and profitability. In PPP, the private sector entity provides public goods and services such as power and water utilities, transport infrastructure and social services such as healthcare, education etc. According to the Planning Commission (2007), the infrastructure financing requirement of India for the next five years is estimated to be $488 billion in areas such as water, roads, seaports, and airports. For meeting this investment requirement, the private sector is recognized as a significant financing source.

The concept of PPP is founded on the cardinal principle that risks should be borne by the party who can best manage it. In order to formulate an appropriate risk response plan, the risks must not only be identified, but their impact also must be assessed. This is even more difficult due to the complex interactions that occur between these risks. With this in mind, project risk management (PRM) process is the key to successful structuring of projects. The overall process of PRM is composed of two stages; risk analysis and risk management (Chapman 2001). The first stage; risk analysis can be further subdivided into two: qualitative analysis, which focuses on the identification and assessment of risks; and quantitative analysis that focuses on the evaluation of risks. The risk management stage involves identifying responses, implementing and tracking the effectiveness of these responses, reviewing the priority of response management and monitoring the status of projects.

Several techniques are available for risk identification. The two most commonly used are structured one-to-one interviews and brainstorming. The less frequently employed techniques are Nominal group technique and Delphi technique. However, these techniques produce an unstructured list of risks and fail to assist the project manager in focusing risk management efforts. Qualitative assessment can help in prioritizing identified risks by estimating the probability and impact, thus determining the exposure (which is obtained by multiplying probability with impact). But this technique deals with one risk at a time, thus failing to notice the interactions or interdependencies between different risks. Since many risks are interdependent and have multiple effects, it becomes cumbersome for the decision maker to trace the actual source of these risks. Rather than focusing on the root cause, they often tend to focus on the immediate preceding activity. The Pareto's principle (also known as 80-20 rule, the law of vital few and trivial many) states that for many events, 80% of effects come

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from 20% of the causes. The vital risks in PPP projects, controlling of which should give maximum benefit, have not yet been identified by the past researchers and therefore this paper attempts to find their hierarchical structure.

With large data in hand, structuring them could be considered a good strategy to understand and decipher information. Work breakdown structure (WBS) is a demonstration of the power of structuring where it provides a means to structure the work to be done to accomplish the project objectives. The entire project is presented in hierarchical, manageable and defined packages to assist in the planning, communication, reporting, and accountability. WBS has evolved into a powerful tool in the hands of a project manager (Eldin 1989). In the same way, Hillson (2002) has proposed a hierarchical structure of risk sources known as risk breakdown structure (RBS). According to Hillson, RBS is a source-oriented grouping of project risks that organizes and defines the total risk exposure of the project. Each descending level represents an increasingly detailed definition of sources of risk to the project. However, RBS fails to account for the interaction and interdependencies between the various individual project risks. Linstone et al. (1979) and Lendaris (1980) compared different methods on the basis of their characteristics and selected a list of nine structuring tools. They found these methods to be cheap, time-saving, easily understandable, and fully implementable. Among these nine structuring tools ISM (interpretative structural modeling), ELECTRE, SPIN, IMPACT, KSIM, XIMP and QSM were found to be most frequently used (Sharma et al. 1995).

The objective of this paper is to provide a hierarchical structural framework of risks in PPP projects through the application of ISM method. MICMAC (*matrice d'impacts croises-multiplication appliqué a un classemen*, which means Cross Impact Matrix Multiplication Applied to Classification) analysis is also done to determine the dependency and driving power of the risks. ISM and MICMAC analysis have seen extensive applications in various fields of management (Palanisami 2003). Understanding these varied applications, this paper explores its applicability and usefulness in the systematic risk analysis of PPP projects.

Interpretative Structural Modeling

ISM is a computer assisted learning process, first proposed by J. Warfield in 1973. Sage (1977) explains this method as a process that transforms unclear, poorly articulated mental models of systems into well defined models useful for many purposes. Malone (1975) defines ISM as a process intended for use when it is desired to utilize systematic and logical thinking to approach a complex issue and then to communicate the results to others. ISM uses experts' practical experience and knowledge to decompose a complicated system into several subsystems and construct a multilevel structural model. The fundamental concepts of the process are an "element set" and a "contextual relation." The element set is identified within some situational context, and the contextual relation is selected as a possible statement of relationship among the elements in a manner that is contextually significant for the purposes of the inquiry. The elements correspond to the nodes of a network model and the presence of the relation between any two elements is denoted by a directed line (or link) connecting those two elements (nodes). In an equivalent binary matrix representation, the elements are the contents of the index set for the rows and columns of the matrix, and the presence of a relation directed from element i to element j is indicated by placing "1" in the corresponding intersection of row i and column j. From a binary matrix (also called as reachability matrix), through an iterative process redundant relationships between elements are eliminated and the final level of relationship between elements is established in a hierarchical form, also called as directed graph or digraph. The digraph is then converted to a structural model, and inspected and revised to capture the user's best perceptions of the situation.

