Analysis of Supply Chain Risks in Concrete Dam Construction

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ABSTRACT

This study identifies 35 risks related to the supply chain of concrete dams, of which 25 were selected as critical risks using the Delphi method. Risks were categorized into three groups based on their sources including environmental, network and organizational risks. The Failure Mode and Effect Analysis (FMEA) method was then applied to evaluate the significance of risks in three areas of construction cost, time and quality. The results revealed that 44% of risks in the construction cost category were critical, while 21% of risks in construction time and 12% in construction quality were found to be critical. Appropriate responses to mitigate critical risks were provided, including the use of alternative supply resources, rigorous project scheduling, and diversified financial strategies. This study highlights the importance of risk management in improving project performance in terms of cost, time, and quality, and emphasizes the need for effective communication and continuous risk monitoring throughout the project lifecycle.

KEYWORDS

Supply Chain; Risk Assessment; Concrete Dam; Construction Management; Project Management.

1. Introduction

Application of new technologies and modern management methods has caused a significant growth in construction industry. It has also raised the number of chain supply suppliers to acquire raw materials and services. Therefore, it is essential to communicate with different suppliers, employees, departments and organizations as a team to guarantee the best function [1]. Partners' complex international networks, unpredictable demand, increased costs, use of outsourcing, have raised dependence between different supply chain segments [2]. Affiliation of different supply chain sectors has created many internal and external risks such as economic crises, natural disasters or political conflicts, whose occurrence in any part of supply chain which can directly or indirectly affect other areas [3]. Different kind of risks disturbed supply chain and affected global industry [4]. The supply chain is usually convergent in manufacturing industry and in the construction industry, supply chain activities lead to the production of a product and there may be different risks of varying importance [5]. One of the characteristics of construction of a unique product in a specific location is that different parts of the supply chain are occupied different distances, which are related to the location of products and have acquired deeper insight about this location [6].

The construction industry has been generally characterized by low integration, low productivity, cost and extra time, several conflicts and disagreements over other industries. These problems are rooted in supply chain disruptions in this industry [7]. Attention to supply chain risks management for eliminating or reducing the effects of failures, which arise from potential risks in different sectors such as economic issues, natural disasters or human errors, seems to be necessary [8]. Dam construction as one of the oldest industries, involving many countries, is considered the subset of manufacturing. Dam construction projects are mostly implemented in a relatively long period of time and require significant financial resources [9]. In the context of examining risks in the construction sector, Chen et al. analyzed financial and credit risks in the real estate sector [10]. Wang et al. investigated the impact of adverse weather conditions on the supply chain risks associated with prefabricated structures [11]. Studies show that the cost is estimated to be double for one out of five dams and triple for one out of ten [12]. They should always be designed and constructed with consideration of all aspects because the weakness in the quality of the finished project can cause considerable damages [13]. There have been several studies in field of risks identification and investigation. In one case, supply chain risks, including demand change, manufacturing new product, lack of durable products and delay in supply in products, were investigated by Johnson, working on another field, toy industry [14]. In another research, Qaraqanabadi and Sarkardeh examined supply chain risks in road construction projects [15]. Wilson worked on the effect of transportation on supply chain function by introducing some factors leading disruption of supply chain [16]. Gaudenzi evaluated supply chain risks by AHP method, which includes resource shortage, lack of coordination between different parts, incorrect prediction, lack of information system as well as error in estimation and lack of depot [17]. Supply chain also was investigated by Tuncel and Alpan via FMECA method. In their research, shortage of initial materials, human errors and problems related to equipment were considered as parts of supply chain risks [18]. Giri and Bardhan worked on investigation of supply chain integration method in case of disruptions, such as political instability, labor strikes, earthquakes, fires, disruptions of transit system and floods [19]. In a study conducted by Yang and Xu, several risks like recession, financial fluctuations and lack of liquidity are categorized as supply chain risks [20]. Investigation of the causes of some problems, such as project delay and increasing of costs, in dam construction projects indicates the probability of problem in supply chain management. Some factors, like error in determination of request for initial material, natural hazard, change in plans, are important reasons for delay in dam construction project in Oman [21]. In other example, difference between sections, lack of knowledge, shortage of equipment, incorrect planning are considered as causes for unfinished projects in dam construction area in Albania [22].

