



Identifying Tools and Methods for Risk Identification and Assessment in Construction Supply Chain

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ABSTRACT

The construction project is a business full of risk in every process due to its complexity, changes, and involvement from various stakeholders. One of the critical risks in the construction project is in the supply chain. Identifying and assessing the risk with the right tools and methods in that area will inevitably affect the success of the project. Unfortunately, the research for the tools and methods in a construction supply chain is still limited and scattered. This research objective is to analyze the gap between literature and to create improvement in tools and methods for risk identification and assessment in the construction supply chain. This research will use the systematic literature review method in finding and investigating the tools and methods. The four methods that were found are: Analytical Hierical Process (AHP), Failure Mode Effect Analysis (FMEA), Supply Chain Operation Reference (SCOR), and Hazard and Operational (HAZOP). Strength and weakness with their potential use as tools and methods for identifying and assessing the construction supply chain risk then summarized. The use of SCOR combined with FMEA methods has shown to be practical tools and methods for identifying and assessing the construction supply chain risk.

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1. INTRODUCTION

Construction is a business that consists of risk in every process and exposing to more risks due to their complexity, changes, and various involvement from the stakeholders. Construction is also a project-based business that is temporary, schedule-based, and resource constraint, and failure to create proper risk management will affect the business tremendously. One of the risks that have the most effects is the risk that is associated with supply chain activity, therefore mitigating the risk for the supply chain is the most critical factor to achieve project success [1].

The supply chain is a flow of information, cost, and material that produce value in the form of products or service and delivered to "customers." A construction supply chain is formed by much more complex information, products, and cost that is delivered to the customer as a final product or semi-products. The

process of the supply chain is task-based that can acts series or parallel depending on the activity that is affected [3]. Vrijhoef and Koskela [2] have characterized the construction supply chain by the following elements: a) materials for construction works were delivered to a construction site and build inside what called "construction factory," b) the construction supply chain is typified with instability and separation from the design and build, c) a project will produce a new product, little similarities among the products, however, the process could be the same. Gosling and Naim [4,48,49] have constructed and structured the supply chain families based on engineering to order, buy to order, make to order, make to stock, assemble to order, make to stock, and ship to stock structures. The construction supply chain was the most complex system because it involves lots of decision-makers and stakeholders. Uncertainty in the networks has increased within the chains, and more complex the networks are, the more uncertainty and risk will be. A general issue that usually happens in a construction supply chain is

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the flow of material, communication in the internal company, project communication, and complexity [5].

Supply Chain Management (SCM) is integration in the business process and improvement of the value within the chain. SCM is aiming to improve productivity and competitiveness, value-added, and profitability for the company and also to the whole supply chain networks, including the end-user. Supply Chain Risk Management (SCRM) by simple definition is a methodology to separate, identify, and mitigate the risk, and ensuring the continuity of the process to achieve profitability[6]. However, the definition of SCRM is still debatable among the researcher. Jüttner, Peck, and Martin [7], for example, defined SCRM as the identification and management of supply chain risk through a coordinated approach among the member of the supply chain to reduce the whole vulnerability. Till now, there still no final consensus on the definition of Supply Chain Risk Management.

Risk identification and assessment are part of the risk management body of knowledge supported by ISO 31000:2009. There is a sixth step standard process in managing the risk, which is the identification, assessment, management, controlling, and communication (Figure 1). Risk identification and assessment is a vital part of the process, where they act as the frontier and responsible for the next phase. Risk identification and assessment are also used in identifying risk types and factors [8].

Research for SCRM has constantly increased. Unfortunately, the majority of industries that have been studied were based on manufacturing, and only a few research has touched the construction. However, now, the construction supply chain has become an exciting topic to discuss, especially in risk management. Furthermore, much research, both in qualitative and quantitative ways, have developed. However, the papers are still scattered and required more effort in modifying the tools and methods to use in practice.

