RISK OF CATASTROPHIC EVENTS ON CONSTRUCTION SUPPLY CHAIN

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ABSTRACT

Construction supply chain flow through the entire business process initiated from the demand by the client to create the project, till the demolition of the construction. Catastrophic events are rare events which are difficult to predict its occurrence. However, catastrophic events take place within the construction supply chain; have a severe impact over the project.

Most of the researches on supply chain were keen to understand the factors increasing efficiency and reducing cost. As a result, many findings were there to keep the supply chain live at ordinary times, but at the cost of being vulnerable to disruptions. It was identified that catastrophic events take place in the construction supply chain have not been highlighted in supply chain researches. Therefore, the aim of this paper is to present the catastrophic events take place in construction supply chain and their risk levels.

A comprehensive literature review has laid the initial path to gather current knowledge on catastrophic events in construction supply chain. In order to fill the gaps in literature, a preliminary study has been carried out to gather further information on practical experience with catastrophic events in construction supply chain. The study revealed that although there are number of findings on catastrophic events on supply chain management, the risk levels of these catastrophic events change under different conditions. Therefore, through the findings of the above two phases and the survey carried out among construction industry experts, this paper list out the catastrophic events, ranked according to the risk level under a developing economic and tropical environment. This fascinating strategic finding is a great tool for construction decision makers to fight the risks in construction supply chain.

Keywords: *Catastrophic Events; Construction Supply Chain; Likelihood; Risk Analysis; Severity.*

1. INTRODUCTION

Heightened challenges due to series of catastrophic events that have disrupted economies around the world have prompted academics and practitioners to investigate new strategies to minimise their impact on supply chain. Mentzer *et al*. (2001) defined supply chain as '*a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer*'.

Although supply chains exist in any type of organisation, the complexity of the chain to vary greatly from firm to firm, culture to culture and also from industry to industry. The construction industry consists of certain peculiarities, as one-of-a-kind nature of project, temporary multi-organisation, site production, and regulatory intervention preventing the attainment of flows as efficient as in manufacturing (Koskela, 1992). Vrijhoef and Koskela (2000) argued that due to construction peculiarities, supply chain management has specific roles in construction. The construction supply chain primarily represents a series of serial and parallel connections between clients and suppliers leading to the delivery of one or more products to one or more end clients (Vrijhoef and De Ridder, 2005).

Supply chains are increasingly vulnerable to catastrophic events and a diverse set of risks (Knemeyer *et al*., 2009). According to Atley and Ramirez (2010), there are evidence that failure to manage supply chain risks effectively may lead to a significant negative impact on organisations. Such impacts include not only financial losses but also reduction in product quality, damage to assets and loss of reputation (Khan and Burnes, 2007).

Thus, the paper structure begins with a review of construction supply chain management and identification of catastrophic events on construction supply chain. The next section presents the research methodology

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and conceptual framework. Research findings are presented in the fifth section and followed by concluding discussions.

2. CONSTRUCTION SUPPLY CHAIN MANAGEMENT

A major distinction between construction and manufacturing is that the construction industry is project based and of discontinuous nature, while manufacturing industries involve continuous processes and relationships (Segerstedt and Olofsson, 2010). The construction industry is one of the most complex industries, because the total development of a project normally consists of several phases requiring a diverse range of specialised services and involvement of numerous participants. Therefore, it is difficult to control and manage construction projects effectively (Tserng *et al*., 2005). Production in construction is relatively disconnected and fragmented due to the nature of demand and supply systems in construction have traditionally been organised (Vrijohoef and De Ridder, 2005).

Supply chain management (SCM) in manufacturing industry is defined as '*the systemic and strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole'* (Mentzer *et al.*, 2001). Supply chain in construction consists of all the construction business processes initiated from the demands by the client as conceptual, design and construction to maintenance, replacement and eventual decommission of building (Xeu *et al.*, 2007). Further to Xeu and his co-workers, construction supply chain is not a chain of construction businesses with business-to-business relationships, but a network of multiple organisations and relationships, which includes the flow of information, the flow of materials, services or products, and the flow of funds between client, designer, contractor and supplier. Fisher and Morledge (2002) have reported three types of construction supply chains: the primary supply chain, which delivers the materials incorporated into the final construction products; the support chain, which provides equipment and materials that facilitate construction; and the human resource supply chain, which involves the supply of labour. Kumar and Viswanadham (2007) argued that in construction, materials have to be imported many times and it makes supply chain global and more difficult to manage. Vrijhoef and Koskela (1999) stated that actual practice in construction not only fails to address issues of supply chain, but also follows principles that make supply chain performance worse.