Despite to the previous studies and importance of a dam safety, no comprehensive study was performed to identify the construction risks in a concrete dam. In the present research, according to the previous researches, the supply chain risks were identified and using Delphi method, related risks of supply chain of a concrete dam construction were classified. Furthermore, using FMEA, identified risks according to possible factors are prioritized in three parts of construction cost, time and quality. Eventually, interviews were conducted with experts to find the most proper response for the most important risks.

2. Methods and Materials

2.1. Delphi method

Delphi technique helps experts to achieve a unanimous agreement about a specific topic in which to identify of participation is kept unknown [23]. Delphi method process begins with preparing an initial questionnaire as a general strategy to find answers for researcher's questions. In the first step, a questionnaire is provided for a number of experts to both answer the question and elaborate their further viewpoint. The second questionnaire is designed based on the results of the former one. This process is continued in the next stages and each member's response is shared with others responses to be revised if required. The procedure will be continued until all responses are in coordination. In addition, in this method, each step is constructed based on the previous step [24].

2.2. Supply chain category

There are different categories of supply chain risks. The risks fall into two types of demand and supply risks. Kleindorfer categorized risks according to their source in three groups, including operational source, natural disasters and political source where risks related to concrete dams supply chain, based on their source, are categorized in three groups of environmental, network and organizational risks. Environmental risks include all risks and factors out of supply chain, leading to uncertainty in supply chain functions and can be caused by accidents, social and political actions or natural disasters. Network risks refer to the ones resulting from organizations interactions in supply chain; accordingly, damages rooted in uncoordinated interactions between organization fall in this category. Organizational risks include the risks which are directly involved in main organization boundaries [25-27].

2.3. Identification and classification of concrete dams supply chain

The initial questionnaire, in the present study which was prepared in Delphi method, included questions related to concrete dams supply chain risks choices among 35 identified risks. Furthermore, the source of each risk was investigated. This questionnaire was distributed among seven experts of dam construction area. Ultimate responses were achieved in three steps, in which experts answered and modified the questions. The identified supply chain risks are indicated in Table 1. Eventually, 25 risks were identified as risks related to concrete dams supply chain, in which organizational source made up 36% of the whole risks and environmental and network source constituted 36% and 28% of all risks, respectively.

Table 1. Concrete dams supply chain risks in and the sources

Number	Risk	Risk source	Number	Risk	Risk source
1	Human error in design	organizational	14	recession	environmental
2	Incorrect estimation of initial material	organizational	15	Natural disasters	environmental
3	Lack of equipment and construction and transport technology	organizational	16	Political instability	environmental
4	Damages to equipment	organizational	17	Ownership conflicts	network
5	Transportation problems	network	18	War	environmental
6	Weakness in personnel responsibility	network	19	terrorism	environmental
7	Lack of store for material depot	organizational	20	shortage of sufficient supplier	network
8	Lack of personal hygiene	organizational	21	Lack of resources to supply materials	organizational
9	Low quality in material	organizational	22	Error in initial project schedule	organizational
10	Labor strike	network	23	Geographic and cultural unawareness	network
11	International disputes in the field of water	environmental	24	Work conflicts	network
12	Increase in interest rates	environmental	25	Changes in laws	environmental
13	Exchange rate fluctuations and price changes	environmental			

2.4. FMEA Method

FMEA is a method applied for identifying, reducing or eliminating existing and potential risks of the system and designing products, processing production or distributing prior to products reaching the customers [28]. In FMEA, after risks identification, they are estimated via calculating Risks Priority Number (RPN) for both potential errors and their effects. RPN = S×O×D is obtained by finding the multiplication of three factors, involving the severity of the failure (S), the probability of occurrence (O) and probability of detection (D). These three factors are categorized in a qualitative scale from 1 to 10. Risk priority number is the basis for prioritizing the failure scenario. According to 1-10 domain for these three factors, RPN will have a number between 1 to 1000 [26]. RPN analysis method is one of the most significant requirements in FMEA. Several researchers have identified the value of RPN as priority criteria, yet this category is not sufficient for risks mode analysis since risks deterioration is not taken into account. For instance, although different combination of S, O and D can present equal RPNs, the consequences of each risk and its modes may be different. Moreover, risk priority number is sensitive to disparity in risks factors evaluation. A slight change in number of each factor leads to a major change in RPN, which in turn causes change in grade. In this research, due to the importance of these three factors of severity of the failure, the probability of occurrence and the probability of detection, a criterion is defined and applied as crisis levels explained in detail as follows [29]:

Level 1: normal level, in which all three RPN factors (especially severity and possibility of occurrence) have a value less than 5, or RPN value is very low (RPN<70). This case does not require corrective and preventive actions.