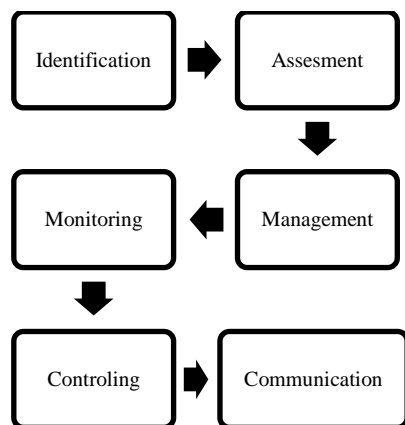


Figure 1. Process of Risk Management

The objective of this paper is to analyze and bridge the gap between literature and to create improvement in tools and methods for risk identification and assessment in the construction supply chain. This paper is organized and divided by sections; Section 2 shows the literature review methodology, describing how to select the literature. Section 3 is analyzing the tools and methods (include the strength and weaknesses) for risk identification and assessment in Supply Chain Risk in the Construction. Section 4 will discuss Proposed Tools and Methods for Risk Identification and Assessment in Construction Supply Chain, and we will conclude this paper in Section 5.

2. LITERATURE REVIEW METHODOLOGY

This paper will follow the methodology from the Systematic Literature Review (SLR)—which is the standard method for investigating a specific subject, which consists of four steps, as seen in Figure 2 below:

In the first stage of this study, papers were selected from the peer-reviewed journal with trustful databases, such as Elsevier, Springer-Link, Francis & Taylor, Inderscience, Emerald, International Journal of Engineering (IJE), Journal of Industrial Engineering and Management (JIEM), International Journal of Industrial Engineering: Theory, Applications, and Practice (IJIETAP), Project Management Journal, Journal of Modern Project Management. Google Scholar also included with careful selection of the journal based on their SCOPUS index. With years of publication range from 2000 -2019.

To achieve the objective of this paper, we will use the keywords “Construction Supply Chain Risk Management,” “Construction Supply Chain Risk Identification,” and “Construction Supply Chain Risk Assessment.” These keywords are put in the advanced search where it does not just search in the title but also will search in contents, abstracts, and keywords. The

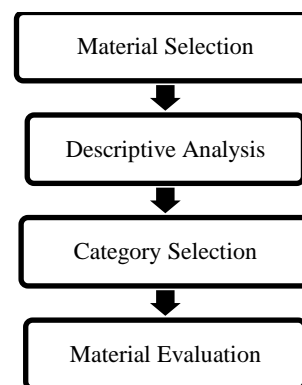


Figure 2. Four steps of Systematic Literature Review

keywords “Construction Supply Chain” combined with the function “And” with “Risk Management” to performs a search for “Construction Supply Chain Risk Management,” “Construction Supply Chain” combined with the function “And” with “Risk Identification” to conducts a search for “Construction Supply Chain Risk Identification,” also “Construction Supply Chain” combined with the function “And” with “Risk Assessment” to performs a search for “Construction Supply Chain Risk Assessment” The years then input in advance filter menu for 2000 -2019. The summary of keywords and search location, as seen in Table 1 below:

The category of the papers will be selected based on the criteria : (1) tools and methods (2) Research Type (Case Study, Literature Study, and Survey) (3) Industries (Manufacturing and Construction). The final phase is to analyze the weakness and advantages of the methods, and from the analysis, new or improved methods will be proposed.

3. CATEGORY FOR TOOLS AND METHOD SELECTION REVIEW

Thirty-five journals selected and then categorized based on the tools and methods, research type, and industries.

Figures 3, 4 and 5 summarizes numbers of tools and methods being used, numbers of industries and numbers of research type based on the findings from the selected journal.

Based on Figure 3, there are four methods identified: Analytical Hierarchy Process (AHP), Failure Mode and Effect Analysis (FMEA), Supply Chain Operational Reference (SCOR) model, and Hazard and Operability (HAZOP) analysis. The tables below summarize the tools and methods with their reference.

3. 1. Review of AHP for Risk Identification and Assessments

Gaudenzi and Borghesi [11] have introduced the use of the AHP in their paper to identify and assess risk in the supply chain. They have

TABLE 1. List of Keywords and Search Location

Keywords	Search Location
Construction Supply Chain AND Risk Management	Elsevier, Springer-Link, Francis & Taylor, Inderscience, Emerald, International Journal of Engineering (IJE), Journal of Industrial Engineering and Management (JIEM), International Journal of Industrial Engineering: Theory, Applications, and Practice (IJIETAP), Project Management Journal, Journal of Modern Project Management. Google Scholar with a selective journal based on the SCOPUS index.
Construction Supply Chain AND Risk Identification	
Construction Supply Chain AND Risk Assessment	