A compilation of literature on the application of ISM in various areas is summarized in Table 1. The review clearly brings out the versatility of ISM as a tool capable of modeling a diverse range of complex issues. The application brings structural clarity and establishes a hierarchical order for prioritization and consequent action. It is in this background that this paper attempts to analyze the dynamics of relationships between the various risks encountered during the life-cycle of build-operate-transfer (BOT) road projects. This tool helps in modeling the interactions between the various risks which occur during the life-cycle of highway projects executed under BOT mode of project delivery.

Identification of Risks in Indian BOT Road Projects

In the present study, a comprehensive list of all risks encountered during the development phase of an Indian BOT road project was prepared. Expert interviews, literature review, and case studies were adopted to identify the risks. A total of 17 risks which were found to be prevalent in the Indian road sector were identified. A brief summary of these risks is given below

1. Preinvestment risk: a road project promoter is exposed to such risks on account of the cancellation of project for reasons such as poor bidder turnout, unfair bid, government decision to drop the project, litigation or inordinate delay in signing the concession agreement after a considerable investment of money for project feasibility study, bid preparation, etc. In India, project bidding is done on the basis of a detailed project report prepared by third-party consultants. The quality of information available from such studies is often inadequate and the bidder is forced to carry out individual investigations resulting in substantial investment on project preparation. Thus, the probability of occurrence of these risks is very high.
2. Delay in financial closure: this risk refers to the delay in timely arrangement of necessary debt and equity finance for the project. Road projects under BOT arrangement require huge capital investments upfront which are to be arranged through nonrecourse type of project financing. Indian BOT roads are commonly promoted by medium-sized contracting companies, which themselves are not well capitalized. Under the bidding rules, delay in financial closure beyond a prescribed limit could lead to termination of concession by the Government (Planning Commission 2006).
3. Resettlement and rehabilitation: since road projects are spread over long stretches, they are likely to displace human settlements. Inadequate monetary compensation and nonavailability/nonsuitability of alternate land for resettlement and rehabilitation of those whose livelihood gets affected can stoke public resistance and derail such projects.
4. Delay in land acquisition: road projects under BOT setup require vast stretches of land. Delay in survey and notification process, politically motivated public resistance, nonavailability of alternate land at reasonable cost, politi-

Table 1. Summary of Selected Past Works on Application of ISM

Writers and year	Main contribution
Malone (1975)	• Introduction to the fundamental concepts and operation of ISM methodology. • Demonstration of utility of ISM for capturing and communicating individual and group perceptions regarding complex issues.
Sage (1977)	• Outline theory and application for deploying ISM on complex situations presented by large systems.
Janes (1988)	• Introduces the theory and components of ISM and their interactions in complexities.
Flood (1989)	• Six scenarios for the future of systems "problem solving" were investigated. • ISM has been identified as a tool in systems thinking, with affinity for consensus making.
Saxena et al. (1992)	• A methodology for the hierarchy building of sub elements, graphical presentation of their driver power and dependence, and classification in categories such as autonomous, dependent, linkages and independent variables have been proposed using the case study of energy conservation in Indian cement industry.
Mandal and Deshmukh (1994)	• Evaluation and selection of alternative vendors are based on various criteria. • ISM technique used to analyze the interrelationships of these criteria and their levels.
Ravi and Shankar (2004)	• ISM technique used to analyze the interaction among the major barriers which hinder or prevent the application of reverse logistics in automobile industries.
Jharkharia and Shankar (2004)	• Enablers which support the information technology (IT) enablement of supply chains were identified and ranked using a questionnaire-based survey, • ISM technique was used to evolve the mutual relationships among the enablers.
Ravi et al. (2005)	• To determine and model the reverse logistics variables found in computer hardware supply chains, ISM-based approach was employed.
Faisal et al. (2006)	• A hierarchy based model evolved for understanding the dynamics of various risk enablers that can help in supply chain risk mitigation.
Hawthorne and Sage (1975)	• ISM used as an aid to conceptualize the structure and interrelationships of elements in a complex public and societal system such as higher education.
Kanungo et al. (1999)	• An hierarchical approach with the help of ISM technique has been used to develop a model for measuring Information Systems (IS) effectiveness.
H siao and Liu (2004)	• An approach for establishing an intelligent support system in order to design a product family through managing variety has been proposed. • After identifying the exterior drivers of design variation, ISM technique applied to visualize the hierarchy of component interactions within a product. • Methodology further illustrated with the example of the design of a family of automatic drip coffee makers.
Bolanos et al. (2005)	• ISM used in the simulation of a strategic group decision making process, for clarification of perceptions of different individuals in a managerial group to improve group decision making.
Thakkar et al. (2007)	• To address the shortcomings related to the development of Balance Score Card, ISM technique has been used in conjunction with cause and effect diagram and Analytical Network Process.
Jha and Devaya (2008)	• Fourteen international construction risk factors from Indian construction professionals' viewpoint, identified through literature reviewand interaction with industry experts. • ISM used to present a hierarchical model showing the interrelationships between risk factors.

cal patronage for encroachments, litigation and court proceedings, etc. can often lead to long delays in land acquisition.