Level 2: semi-critical, in which at least one out of three factors (especially severity and possibility of occurrence) has a value more than 5, or RPN value is moderate or low (70<RPN<140). This case requires corrective and preventive actions.

Level 3: critical level, in which at least two out of three factors (especially severity and possibility of occurrence) have a value more than 5, or RPN value is very high (RPN>140). It is clear that corrective and preventive actions are essential in this case.

2.5. RPN calculation and crisis level determination of concrete dams supply chain

The questionnaire based on FMEA is used for obtaining data which leads to RPN. Each risk in three sectors, severity of the failure, the probability of occurrence and the probability of detection, in three areas, including construction cost, construction time and construction quality are investigated by dam construction experts. Statistical population includes dam construction experts, who are 34 members directly working at least 15 years on dam projects in fields of constructing and designing from beginning to end of project. Table 2 shows the result of cost construction part achieved from analysis of questionnaire [30]. Regarding to these results, the most important risks, in this area, are exchange rate fluctuations, shortage of liquidity, Increase in interest rates. Moreover, the lowest levels of importance are related to disruptions of transit system, shortage of depot, shortage of sanitation. In another part of this study, the importance of risks on construction time is evaluated. According to Table 3, the risks of shortage of liquidity, delay in activities and international conflicts have the highest impact on ultimate time, and the lowest impact is related to shortage of materials quality, shortage of depot and lack of hygiene. The effect of risks on construction quality is shown in Table 4. The results indicate that risks of international conflicts, exchange rate fluctuations and human errors are most effective, and disruptions of transit system, ownership conflicts and shortage of depot have the lowest significance in this part.

Table 2. The Importance of Risks on Construction Cost

Risk	RPN	Crisis level	Risk	RPN	Crisis level
Exchange rate fluctuations and price changes	258.70	critical	Changes in laws	102.75	Semi-critical
Error in initial project schedule	234.80	critical	Workforce strikes	89.06	Semi-critical
Increase in interest rates	229.01	critical	Political instability	77.35	Semi-critical
International conflicts	221.50	critical	Shortage of equipment and technology	67.61	Normal
recession	221.37	critical	Lack of materials quality	62.49	Normal
Weakness in personnel responsibility	210.90	critical	war	55.75	Normal
Lack of resources to supply materials	159.26	critical	Equipment damage	51.90	Normal
shortage of sufficient supplier	138.65	critical	Ownership conflicts	40.10	Normal
Human error in design Incorrect	135.98	critical	terrorism	39.54	Normal
Natural disasters	129.09	critical	Disruptions of transit system	39.44	Normal
Estimation of initial material	123.71	Semi-critical	Shortage of sanitation	29.34	Normal
Geographic and cultural unawareness	110.87	Semi-critical	Shortage of depot	25.00	Normal
Work conflicts	105.91	Semi-critical			

Table 3. The importance of risks on construction time

Risk	RPN	Crisis level	Risk	RPN	Crisis level
Error in initial project schedule	265.69	critical	Incorrect estimation	100.18	Semi-critical
Weakness in personnel responsibility	237.26	critical	Changes in laws	90.83	Semi-critical
International disputes in the field of water	220.06	critical	Shortage of equipment and technology	82.97	Semi-critical
recession	219.99	Semi-critical	Political instability	78.96	Semi-critical
Human error in design Incorrect	194.39	critical	war	64.29	Semi-critical
shortage of sufficient supplier	188.57	critical	Equipment damage	57.39	normal
Exchange rate fluctuations and price changes	156.91	Semi-critical	Disruptions of transit system	49.98	normal
Increase in interest rates	154.84	Semi-critical	Ownership conflicts	47.45	normal
Natural disasters	129.09	Semi-critical	terrorism	45.92	normal
Work conflicts	126.38	Semi-critical	Lack of materials quality	45.40	normal
Geographic and cultural unawareness	118.20	Semi-critical	Shortage of depot	25.38	normal
Human error in design Incorrect	116.01	Semi-critical	Shortage of sanitation	23.54	normal
Workforce strikes	106.33	Semi-critical			