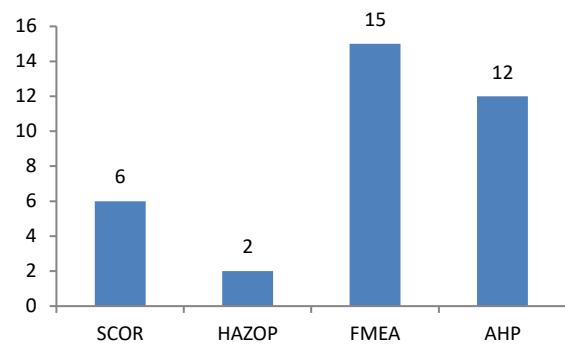


Figure 3. Tools and Methods with total published journal

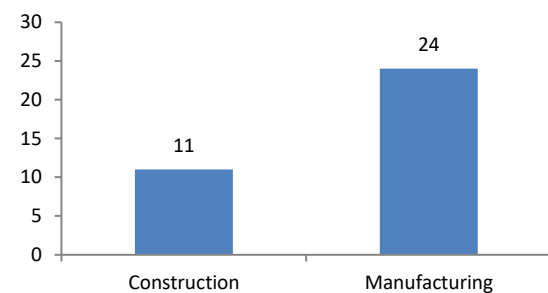


Figure 4. Industries researched with total published journal

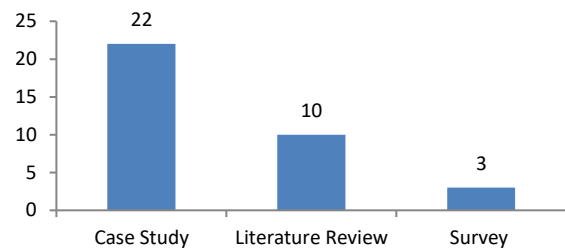


Figure 5. Research type with total published journal

TABLE 2. Summary of tools and methods and references article

Tools and Methods	Industries	References
Analytical Hierarchy Process (AHP)	Manufacturing	[9 -14]
	Construction	[15-20]
Failure Mode and Effect Analysis (FMEA)	Manufacturing	[21-32]
	Construction	[33-35]
Supply Chain and Operational Reference (SCOR)	Manufacturing	[36-39]
	Construction	[40-41]
Hazard and Operational (HAZOP)	Manufacturing	[42-43]

successfully created a model that can identify a panel of risk indicators that were applied in various levels of the

chain. Sharma and Bhat [14] have used AHP by classification of the risk factor in the hierarchy and rated all risks in the pairwise comparison matrix. The papers have successfully shown how to calculate the matrices of AHP and rank the risk prioritization. There are a number of research that successfully combined the AHP models by other methods to identify and assess the risk. Li et al. [12] have used the AHP-fuzzy comprehensive evaluation model, which based on the combination of AHP and fuzzy mathematical theory, to assess the risks in the supply chain. Dong and Cooper [10] have also developed the orders-of-magnitude AHP (OM-AHP) that was enabled to compare tangible and intangible elements that influence supply chain risks, and also succeed in creating a risk assessment based on their probability and consequence severity. AHP is a fascinating method to discuss and to apply in risk identification and assessment for the supply chain, but the research is mostly used in manufacturing industries.

AHP in the construction supply chain was mainly used to assessing supplier or material selection [36, 20, 18]. There is no significant research that AHP was used in risk identification and assessment in the construction supply chain.

In general, the phases of AHP are: 1) defining the objective(s) and preferable solution(s), and 2) creating a hierarchical structure based on the main objective (Figure 6).

Create a pairwise comparison matrix that describes relative contributions or influences of each element to goals or criteria on the same level. To get higher accuracy, it requires a full decomposition until it reaches the end. Some levels are developed from goal, decompose to criterion, and alternatives. The second phase is to set up priority or judgment. Prioritization is being done at every level of the hierarchy. A pairwise judgment matrix constructs by element and element and also compared to their next level using the nine-point rating that has been developed by Saaty [9].