5. Permit/approval risk: in India, prior to the start of construction, approvals have to be obtained from multiple agencies at the federal, state and local level. Though the Government procurer facilitates in obtaining these statutory clearances, there could be inordinate delay due to reasons such as lack of cooperation from Government agencies, frequent transfer of concerned officials, corruption, lack of legal awareness, lack of coordination among Government departments, poor documentation, etc. (Thomas 2003).
6. Technology risk: such risks arise due to adoption of outdated or inappropriate technology in design and construction of the road structures.
7. Design and latent defect risk: such risks, normally incurred by design professionals, include defective design, ambiguous specifications and plans, errors and omissions in design, and inaccurate geological and geotechnical exploration.
8. Cost overrun risk: this arises on account of the failure to complete the project within the budgeted cost. This may be due to various reasons such as increase in general price level and other economic factors such as inflation, interest rates etc.
9. Schedule risk: such risk arises due to failure to complete the project within the stipulated time lines.
10. Direct political risk: this arises on account of changes in law, compulsory acquisition or expropriation of project assets or concessionaire rights, unlawful or unauthorized revocation or refusal to grant any license, permit, consent, approval, etc. required by the concessionaire (World Bank 2008). The Indian federal system is dominated by several regional political parties with differing ideologies and development agenda. When a political party/grouping is voted to power, there is a likelihood of reversing or modifying the actions/decisions of the earlier regime. This could result in unlawful or unauthorized revocation/refusal to grant any license, permit etc. For example, in the construction of 111-km-Banglore-Mysore Infrastructure Corridor in the Karnataka State of India, the concession granted to Nandi Infrastructure Corridor Enterprise, a consortium of Kalyani Group and SAB International U.S.A. in 2000 was arbitrarily revoked by a new government which assumed office later. The revocation was subsequently challenged by the concessionaire and the Supreme Court, the

J. Constr. Eng. Manage. 2010.136:151-159.

apex court of India ordered to restore the concession (The Hindu 2006). In the process there was a time loss of about 48 months.

11. Indirect political risk: any deviation from the expected outcomes arising out of an act of war, invasion, armed conflict, blockade, embargo, riot, insurrection, terrorist or military action, industrial strike, civil commotion, boycott, political agitation etc. constitute indirect political risks (World Bank 2008).
12. Legal risk: this risk arises out of the complexity in the legal environment under which the project is being executed. In India, there are about 35 laws that have a direct or indirect bearing on private road projects (Thomas 2003). Moreover, the Indian judicial system is overburdened with a huge backlog of cases. Under such circumstances, recourse to legal remedy for enforcement of contracts can be a long drawn process.
13. Financial risk: a globally integrated economy is vulnerable to sudden changes in exchange rates, interest rates and commodity prices because of large cross-border capital flows. Financial issues like currency exchange rate, fluctuations in inflation rate, change in cost of indemnities and insurance, frequent changes in taxes and import duties, working capital shortage and changes in cost of debt increase the risk of investment in BOT road projects. In the Indian context, a majority of the promoters are not sufficiently capitalized, primarily relying on foreign equity or debt. Since toll revenues are in local currency, repayment of foreign investment (debt or equity) from domestic revenue can be unsustainable in the long run.
14. Nonpolitical force majeure: this risk category deals with nonpolitical events of force majeure considered as "acts of God" such as epidemics, natural disasters, earthquakes, floods, and such other events. The impact of these risks on the project development could range from minor to severe, where the damage may render the facilities irreparable.
15. Partnering risk: most of the BOT road projects are undertaken on a consortium approach. Team spirit and mutual trust are vital to the success of a consortium. Organizational structure with well-defined functional areas is necessary to avoid conflict among various groups. Project risk may be aggravated by the inadequate performance of individuals and organizations contributing to the project. It has been reported that international joint ventures are subject to very high rates of failure due to cultural and operational difficulties at both national and organizational level (Sridharan 1997).
16. Environmental risk: risks due to environmental impact liability, public protests and litigation by environmental activists, etc. can occur during the project life cycle, though their criticality is more during the construction and operation phases of the project.
17. Physical risk: like any other infrastructure project, physical risks such as damage to road structures, construction equipment, labor, etc. are equally critical during construction and operation phases of the road projects.