Table 4. The Importance of Risks on Construction quality

Risk	RPN	Crisis level	Risk	RPN	Crisis level
International disputes in the field of water	163.96	critical	Workforce strikes	65.43	normal
Exchange rate fluctuations and price changes	142.55	critical	Timing error	64.04	normal
Lack of resources to supply materials	148.29	critical	Changes in laws	55.02	normal
shortage of sufficient supplier	127.08	Semi-critical	Incorrect estimation	54.88	normal
Human error in design	119.83	Semi-critical	Equipment damage	52.40	normal
Incorrect recession	115.70	Semi-critical	Political instability	50.76	normal
Low quality in material	104.24	Semi-critical	war	35.28	normal
Increase in interest rates	98.89	Semi-critical	Shortage of sanitation	31.19	normal
Natural disasters	90.16	Semi-critical	terrorism	26.85	normal
Lack of equipment and construction and transport technology	87.16	Semi-critical	Disruptions of transit system	24.30	normal
Weakness in personnel responsibility	77.45	Semi-critical	Ownership conflicts	22.59	normal
Work conflicts	72.09	Semi-critical	Sortage of depot	17.69	normal
Geographic and cultural unawareness	68.47	normal			

3. Results and Discussions

Results of interview with experts and using the statistical analysis were discussed in two parts of supply chain risks assessment of concrete dams and risks responses.

3.1. Assessment of Supply Chain Risks of Concrete Dams

In construction cost part, 44% of risks are in critical conditions which need an adequate response immediately. The majority of critical risks in this part have environmental source and rest of them are divided between organizational and network source. Semi-critical risks make up 26% of whole which should be investigated by risk management experts who make essential modifications during the study for prevention of such risks. Portion of network source is more than others in this part. Furthermore, crisis level of 30% of risks is normal in which organizational source is more effective than others (Figure 1). Construction time investigation indicates that 21% of risks are critical and require response straightaway. The sources of these risks are 40% organizational, 40% network and 20% environmental. Half of risks are semi-critical which must be investigated persistently, and also require an appropriate response. 58% of semi-critical risks have environmental source and rest of them have organizational and network source. Crisis level of 29% of construction time part are normal which organizational source constitutes 57% of all, environmental and network make up 14% and 29% of whole respectively (Figure 2). Risks evaluation in part of construction quality importance indicates that only 12% of all risks are in critical level which 67% of them have environmental source and 33% have organizational source. There are no risks with network source in this part. Semi-critical condition accounts for 36% of risks which have an equal portion in all three sources. In addition, 52% of risks are in normal condition in construction quality part, and the source of 38% of them is organizational; meanwhile, each of environmental and network sources make up 31% of all risks (Figure 3).