The relative weights were then calculated by the right eigenvector (w) corresponding to the largest eigenvalue (λ_{max}), as shown in Equation (1):

$$A_w = \lambda_{max} w \tag{1}$$

The matrix was said consistently if matrix A has a rank of one and $\lambda_{max} = n$, and weights can be obtained by normalizing rows or columns in A. Then, the measure of consistency, called Consistency Index(CI), as deviation or degree of consistency is calculated using the following Equation (2):

$$CI = (\lambda_{max} - n) / (n - 1) \tag{2}$$

The final Consistency Ratio (CR) is then calculated to see whether the evaluation is sufficiently consistent; the calculation is based on Equation (3):

$$CR = \frac{CI}{RI} \tag{3}$$

where, RI is Random Index, if $CR \leq 10\%$, then inconsistency is acceptable, however, if the CR is $\geq 10\%$, the procedure then to be repeated to improve the CR [11-14].

The advantages in using AHP methods in risk identification and assessment in the construction supply chain are: (1) It is a flexible and straightforward model; (2) The evaluation model will be based on the expert judgment from a variety of discipline; (3) Details of risk can be presented detail in level; (4) It can measure the consistency of judgments/decision

However, in the construction supply chain, the AHP methods have some weaknesses, including: (1) Construction supply chain is the most sophisticated model of the supply chain, and the complexity will make AHP become unrealistic methods to run with; (2) Subjective matters on the expert judgments will be the constraint of AHP, wherein construction will require efforts from all project member to get consensus; (3) It will require help from the computational assistance to speed up the process; (4) There is no certainty based on the statistics, where AHP is only a mathematical model.

3. 2. Review of Scor for Risk Identification and Assessments

Only a few studies have been identified for SCOR methods in the identification and assessment of supply chain risk. Faisal, Banwet, and Shankar [37] have shown to mitigate the risk in the supply chain using the SCOR model and analytical network process. [38] has briefly described the use of the SCOR model for evaluating the risks and combined with AHP. Lemghari, Okar, and Sarsri [39] identified the limitation and benefit of the SCOR model in automotive industries. Cheng et al.[40] have comprehensively discussed the use of the SCOR model on the construction supply chain and successfully modeled the construction supply chain based on the SCOR and evaluating the processes performance. Pan, Lee, and Chen [41] have also used the SCOR model to improve the supply chain system in construction. All of the research has not used the newest version of the

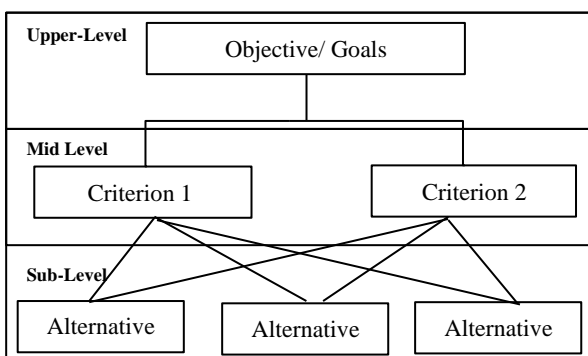


Figure 6. A standard hierarchical structure sample for AHP

SCOR, as seen in Figure 6.

Building SCOR methods for the construction supply chain is as follows: (1) The material needs to be identified as engineering to order, buy to order, make to order, make to stock, assemble to order, make to stock, or ship to stock; (2) SCOR level 1 (Figure 6) and level 2 models are created based on the material; (3) Create a Level 3 SCOR Business Model; (4) The last one is to identify the risk in the processes. The general model of level in the SCOR can be seen in Figure 7.

The advantages of using SCOR for risk identification and assessment in Construction Supply Chain are: (1) The business process is identified based on the organization of the material; (2) It is a standardized method in modeling the supply chain based on the business process; (3) Risk can be identified within the process in the supply chain. Although the SCOR model seems to be a powerful method, it also has weaknesses and limitations, including: (1) The models in Level 1-3 in SCOR model are based on the knowledge of the process; (2) Creating the process required involvement with the experienced and skilled team that knows Construction Supply Chain; (3) It requires training and experience in developing the SCOR model.