3. CATASTROPHIC EVENTS

Stecke and Kumar (2006) showed that there has been a marked increase in the frequency and economic losses from natural and man-made catastrophes. But, Vanany *et al.* (2009) highlighted that catastrophic events have received relatively less attention in the supply chain management literature.

Gilbertson *et al*. (2011) defined catastrophic events as events that are beyond the ordinary or routine and are characterised by being of low probability but high consequence. Mitroff and Alpaslan (2003) identified seven categories of catastrophes as; economic crises (recessions, hostile takeovers), physical crises (industrial accidents, product failures), personnel crises (strikes, exodus of key employees, workplace violence or vandalism), criminal crises (product tampering, act of terrorism), information crises (theft of proprietary information, tampering with company records), reputation crises (logo tampering, rumour mongering), and natural disasters (floods, fires). Wagener and Bode (2006) recognised natural hazards, socio-political instability, civil unrest, economic disruptions and terrorist attacks as catastrophic events. Stecke and Kumar (2006) broadly classified catastrophes into two main parts: man-made and natural catastrophes and further divided them into other sub groups.

Gilbertson *et al*. (2011) identified several catastrophic events that could occur during construction phase as, structural collapse of permanent structure, collapse of temporary works, collapse of plant and equipment such as cranes, major fire, tunnel collapse, and disruption of underground services. Gilbertson *et al*. (2011) identified the most significant factor, which could affect the probability of a catastrophic event in construction industry as the failure to recognise hazardous scenarios and influencing events. Other important factors include lack of site control, interface problems with various parties, lack of checking and competent reviewing and lack of designer's involvement on site.

4. RESEARCH METHODOLOGY

The objectives of this study are to identify likelihood and severity of catastrophic events and their level of risk on construction supply chain. An extensive literature review was carried out to develop a research framework to gather data required for an empirical study. Different types of catastrophes affecting construction supply chain were initially identified using a literature review. The findings of the literature review initiated the pilot survey to investigate the applicability and suitability of literature findings to the Sri Lankan construction supply chain characteristics and conditions. One of the main objectives of the pilot survey was to develop a detailed questionnaire for the main survey.

The conceptual framework developed form the literature and pilot study findings is shown in Figure 1.