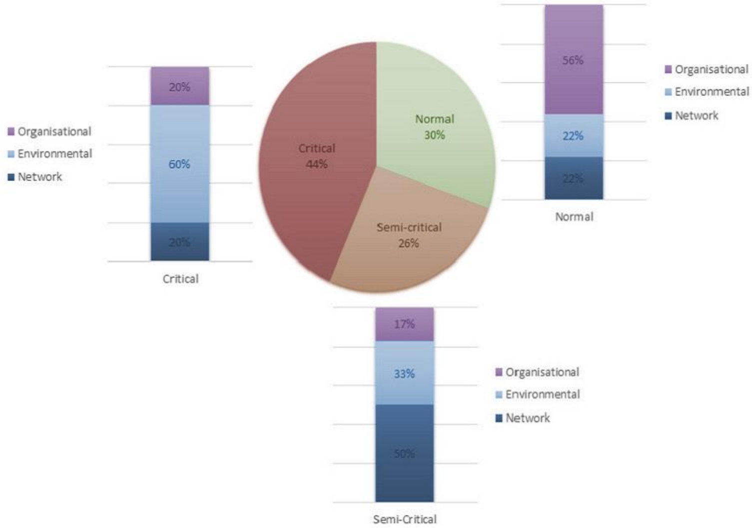

Figure 1. Risks evaluation in construction cost part

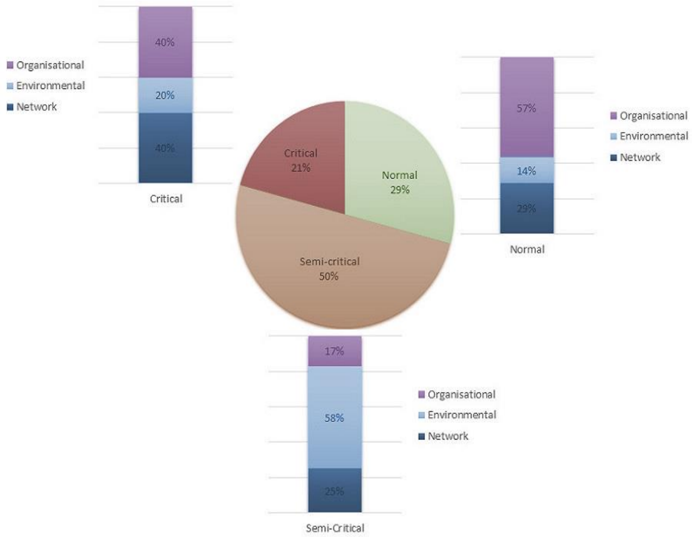

Figure 2. Risks evaluation in construction time

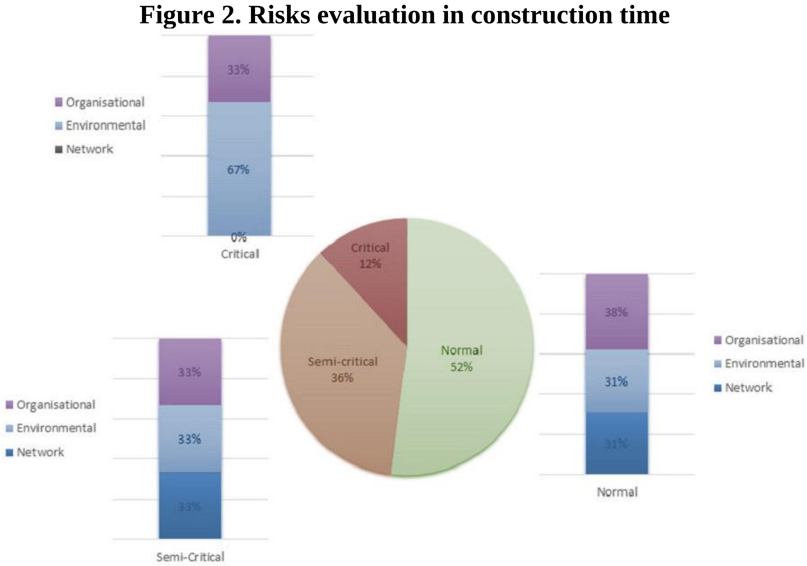

Figure 3. Risks evaluation in construction quality

3.2. Responses to the risks

Organizations should take corrective actions as soon as possible to decrease critical risks; thus, in this article appropriate responses are elicited from interview in three parts including, construction cost, time and quality. Totally, 10 risks are in critical conditions for which there are proper responses (Table 5).

Table 5. Responses to the risks

Critical risks	response
Exchange rate fluctuations and price changes	Deposit exchange in beginning of project Redesign of project according to exchange rate fluctuations Use of new supply resources
Error in initial project schedule	Regular Supervision and investigation of payments Supply of financial resources by banks mediation Investigation of different parts of organization to find ways for deposit
Increase in interest rates	Diversify the portfolio of companies Debt of settlement in short timeframes Select of sources with lower interest rates
International disputes in the field of water	Use of different suppliers from different countries Investments in upgrading technology and knowledge of suppliers Negotiation to resolve disputes Use of mediation to supply resources
recession	Saving liquidity for recession Expanding investment in different sectors Reducing extra costs
Weakness in personnel responsibility	Accurate coordination between different parts of the supply chain Learn from past events and delays Prevent unnecessary repetition of activities
Lack of resources to supply materials	Providing accurate daily reports of project trends Providing flexible scheduling Accurate investigation of activities relations
Shortage of sufficient supplier	Accurate estimation of required materials and services Use of different methods for distribution and shipping Considering alternative supply resources
Human error in design Incorrect	control and supervision of project Determination of the rules and regulations at each stage of the project Use of experts related to their responsibilities
Natural disasters	Collaboration with insurance companies to conclude contracts Construction of dams and increase of vegetation Pay attention to the predictions and early warning signs

4. Summary and Conclusions

In this study, 35 supply chain risks are identified from previous studies which 25 of them are chosen via Delphi method as a concrete dam construction supply chain risks. These risks are classified in three categories based on their source. Then, FMEA is applied to evaluate the importance of risks in three parts namely, construction cost, time and quality. In critical level, there are 10, 5 and 3 risks in construction cost, time and quality parts, respectively. In addition, the risks and impacts in each part of the supply chain can be extended to other sections, ultimately affecting the entire project. It should be noted that more attention to related risks of supply chain of dam construction and management can lead to better financial resources management. It also increases accuracy of time management, quality of construction, labor productivity and environmental friendliness.

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