3. 3. Review of Fmea for Risk Identification and Assessments The Failure Mode Effect Analysis (FMEA) has gained popularity in the risk management



Figure 6. SCOR version 12.0 Level 1 – APICS

Level	Description	Schematic	Comments
1	Major processes	(P)lan (S)ource (M)ake (D)eliver (R)eturn (E)nable	Defines the scope, content, and performance targets of the supply chain
2	Process categories	sD1 MIS sD2 MTO sD3 ETO sD4 Retail	Defines the operations strategy; process capabilities are set
3	Process elements	sD1.1 Process inquiry and quote sD1.2 Receive, enter, validate order sD1.3 Reserve inv. and delivery date sD1.4 Consolidate orders sD1.5 Build loads sD1.6 Route shipments	Defines the configuration of individual processes. The ability to execute is set. Focus is on processes, inputs/outputs, skills, performance, best practices, and capabilities.
4	Improvement tools/activities	Use of kaizen, lean, TQM, six sigma, benchmarking	Use of kaizen, lean, TQM, six sigma, benchmarking

Figure 7. Four levels of SCOR version 12.0 business processes-APICS

tools and reached the supply chain risk management for years. FMEA is a hybrid tool derived from the Fault Tree Analysis (FTA) methods. It was one of the popular methods and has been used by professionals and researchers in risk identification and assessment. Curkovic, Scannell, and Wagner [24] have made a study of how FMEA is used in managing risk in the company and how familiar the stakeholder is in the methodology. Shinha, Whitman, and Malzahn [30] have used FMEA for risk assessment in supply chain risk management. FMEA has also been widely used in assessing the performance of the supplier, logistics, and material in the supply chain. In the construction projects, FMEA was mostly used in assessing the project risk. Rohmah et al. [28] have used in their paper fuzzy FMEA methods to assess the risks.

Unfortunately, significant research focusing on using FMEA for risk identification and assessment in the construction supply chain has not yet been identified. However, FMEA was used to identifying and assessing the risk in the whole construction project processes and also mostly used to identify the risk from the supplier, logistics, product, and material in the construction supply chain [33 -35].

The steps in FMEA are as follows: A table is generated as standard FMEA table (Table 3), FMEA team that consists of experts in the area need to be assembled for justification and judgment, the process in the supply chain then be listed in the table comprehensively. Failure mode(s) are listed in the table for every process steps, that are: (1) Listing the effects of failure; (2) Inputting the severity rating based on the agreed scale, with scale 1-10 (from low to high severity); (3) Identification of the potential cause of failure, input the occurrence factor from the potential cause of failure with scale 1- 10 (from low to a high probability); (4) Identification of the control to detect the risks, input the rating for detection, usually with scale 1-10, (5) Calculating Risk Priority Number (RPN) based on Equation (4), and (6) input the recommended actions for mitigation [27].

$$RPN = Severity\ factor \times Occurrence\ or\ Probability\ factor \times Detection\ factor \tag{4}$$

FMEA has offered several advantages for identification and assessment in construction supply chain risk, which are: (1) It is a simple method and commonly is used practically in assessing the supply chain and project risks; (2) It is an early identification to identify and mitigate the risks; (3) Risk prioritization can be identified; (4) Create a sense of belonging in each of department for the risks; Can capture most of the risks.

Some of the weaknesses of using FMEA for risk identification and assessment in the construction supply

chain are: (1) Factors in severity, occurrence/probability, and detection were based on the agreement. Therefore, the numbers are not statistically correct and somehow potentially bias; (2) The identification of risk will be based on the knowledge of the experts, which will limit the risk and potentially losing some of the critical risks.

3. 4. Review of Hazop for Risk Identification and Assessments

The Hazard and Operability (HAZOP) was initially developed in the chemical process industry and has now been widely used to assess the risk associated with health, safety, and the environment in the process and manufacturing industries. Trough the years, the researcher has widely spread the use of HAZOP into several risk management process and have touched the SCRM. Adithya, Srinivasan, Karimi [42] have used the Hazard and Operability (HAZOP) method to identify the risk involved in the supply chain, by following the general rule in HAZOP methods where risks are drawn using a diagram. The diagram itself is following the process flow diagram. Mitkowski and Zenka-Podlaszewka [43]

have successfully transferred the HAZOP method from the process to supply chain management and identified the risk in the supply chain. The search for HAZOP as a method in Supply Chain Risk Management in Construction has come to a disappointment. Most of the literature showing the use of HAZOP for assessing the design and processing of the construction.

The first step in using HAZOP is creating what was called Work Flow Diagram (WFD) and Supply Chain Flow Diagram (SCFD), forms of the diagram similar to Process Flow Diagram (PFD). The WFD describes the sequence of works of one or more activities. Examples of WFD is shown in Figure 8.