Pairwise Comparison of Identified Risks

A contextual relationship, "leads to" was chosen to identify the interacting position of each risk for analysis. This means that one risk *leads to* the other. An initial 17 × 17 matrix of the identified risk elements with "Y" for "Yes" and "N" for "No" as option for paired comparison between each pair of elements was developed and sent to the experts for their opinion. Since past literature does not contain any reference about the minimum number of experts to be contacted for their opinion, it is presumed that responses from even a fewer experts would suffice, provided they are consistent. A total of four experts from infrastructure companies executing BOT highway projects were contacted. All the four experts had a deep understanding of construction projects and experience of administering BOT projects for over ten years. Each of them has been holding very senior position in their respective organization and associated with more than five PPP projects across all geographical regions of India. After obtaining the individual responses, Delphi technique was used to generate consensus among the participants.

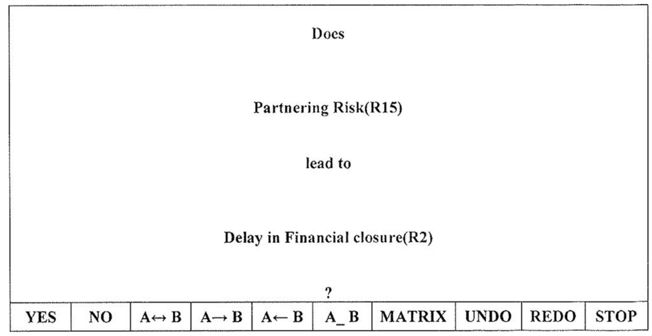

Fig. 1. Sample window for element comparison

For each pairwise comparison, Y was coded 1 and N as 0. The mean of each response was calculated. Mean values of 0 or 1 indicate perfect agreement among all the respondents while mean values lying between 0 and 1 would indicate variance of opinion among the respondents. Out of the 272 pairwise comparisons (17 × 17 minus diagonal elements representing comparison with self), 217 had mean values of 0 or 1. The remaining 55 comparisons were taken back to the respondents indicating the level of differences in opinion. The participants were asked to revise their responses in the light of replies from other members of the group. After the second round, 32 more pairwise comparisons had a mean of 0 or 1. Thus, after the second round, the respondents had perfect agreement for 249 pairwise comparisons. This Delphi process could have been carried forward, but to cut short, majority opinion was taken for the remaining 23 pairwise comparisons. As a next step, the reachability matrix which indicates both the direct and indirect effects of an element on all other elements is generated.

ISM software developed by Warfield (1976) was used to generate reachability matrix where the paired comparison results was used as input. The ISM software utilizes mathematical algorithms that minimize the number of queries necessary for exploring relationships among a set of ideas. The relationship Yes is encoded as 1 and No as 0 as default values in the software. A window snapshot depicting the structural analysis comparison between each pair is shown in Fig. 1. The reachability matrix indicating the relationship between elements arrived at in binary form is presented in Table 2.

J. Constr. Eng. Manage. 2010.136:151-159.

Table 2. Reachability Matrix

Elements (*i*/*j*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Driving power
1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4
2	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3
3	0	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	5
4	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	4
5	0	1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	5
6	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	5
7	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	4
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
10	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	4
11	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	1	5
12	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	5
13	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2
14	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	4
15	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	4
16	0	1	0	0	1	0	0	1	1	1	0	0	0	0	0	1	0	6
17	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	3
Dependence power	1	9	1	2	2	1	2	16	15	4	1	1	2	1	1	1	5	

Mapping Relationship between Elements

Partitioning the Reachability Matrix

The reachability matrix obtained above was then partitioned by deriving the *reachability set* and *antecedent set* to obtain ISM hierarchy. The reachability set for each risk element represents a set of elements (i.e., several risk elements including itself) upon which the current element has an impact. This is identified from the entry 1 in different cells of the horizontal row of the reachability matrix corresponding to the current element. For example, the reachability set of element 2 consists of elements 2, 8, and 9 as can be identified from the entry 1 in the horizontal row corresponding to element 2. The antecedent set represents the set of risk elements which have an impact on the current element. For example, nine elements (1, 2, 3, 4, 5, 10, 12, 15, and 16) have their impact on element 2. This can be seen from the entry 1 in various cells of the column corresponding to element 2 in the reachability matrix. In a similar way, the reachability set and antecedent set for all elements are determined and is given in Table 3.

For any element, if the reachability set is a complete subset of antecedent set, that element(s) is taken out and assigned a particular level. In the present study, after first iteration, the reachability sets for elements 8 and 9 are found to be a complete subset of antecedent set (Table 3). Hence, elements 8 and 9 are taken out from the reachability matrix and kept at Level I. The iterative process is continued with the remaining elements and the reachability set and antecedent set of remaining elements