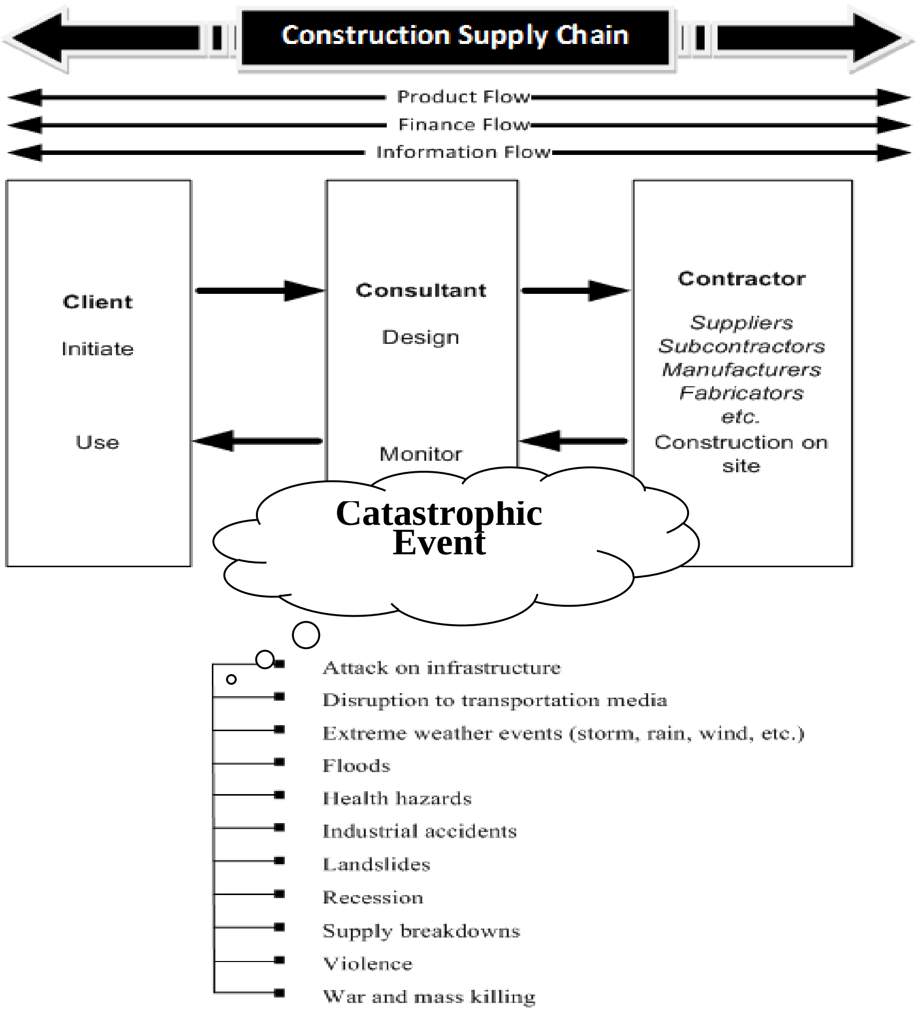

Figure 1: Conceptual Framework

Client, consultant and contractor are the three direct stakeholders in construction industry. The involvement of these parties in typical construction chain is illustrated on the above figure. Client initiates the construction with his need and plan. Based on the client requirement, consultant takes the construction process forward by developing a design which caters the client needs. At the next stage contractor builds a link between suppliers, subcontractors, manufactures and other such parties whose involvement is needed to the construction of the physical model of the consultant's design. After developing a strong link with the necessary outside parties, contractor starts the construction work and consultant monitor the contractor on behalf of the client till the contractor handover the project to the client to use. However, supply chain keeps the construction process live at each of the above mentioned phases. Finance, information and products are flown both ways throughout the construction supply chain to complete the supply chain loop. The smooth flow of these resources is disturbed by the catastrophic events and these events are listed in the figure.

As a result, 31 catastrophic events were identified during the literature review and all the identified catastrophes where presented in pilot survey to analyse their applicability in Sri Lankan construction supply chain. Further, the pilot survey questionnaire was prepared to gather any other catastrophe faced by the Sri Lankan practitioners which is not found during the literature review. Five construction project managers who are involving in construction supply chain management were interviewed during the pilot survey.

Findings of the pilot survey highlighted 14 out of the 31 catastrophic events which were found in literature. Catastrophes such as cyber attacks and biological, chemical and nuclear attacks were not considered for the main survey as they were recognised as not applicable to Sri Lankan phenomenon. Also, few catastrophes were merged to cover a broad area as well as to give a clear idea to the participants of the main survey. For example, catastrophic events such as flood, storm, and wind were taken as one catastrophe named extreme weather events. Further, strikes were renamed as trade union actions to reflect all possible catastrophes related to employees. Finally, 14 catastrophic events identified were used to develop a structured questionnaire for the main survey. Detailed questionnaire was distributed among the experts in the construction industry to identify the likelihood and severity of the catastrophic events that disrupt construction supply chain.

Construction industry experts were selected from C1 grade contracting organisations in western province due to complex nature of supply chain activities carried out by the construction companies of this grade. C1 is the highest grade that can be achieved by a contractor according to the categorisation of Institute for Construction Training and Development (ICTAD), the regulating authority of construction in Sri Lanka. During the study, researchers requested assistance from the initial respondents to identify professionals with similar experience and/or interest. The survey was limited among the contractors who carry their business in western province due to the time limitation. However, it is an area where most of the contractors do business. The detailed survey was then continued with the nominated respondents until obtaining the sufficient number of responds. Hence, snowball sampling method is used for this study. The questionnaires were given to 35 construction industry experts and 32 were responded. Composition of paricipants and their response rate are shown in Table 1.

Table 1: Composition of Participants

Designation	Number of Questionnaires Distributed	Number of Responses Received	Response Rate
Senior Managers	7	7	100%
Project Managers	18	15	83.3%
Planning Engineers	6	6	100%
Purchasing Managers	4	4	100%
Total	35	32	91.4%

The questionnaire used Likert scale to receive the responses for each question. Mean weighted rating was calculated for each catastrophic event in order to identify the likelihood and severity level of catastrophic events.

5. RESEARCH FINDINGS

The most important findings of the survey are summarised in the discussion below, supplemented by a series of tables. Severity and likelihood of different catastrophic events that affect construction supply chain are discussed first, followed by risk analysis of catastrophic events.

All catastrophes do not pose the same type or amount of risk to construction supply chain. For example, war may have the severe consequence such as large number of human and facility losses, while a disruption to transportation media may only affect supplies. Catastrophes such as extreme weather events and landslides may have different consequences on construction supply chain. This makes it difficult for construction organisations to plan their projects to face different catastrophes. Therefore, identification of severity and likelihood of catastrophes may ease the construction planning process.

First part of the questionnaire is focused on the identification of likelihood and severity of catastrophic events that threaten or disrupt the construction supply chain. The likelihood and severity corresponds to "how likely" and "how much" a catastrophe might affect the construction supply chain.