Supply Chain Flow Diagram (SCFD) is showing the connections between the chain. It contains the flow of material and information along the chain. After the Work Flow Diagram and Supply Chain Diagram are created, a risk analysis process is conducted by a specialized team.

The advantages using HAZOP for risk identification and assessment in the construction supply chain are: (1) Flow processes are described comprehensively; (2) The risk in every chain is identified; (3) It is a systematic

TABLE 3. A standard FMEA Table

Process Input	Failure Mode/Risk	Effect(s) of Failure	Severity (1-10)	Potential Cause(s)/ Mechanism(s) of Failure	Occurance /Probability (1-10)	Current Process Controls	Detection (1-10)	RPN (Risk Priority Number)	Recommended Action(s)
What is the process step or feature under investigation?	In what ways could the step or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?	Scale 1-10 based on the severity	What causes the step or feature to go wrong? (how could it occur?)	Scale 1-10 based on the occurrence/probability	What controls exist that either prevent or detect the failure?	Scale 1-10 based on the detection	$RPN = Sev \times Occ \times Detc$	What are the recommended actions for reducing the occurrence of the cause or improving detection?

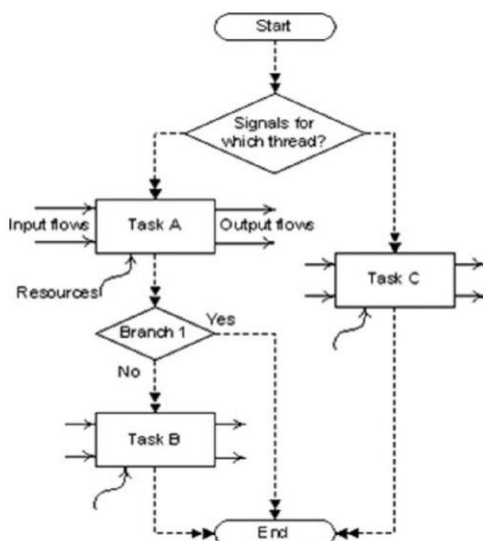


Figure 8. Structure of Work Flow Diagram (WFD) [42]

model to identifying the risks. However, HAZOP has several weaknesses, especially in the construction supply chain, that are: (1) The flow of material, information, and cost in the supply chain are complicated, where every chain can intervene one another, and that can cause more issue in the HAZOP model; (2) The diagram still does not have a common standard, there will be variety in creating the diagram; (3) It will take time and effort in describing one process to another.

4. PROPOSED TOOLS AND METHODS FOR RISK IDENTIFICATION AND ASSESSMENT IN CONSTRUCTION SUPPLY CHAIN

In general, the four methods that have been described in this paper are not directly implied and gained their popularity for identifying and assessing the risk in the

construction supply chain. However, to assess the applicability of those methods, we will look back on their advantages and weaknesses compared with the nature of the construction supply chain, driven by the complexity of the processes, the structure of the materials, and considerable stakeholder involvement. AHP and HAZOP models have their weakness in their flexibility to withstand the complexity of the supply chain process. Moreover, it will be unrealistic and impractical to use those methods in significant and complex construction projects. It will consume time and effort, and sometimes losing the significant risk that needs to be recorded.

On the other hand, the SCOR method has several advantages that are: the models can describe the supply chain behavior in every step of the processes; showing the risk in each level in the business process; it has become a universal standard tool in describing supply chain process. FMEA also has its advantages in its simplicity, and it can capture most of the risk, and model the risk prioritization in simple mathematical methods. FMEA is a popular model in supply chain risk management and has gain familiarity in construction projects. One of the weaknesses of using FMEA is that it requires a correct input of the process so that the risk can be identified and assessed correctly.

Based on these reviews, we proposed a method for identifying and assessing the risk in the construction supply chain by using SCOR and FMEA methods. The SCOR methods will be used as the first phase. This consists of three steps: (1) Identifying the material based on engineering to order, buy to order, make to order, make to stock, assemble to order, make to stock, and ship to stock; (2) Identifying the level 1 and 2 models in SCOR based on the category of material; (3) Creating a level 3 business process in the SCOR model.