Table 3. First Iteration

Element (Pi)	Reachability set: *R* (Pi)	Antecedent set: *A* (Pi)	Intersection $R(\text{Pi}) \cap A(\text{Pi})$	Level
1	1, 2, 8, 9	1		
2	2, 8, 9	1, 2, 3, 4, 5, 10,12, 15, 16		
3	2, 3, 4, 8, 9	3		
4	2, 4, 8, 9	3, 4		
5	2, 5, 8, 9, 10	5, 16		
6	6, 7, 8, 9, 17	6		
7	7, 8, 9, 17	6, 7		
8	8	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17	8	I
9	9	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17	9	I
10	2, 8, 9, 10	5, 10, 12, 16		
11	8, 9, 11, 13, 17	11		
12	2, 8, 9, 10, 12	12		
13	8, 13	11, 13		
14	8, 9, 14, 17	14		
15	2, 8, 9, 15	15		
16	2, 5, 8, 9, 10, 16	16		
17	8, 9, 17	6, 7, 11, 14, 17		

J. Constr. Eng. Manage. 2010.136:151-159.

Table 4. Second Iteration

Element (Pi)	Reachability set: R (Pi)	Antecedent set: A (Pi)	Intersection R(Pi)∩A(Pi)	Level
1	1, 2	1		
2	2	1, 2, 3, 4, 5, 10, 12, 15, 16	2	II
3	2, 3, 4	3		
4	2, 4	3, 4		
5	2, 5, 10	5, 16		
6	6, 7, 17	6		
7	7, 17	6, 7		
10	2, 10	5, 10, 12, 16		
11	11, 13, 17	11		
12	2, 10, 12	12		
13	13	11, 13	13	II
14	14, 17	14		
15	2, 15	15		
16	2, 5, 10, 16	16		
17	17	6, 7, 11, 14, 17	17	II

are determined (Table 4). In the second iteration, the elements: 2, 13, and 17 are taken out and placed at Level II. The process is repeated till all the elements are exhausted and their respective levels obtained. The result of the final iteration is shown in Table 5.

Forming Lower Triangular Matrix or Conical Form of Matrix

The levels of risks brought out from the intersection of the reachability and antecedent sets can be converted into a lower triangular matrix or conical matrix. This provides a clear indication of the hierarchy of influence of each element. Beginning with Level I element and its corresponding elements that reach up to it, a binary matrix is formed. In the present case, the binary matrix is presented in Table 6, the top level elements being 8 Cost overrun risks and 9 Schedule risks. These are placed as the first two elements followed by 2 delay in financial closure, 13 financial risks, and 17 physical risks. The cost overrun risks and schedule risks being at topmost level indicate that they would not appear by themselves but have their roots elsewhere in other risks.

Development of Digraph

While a lower triangular or conical matrix is a familiar form of presentation in operations research (OR) discipline, it is not an easier form to interpret for the practitioners or policy makers. This exercise of ISM will be successful only if it is interpreted and understood by the relevant stakeholders. A digraph will be able to pictorially interpret the contextual relationship between each of these risk elements and their hierarchies, as derived by modeling.

For preparing the digraph, the elements which move out during the first iteration (Table 3) appear at Level I and are placed at the top of the hierarchy. Thus, cost overrun risk (element 8) and schedule risk (element 9) appear at the top. Thereafter, the elements which move out during the second iteration (elements 2, 13, and 17 in Table 4) appear at Level II and are placed just below the top level. Repeating this process, the various elements (risks) can be placed at different levels. The interrelationship between various risks can be obtained by the corresponding entries in the triangular binary matrix (Table 6). For example, for element 2 (Delay in financial closure), the entries corresponding to elements 8, 9 and 2 are 1 and for all other elements, the entry is 0. Thus, element 2 leads to elements 8 and 9, whereas there exists no relationship between 2 and other remaining elements. In a similar fashion, the interrelationship between the various elements (risks) are identified and denoted as directional arrows representing the direction of relationship. The digraph so obtained from ISM is presented in Fig. 2. Thus, a hierarchy of risks that exists during the life cycle of a highway project executed under BOT mode is obtained.

From the digraph, it can be seen that environmental risks resulting from adverse ecological impact, public protests, litigation etc. can cause delays in the issue/receipt of various statutory approvals and permits. Permit/approval risks arising from bureaucratic corruption, turf-war between different government agencies etc. can result in unlawful refusal to grant approvals. In the Maharashtra State of India, a $1.5 billion Mumbai Trans Harbour Link to be executed as BOT project was won by Reliance Infrastructure-Hyundai consortium. However permit/approval risks led to refusal to grant the concession (PTI 2008). The Indian legal system, being fraught with complexities, differing interpretations, and application of judicial covenants can lead to direct political risks such as lack of continuity in law, appropriation of assets etc. Resettlement and rehabilitation risks which crop up from the refusal of land owners to part with the land due to improper/inadequate compensation or resettlement package can derail the land acquisition process, which in turn can delay the financial closure. Financial closure can be achieved only if the prospective lenders are guaranteed of unencumbered stretches of land. In the same way, preinvestment risks, direct political risks and partnering risks can also add to the delay in financial closure. Selection of improper or outdated technology can cause design and latent defects, which result in physical damage to the facility. Such a physical risk can also be due to nonpolitical force majeure events such as floods, earthquakes, or other disasters. Indirect