5.1. LIKELIHOOD OF CATASTROPHIC EVENTS

The questionnaire used 0-4 likert scale to receive the opinion of respondents regarding the likelihood of each catastrophic event that disrupt construction supply chain. In the particular question, respondents were asked to give their opinion about the level of likelihood based on the scale that indicates; most likely-4, very likely-3, somewhat likely-2, little likely-1 and unlikely-0. This likert scale has five categories and the data range is 4. Therefore, the researcher set the cut off point at intervals of length 4/5, which is 0.8. The new guide to indicate the likelihood of a catastrophic event is; Unlikely (0.00 – 0.80), Little likely (0.81 – 1.60), Somewhat likely (1.61 – 2.40), Very likely (2.41 – 3.20) and Most likely (3.21 – 4.0). Likelihood survey findings are given in Table 2.

Table 2: Likelihood of Catastrophic Event that Disrupt Construction Supply Chain

Catastrophic Event	Mean	p-value	Rank	Likelihood
Unexpected departure of key employees	3.094	1.000	1	Very
Floods	2.906	1.000	2	Very
Trade union actions (strikes)	2.719	1.000	3	Very
Disruption to transportation media	2.688	1.000	4	Very
Supply breakdowns	2.531	1.000	5	Very
Health hazards	2.250	0.946	6	Somewhat
Recession	2.250	0.946	6	Somewhat
Landslides	2.000	0.500	8	Somewhat
Tsunami	1.625	0.002	9	Somewhat
Extreme weather events (storm, rain, wind, etc.)	1.625	0.002	9	Somewhat
Industrial accidents	1.594	0.001	11	Little
Violence	1.531	0.000	12	Little
War and mass killing	1.406	0.000	13	Little
Attack on infrastructure	1.313	0.000	14	Little

According to the survey findings given in Table 2, unexpected departure of key employees, floods, trade union actions, disruption to transportation media, supply breakdowns, health hazards, recession and landslides received p-values greater than 0.05. Therefore, the aforementioned catastrophic events are identified as likely catastrophic events that disrupt construction supply chain. Most of the likely catastrophes that disrupt construction supply chain are non terrorist events except disruption to transportation media. The most likely catastrophe that affects the construction supply chain is unexpected departure of key employees followed by floods, trade union actions, disruption to transportation media and supply breakdowns. According to the ranking list, it is evident that terrorist events have very low likelihood to disrupt the construction supply chain. Because, catastrophes such as violence, war and mass killing and attack on infrastructure are unlikely events for most of the countries.

5.2. SEVERITY OF CATASTROPHIC EVENTS

The survey used 1-5 likert scale to get the respondents' opinions on the severity level of the identified catastrophic events. In the particular question, respondents were asked to give their opinion about the severity level based on the scale that depicts; very high severity-5, high severity-4, average severity-3, little severity-2 and very little severity-1. This likert scale has five severity levels and the range of the data is 4. In order to prepare a guide for indicating the severity of catastrophic events, the researchers set the cut off point at intervals of 4/5, which is 0.8. Therefore, the severity of catastrophic events are categorised based on the guide as; Very little severity (1.00 – 1.80), Little severity (1.81 – 2.60), Average severity (2.61 – 3.40), High severity (3.41 – 4.20) and Very high severity (4.21 – 5.00). Severity survey findings are given in Table 3.

Table 3: Severity of Catastrophic Event that Disrupt Construction Supply Chain

Catastrophic Event	Mean	p-value	Rank	Severity
Disruption to transportation media	4.406	1.000	1	Very High
War and mass killing	4.375	1.000	2	Very High
Attack on infrastructure	4.000	1.000	3	High
Tsunami	3.844	1.000	4	High
Supply breakdowns	3.719	1.000	5	High
Violence	3.656	1.000	6	High
Floods	3.625	1.000	7	High
Trade union actions (strikes)	3.625	1.000	7	High
Recession	3.563	1.000	9	High
Health hazards	3.188	0.882	10	Average
Unexpected departure of key employees	3.031	0.585	11	Average
Extreme weather events (storm, rain, wind, etc.)	2.938	0.380	12	Average
Landslides	2.844	0.096	13	Average
Industrial accidents	2.781	0.177	14	Average

All the p-values shown in Table 3 are greater than 0.05. Therefore, all the catastrophic events that were identified from the literature survey and pilot study remained as severe catastrophic events that disrupt construction supply chain. According to the ranking, terrorist events such as disruption to transportation media, war and mass killing and attack on infrastructure are moved to top of the list. It is obvious that those terrorist events have very high potential of disrupting the construction supply chain than any other. Among the natural catastrophes, Tsunami is the only catastrophe that has been selected as the severe catastrophe within the top five severe catastrophes. Industrial accident is the least severe catastrophic event that disrupts construction supply chain.