Then, next steps are using FMEA model to identify and assess the risk, with following steps: (1) Processing from level 3, then, including the process column in FMEA table; (2) continue to follow the steps of identifying the risk/failure, effects of the risk, severity factor, potential cause, probability/occurrence factor, process control, detection factor, calculating the risk priority number, and the risk mitigation; (3) prioritizing Risk and selected by their criticality using other assistance tools (i.e., Pareto chart). The frameworks can be seen in Figure 9:

5. CONCLUSION

This paper has provided a systematic literature review for risk identification and assessment frameworks in the construction supply chain. Articles published in 2000-2019 are collected. 35 articles were selected and reviewed thoroughly. We have summarized the four methods in risk identification and assessment in the

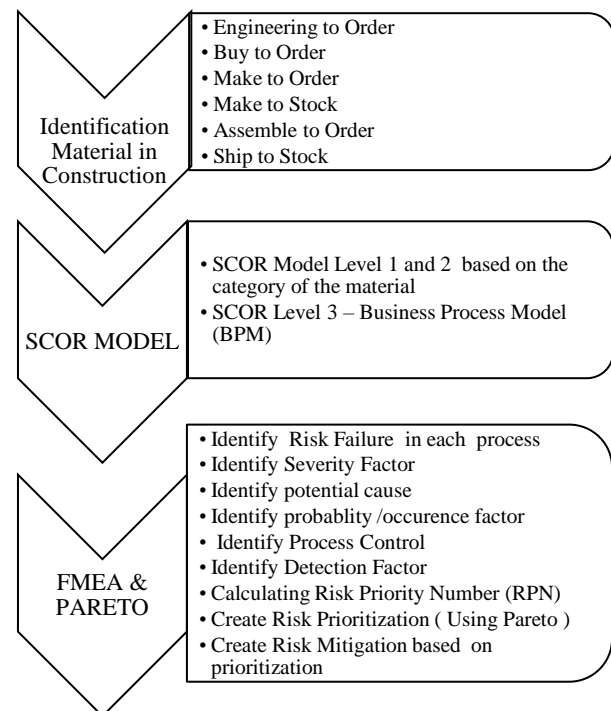


Figure 9. Proposed frameworks for risk identification and assessment in the Construction Supply Chain

supply chain, which are: Analytical Hierarchy Process (AHP), Supply Chain Operating Reference (SCOR), Failure Mode and Effect Analysis (FMEA) and Hazard and Operational (HAZOP). However, the four methods have not yet being used directly for identifying and assessing risk in the construction supply chain. To select the best models, we explore each of the methods to fit in the construction project, and we have found that combining the SCOR model and FMEA will be the best and efficient methods of risk identification and assessment. Further research opportunities for applying this method is still open, where case studies based on these methods are required.

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Persian Abstract

چکیده

پروژه‌ی ساخت‌وساز به دلیل پیچیدگی، تغییرات، و درگیری ذی‌نفعان مختلف، مشاغل پرخطر در هر فرایند است. یکی از خطرات مهم در پروژه‌ی ساخت‌وساز در زنجیره‌ی تأمین است. شناسایی و ارزیابی ریسک با ابزارها و روش‌های مناسب در آن منطقه ناگزیر بر موفقیت پروژه خواهد بود. متأسفانه تحقیقات در مورد ابزارها و روش‌های موجود در زنجیره‌ی تأمین ساخت‌وساز هنوز محدود و پراکنده است. هدف این تحقیق، تحلیل شکاف بین ادبیات و ایجاد پیشرفت در ابزارها و روش‌های شناسایی ریسک و ارزیابی در زنجیره‌ی تأمین ساخت‌وساز است. در این تحقیق از روش مرور ادبیات منظم در یافتن و بررسی ابزارها و روش‌ها استفاده خواهد شد. چهار روشی که برای این تحلیل پیدا شد عبارتند از: فرایند تحلیلی سلسله‌مراتبی (AHP)، تحلیل امکان بروز خطا و اثرات آن (FMEA)، مرجع عملکرد زنجیره‌ی تأمین (SCOR) و خطر و عملیاتی (HAZOP). سپس، نقاط قوت و ضعف با استفاده‌ی بالقوه از آنها به عنوان ابزار و روش‌های شناسایی و ارزیابی ریسک زنجیره‌ی تأمین ساخت‌وساز خلاصه می‌شوند. استفاده از SCOR همراه با روش‌های FMEA نشان داده است که ابزار و روش‌های عملی برای شناسایی و ارزیابی ریسک زنجیره‌ی تأمین ساخت‌وساز است.