Table 5. Last Iteration

Element (Pi)	Reachability set: R (Pi)	Antecedent set: A (Pi)	Intersection R(Pi)∩A(Pi)	Level
16	16	16	16	V

J. Constr. Eng. Manage. 2010.136:151-159.

Table 6. Lower Triangular/Conical Matrix

Elements (i/j)	8	9	2	13	17	1	4	7	10	11	14	15	3	5	6	12	16
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
7	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
10	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
11	1	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0
14	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
15	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
3	1	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0
5	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0
6	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0
12	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0
16	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1

political risk such as armed conflict, commotion, political resistance, etc. could be a factor leading to physical risks as well as financial risks such as changes in exchange rate, interest rate, etc. Risks such as delay in financial closure, direct and indirect political risks and physical risks result in time overrun. Delay in financial closure, direct political risk, financial risk, and physical risk also lead to cost overrun risk.

Degree of Relationship between Risks

After development of digraph, it is necessary to ascertain the degree of relationship between the various risk elements, which was done using MICMAC analysis, developed by J. C. Duperrin and M. Godet. The objective of MICMAC analysis is to analyze the driver power and dependence power of each element (Mandal

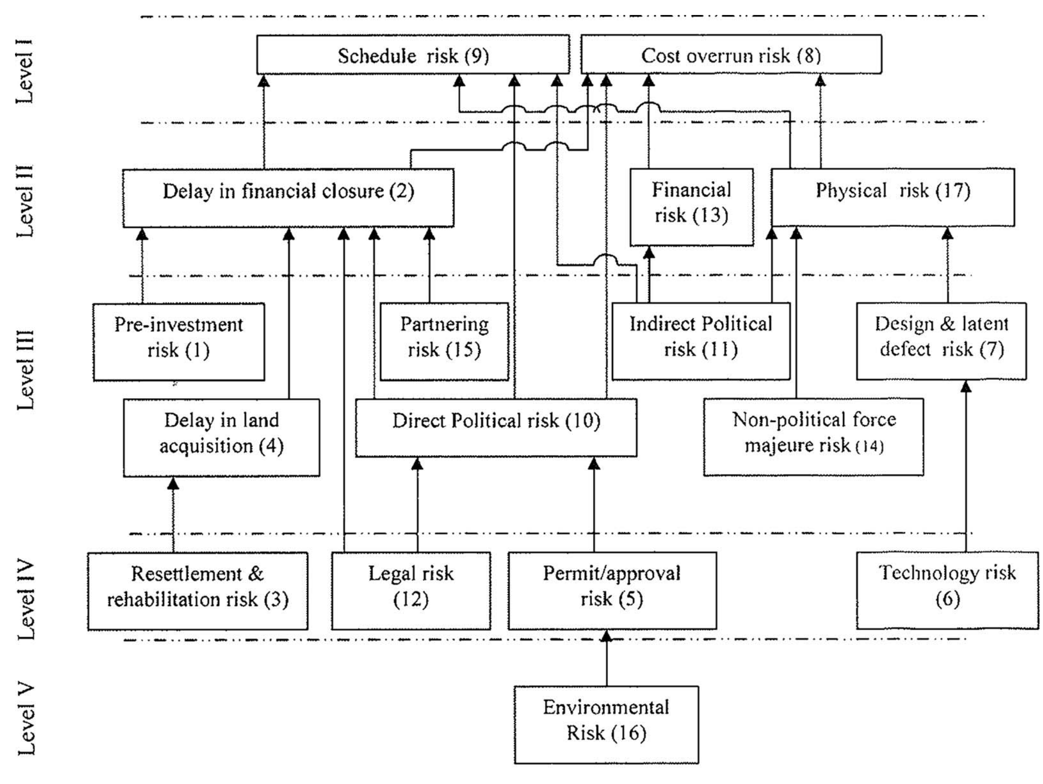

Fig. 2. Digraph of risks in PPP road projects

J. Constr. Eng. Manage. 2010.136:151-159.

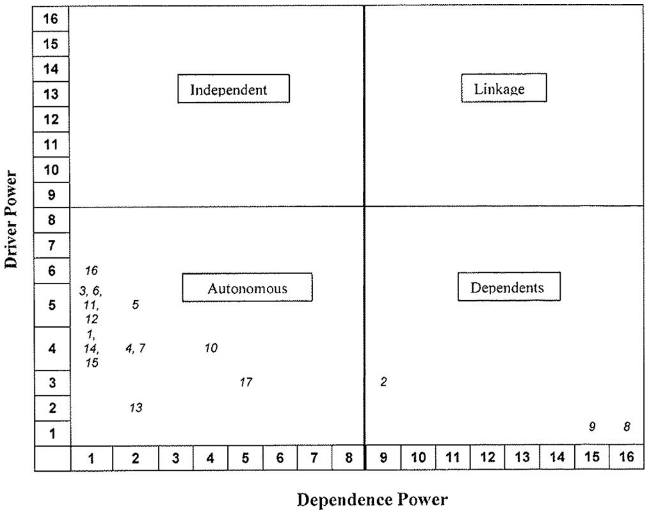

Fig. 3. Classification of risks

and Deshmukh 1994). This formal analysis complements and extends impressions that experienced users draw from visual analysis of influence structures. Specifically, MICMAC explores influence and dependence between issues and classifies them into independent, relay/linkage, dependent, and autonomous clusters. From the reachability matrix, the driver power of each element is obtained by the summation of 1s in the corresponding row. Similarly, dependence power of each element is obtained by the summation of 1s in the corresponding column. After obtaining the driver power (influencer) and dependence power of each element, they are presented in the form of a driver power-dependence matrix. Each element is plotted as a point using the conventional *x-y* coordinate system.

In the present study, the PPP risks described earlier are classified into four groups (Fig. 3). The first group consists of "autonomous risks" that have a weak driving power and weak dependence. The "dependent risks" constitute the second group which has weak driving power but strong dependence. The third group represents the "linkage risks" that has a strong driving power and strong dependence. Any change occurring to them will have an effect on others and also an impact on themselves. The fourth group includes the "independent risks" having strong driving power but weak dependence. The independent and linkage clusters are empty, implying that none of the risks have strong driving power. All the risks have low driving power, whereas a majority of the risks (14 out of 17) have low dependence power. More specifically environmental risks, resettlement and rehabilitation risks, technology risks, indirect political risks, legal risks, and permit/approval risks have a driving power of 5 or more, as perceived by the experts in the BOT industry. These risks are the ones which are beyond the control of the concessionaire. Only