5.3. *RISK ANALYSIS OF CATASTROPHIC EVENTS*

Risk levels of aforementioned catastrophes are different due to the combined effect of likelihood and severity of the catastrophic event. Risk analysis matrix is a way to focus managerial attention on the high priority catastrophic events that have a high possibility to occur and have a high severity if disrupt to a construction supply chain. The study used risk analysis matrix shown in Figure 2 to analyse the combined effect of likelihood and severity of catastrophic events.

		SEVERITY				
		Very Little	Little	Average	High	Very High
LIKELIHOOD	Most Likely	Medium	High	High	Extreme	Extreme
	Very Likely	Medium	Medium	High	High	Extreme
	Somewhat Likely	Low	Medium	Medium	High	High
	Little Likely	Low	Medium	Medium	Medium	High
	Unlikely	Low	Low	Low	Medium	Medium

Figure 2: Risk Analysis Matrix
Source: The Scottish Government (2008)

Table 4 shows the aggregate effect of severity and likelihood of catastrophes. This table helps to identify the risk level of each catastrophic event on construction supply chain. The risk analysis matrix guides to identify suitable actions to mitigate the impact of a catastrophe based on the risk level of a catastrophe.

Table 4: Risk Analysis Matrix for Catastrophes

Event	Likelihood	Severity	Risk level
Disruption to transportation media	Very	Very High	Extreme
Supply breakdowns	Very	High	High
Trade union actions (strikes)	Very	High	High
Flood	Very	High	High
War and mass killing	Little	Very High	High
Tsunami	Somewhat	High	High
Recession	Somewhat	High	High
Unexpected departure of key employees	Very	Average	High
Health hazards	Somewhat	Average	Medium
Extreme weather event (storm, rain, wind, etc.)	Somewhat	Average	Medium
Landslides	Somewhat	Average	Medium
Violence	Little	High	Medium
Attack on infrastructure	Little	High	Medium
Industrial accidents	Little	Average	Medium

When comparing the rankings of likelihood and severity, it is obvious that catastrophes that have high severity if disrupt the construction supply chain are not all the time likely catastrophes that disrupt the construction supply chain. For an example, although war and mass killing, tsunami and recession ranked among highly severe catastrophes, they are little/somewhat likely catastrophes that disrupt the construction supply chain. According to Table 4, disruption to transportation media has an extreme risk level on construction supply chain. Supply breakdown, trade union actions, floods, war and mass killing, tsunami, recession and unexpected departure of key employees have high risk level on construction supply chain, where all the other catastrophes have medium risk level. Key catastrophes that require managerial attention are the events that ranked among top of both the catastrophes which likely to disrupt a construction supply chain and have a severe impact if disrupt the supply chain. Stecke and Kumar (2006) established this idea by stating that managers should focus on mitigating catastrophes that have a high possibility and severity of affecting critical components of a supply chain. Nevertheless, it does not mean that management should not look into other catastrophic events.

6. CONCLUSIONS AND RECOMMENDATIONS

Catastrophic events are unique among other supply chain risks due to low probability of occurrence which is difficult to predict and its' severe impact in terms of magnitude in the area of occurrence. Literature substantiated the vulnerability of construction supply chain for various types of catastrophic events. The aim of this study was to investigate the catastrophes which have a serious effect on construction supply chain under a developing economic conditions and tropical environment. Majority of the catastrophes, which were ranked among the most likely catastrophes to disrupt construction supply chain, are non terrorist events. Findings corroborated the fact that most likely catastrophes to disrupt the construction supply chain are not always the most severe catastrophes. Among the likely catastrophes, unexpected departure of key employees identified as the most likely catastrophic event to disrupt construction supply chain and disruption of transportation media was identified as the most severe catastrophic event. The aggregate effect of likelihood and severity revealed that disruption to transportation media has the extreme risk level on construction supply chain; whereas violence, attack on infrastructure and industrial accidents have medium risk level. All the other catastrophes have high risk level on construction supply chain.

In conclusion, this paper has achieved the research aim by identifying the most critical catastrophes in the construction supply chain under defined criteria. Further, the finding of the research is a strategic tool for decision makers in construction industry. However, the given risk levels are based on particular economic and environment conditions. Therefore, further research needed to be carried out to test the validity of the finding with slight differences in predefined economical and environmental conditions.

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