three risks fall in the dependent cluster. Among them, schedule risk and cost overrun risk have a very high degree of dependence. These risks are at the top of ISM hierarchy. Incidentally, this also reestablishes the common professional concern about time and cost overruns in any construction project to view as major risks, while the third one, delay in financial closure is typical to PPP projects. Thus, it can be deduced that a concessionaire should accord high priority to these three risks for successful project management. In addition, a majority of the risks in PPP projects such as environmental risks, political and nonpolitical risks, delay in land acquisition etc. can only be analyzed qualitatively and they are not amenable to strict mathematical modeling. The present study has demonstrated that the various risks, autonomous in nature, have weak driving power on the schedule and cost overrun risks, while these two risks have very strong dependence on all other risks. Time and cost being the two very important and significant variables to model the project performance, treatment of cost overrun and time overrun would subsume the import of various other qualitative risks.

Summary and Conclusions

This paper has identified and prioritized 17 critical risks which occur during the development phase of highway projects executed in India under PPP. Risk analysis in PPP projects involves subjective assessment of the various risks which are difficult to model. Hence, a need was felt to identify the dominant risks by studying the influence-dependence of these risks. ISM was used as a tool in preparing the hierarchical structure of risks encountered during the development phase in Indian highway projects.

The ISM model developed and the subsequent MICMAC analysis have identified the nature and degree of interrelationship between the risks during the life cycle of PPP highway projects. MICMAC analysis suggests that fourteen out of the 17 risks identified are autonomous and appear as weak drivers and weak dependents and they mutually do not have much influence on each other. However, the financial closure risk, schedule risk, and cost overrun risk have strong dependence on these fourteen risks. Further, the hierarchical structure obtained from ISM also reinforces the same that several risks involved in a project together influence cost overrun risks and schedule risks. Since the cost risks and schedule risks have been found to be having the highest dependency on other risks, they are quite vulnerable and susceptible to be affected most. Hence, due care must be taken by the manager to check the other risks to control time and cost overruns. While the output of this analysis is applies only to India, the methodology has been proven to be a valuable tool for sorting out PPP risks and hence could be used for other complex projects in sectors such as railways, airports, seaports etc, wherein large private investments are forthcoming. This can aid in better understanding and treatment of associated risks.

References

Bolanos, R., Fontela, E., Nenclares, A., and Pastor, P. (2005). "Using interpretative structural modeling in strategic decision-making groups." *Manage. Decis.*, 43(6), 877–895.

Chapman, R. J. (2001). "The controlling influence on effective risk identification and assessment for construction design management." *Int. J. Proj. Manage.*, 19(3), 147–160.

Eldin, N. N. (1989). "Measurement of work progress: Quantitative technique." *J. Constr. Eng. Manage.*, 115(3), 462–474.

Faisal, M. N., Banwet, D. K., and Shankar, R. (2006). "Supply chain risk mitigation: Modeling the enablers." *Bus. Process. Manag. J.*, 12(4), 535–552.

Flood, R. L. (1989). "Six scenarios for the future of systems problem solving." *Syst. Pract. Action Res.*, 2(1), 75–99.

Hawthorne, R. W., and Sage, A. P. (1975). "On applications of interpretive structural modeling to higher education program planning." *Socio-Econ. Plan. Sci.*, 9(1), 31–43.

Hillson, D. (2002). "Use of risk breakdown structure (RBS) to understand your risks." *Proc., Project Management Institute Annual Seminars and Symp.*, San Antonio.

J. Constr. Eng. Manage. 2010.136:151-159.

The Hindu. (2006). "BMIC: Supreme court rejects state's petition." ⟨http://www.thehindu.com/2006/11/03/stories/2006110317560100.htm⟩ (June 19, 2009).
Hsiao, S., and Liu, E. (2004). "A structural component-based approach for designing product family." *Comput. Ind. Eng.*, 56, 13–28.
Janes, F. R. (1988). "Interpretative structural modeling: A methodology for structuring complex issues." *Trans. Inst. Meas. Control (London)*, 10(3), 145–154.
Jha, K. N., and Devaya, M. N. (2008). "Modeling the risks faced by Indian construction companies assessing international projects." *Constr. Manage. Econom.*, 26(4), 337–348.
Jharkharia, S., and Shankar, R. (2004). "IT enablement of supply chains: Modeling the enablers." *Int. J. Prod. Perform. Manage.*, 53(8), 700–712.
Kanungo, S., Duda, S., and Srinivas, Y. (1999). "A structured model for evaluating information systems effectiveness." *Syst. Res. Behav. Sci.*, 16, 495–518.
Lendaris, G. B. (1980). "Structural modeling a tutorial guide." *IEEE Trans. Syst. Man Cybern.*, 10(12), 807–840.
Linstone, H. A., Lendaris, G. B., and Rogers, S. D. (1979). "The use of structural modeling in technology assessment." *Technol. Forecast. Soc. Change*, 14, 291–327.
Malone, D. W. (1975). "An introduction to the application of interpretative structural modeling." *Proc. IEEE*, 63(3), 397–404.
Mandal, A., and Deshmukh, S. G. (1994). "Vendor selection using interpretative structural modeling." *Int. J. Oper. Prod. Manage.*, 14(6), 52–59.
Palanisami, R. (2003). "Evolving research design using flexible systems methodology: Expert systems approach." *Proc., 2nd National Conf. on Mathematical and Computational Models*, PSG College of Technology, Coimbatore, India.
Planning Commission. (2006). *Public private partnership in national highways: Model concession agreement*, Government of India, New Delhi, India, 89–90.
Planning Commission. (2007). *Projections of investment in infrastructure during the eleventh plan*, Government of India, New Delhi, India, 1–2.
PTI. (2008). "Ambanis out of bidding race for Mumbai trans-harbour link." ⟨http://news.in.msn.com/national/article.aspx?cp-documentid=1521202⟩ (June 25, 2008).
Ravi, V., and Shankar, R. (2004). "Analysis of interactions among the barriers of reverse logistics." *Technol. Forecast. Soc. Change*, 72(8), 1011–1029.
Ravi, V., Shankar, R., and Tiwari, M. K. (2005). "Productivity improvement of a computer hardware supply chain." *Int. J. Prod. Perform. Manag.*, 54(4), 239–255.
Sage, A. P. (1977). *Interpretive structural modeling: Methodology for large-scale systems*, McGraw-Hill, New York, 91–164.
Saxena, J. P., Sushil, and Vrat, P. (1992). "Hierarchy and classification of program plan elements using interpretive structural modeling: A case study of energy conservation in the Indian cement industry." *Syst. Pract.*, 5(6), 651–670.
Sharma H. D., Gupta A.D. and Sushil. (1995). "The objectives of waste management in India: A futures inquiry." *Technol. Forecast. Soc. Change*, 48, 285–309.
Sridharan, G. (1997). "Factors affecting the performance of international joint ventures—A research model." *Proc., 1st Int. Conf. on Construction Industry Development*, Vol. 2, National Univ. of Singapore, Singapore, 84–81.
Thakkar, J., Deshmukh, S. G., Gupta, A. D., and Shankar, R. (2007). "Development of a balanced scorecard: An integrated approach of interpretive structural modeling (ISM) and analytic network process (ANP)." *Int. J. Prod. Perform. Manag.*, 56(1), 25–69.
Thomas, A. V. (2003). "Identification, assessment and allocation of critical risks in Indian BOT road projects." Ph.D. dissertation, Indian Institute of Technology, Chennai, India.
Warfield, J. (1976). "Implication structures for system interconnection matrices." *IEEE Trans. Syst. Man Cybern.*, 6(1), 18–24.
World Bank. (2008). "Force majeure clauses." ⟨http://siteresources.worldbank.org/INTINFANDLAW/Resources/Forcemajeure.doc⟩ (June 19, 2009).

J. Constr. Eng. Manage. 2010.136:151-159.